Materials and Design 61 (2014) 239–250

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Role of arc mode in laser-metal active gas arc hybrid welding of mild steel

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ARTICLE INFO

Article history:
Received 23 January 2014
Accepted 28 April 2014
Available online 9 May 2014

Keywords:
Laser-arc hybrid welding
Mild steel
Electron back scattering diffraction
Microtexture
Mechanical properties

ABSTRACT

Arc mode plays an important role in joint characterizations of arc welding, but it has been seldom considered in laser-arc hybrid welding. This paper investigated the role of arc mode on laser-metal active gas (MAG) arc hybrid welding of mild steel. Three arc modes were employed, which were cold metal transfer (CMT), pulsed spray arc and standard short circuiting arc. Microtexture of the joints were observed and measured via electron back scattering diffraction (EBSD) system to reveal the effect of arc mode on microstructure. Mechanical properties of the joints were evaluated by tensile and Charpy V-notch impact tests. It was found that both the stability and mechanical properties of laser-CMT hybrid welding (LCHW) is the best, while those of laser-standard short circuiting arc welding (LSHW) is the worst. OM and EBSD results showed that the fraction of acicular ferrite and high-angle grain boundaries in fusion zone decreases gradually in the sequence of LCHW, laser-pulsed spray arc welding and LSHW, while the mean grain size increases gradually. Finally, the microstructure formation mechanisms and the relationship between microstructure and mechanical properties were summarized by the loss of alloying element and the stirring effect in molten pool.

1. Introduction

Low carbon, low alloy mild steel thick plates have been widely used in shipbuilding, pipeline construction, bridges, and so on [1–3]. Traditionally, they were joined by metal inert gas/active gas (MIG/MAG) welding, tungsten inert gas (TIG) welding or other arc welding methods. Existing studies showed that some problems such as coarse grains, wide heat affected zone (HAZ), great deformation and low production efficiency may occur in arc welding due to large heat input and slow welding speed [4,5]. Laser welding has been given great expectations to solve these problems, as it has high welding speed, deep penetration, narrow bead width and low deformation [6,7]. However, the focal spot size of laser beam is so tiny that it sets a very strict requirement on machining and assembling of workpiece [8]. Hence, pure laser welding has seldom been used in heavy industries regarding thick plates. As a focused research field, laser-MIG/MAG hybrid welding has been paid a lot of attentions because of its superiorities inherited from both laser and arc: high welding speed, deep penetration, excellent mechanical properties, and the most important, good gap bridging ability [9–12]. It would be an effective alternative for joining thick plates.

Up to now, vast majority of laser-MIG/MAG hybrid welding processes have been implemented under pulsed spray arc mode. Previous literatures reported that coupling and synergetic effects are easily established between laser and pulsed spray arc [13]. The pulsed spray arc offers a spray metal transfer at high peak currents, and obtains a stable welding process and accepted bead formability [14–16]. However, the heat input of laser-pulsed spray arc hybrid welding is still a little large and the spatters cannot be entirely eliminated, resulting in non-ignorable deformation and not so nice bead formation. Recently, a novel arc welding, cold metal transfer (CMT) was proposed. It offers a brand-new metal transfer that the arc both works under short circuiting arc mode and has an impulse waveforms at the same time [17]. It is different with pulsed spray arc, and can be called pulsed short circuiting arc. When short circuit occurs, the DSP in the welder both interrupts the power supply and retracts the wire, which results in virtually current-free metal transfer and a great reduction of spatters [18,19].

It is generally known that arc modes play a big role in the characterizations of welded joints. Mukherjee et al. investigated the influences of spray and short circuiting arc in pure MIG welding of SSP 409 M ferrite stainless steel [20]. They found that in the fusion zone (FZ), the spray arc welded joint provides a 10–12% lower stacking fault energy and higher amounts of martensite,

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http://dx.doi.org/10.1016/j.matdes.2014.04.079
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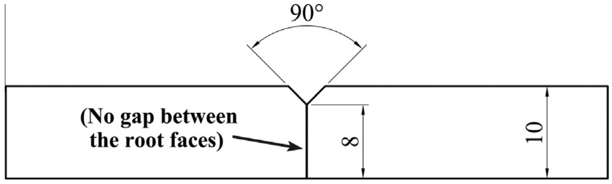

Fig. 1. Groove geometry of welding specimens.

Table 1
Chemical compositions of BM and filler wire (wt.%).

Material	C	Si	Mn	P	S	Others	Fe
BM	0.12	0.15	0.44	0.015	0.008	⩽0.3	Bal.
Filler wire	0.08	0.92	1.52	0.020	0.015	⩽0.5	Bal.

Table 2
Mechanical properties of BM and filler wire.

Properties	BM	Filler wire
Yield strength (MPa)	⩾235	⩾420
Ultimate tensile strength, UTS (MPa)	450	550
Elongation (%)	26	30
Impact absorbed energy, IAE (J)	120	150

resulting in 4–11% and 12–21% higher microhardness and impact toughness compared to short circuiting arc welded joint. In the HAZ, the mean grain size of spray arc welded joint is about 8–11 μm coarser, the impact toughness values are 37–43% lower than short circuiting arc welded joint. Zhang et al. studied the microstructure and tensile strength of laser-CMT (LCHW) and laser-pulsed MIG (LMHW) hybrid welding of AA6061 aluminum alloy sheets [21]. Here, LCHW joint has an about 10–20 μm finer equiaxial dendrites than LMHW joint in the FZ, and much narrower columnar dendrite zone near fusion line. Tensile strength of LCHW joint is about 10% higher than LMHW joint. Besides, porosities that are commonly seen in lone laser or MIG welding of aluminum alloys are almost suppressed by LCHW. Beyond these researches, few reports have been focused on the effects of arc mode on the characterizations of laser-MIG/MAG hybrid welded mild steel joints.

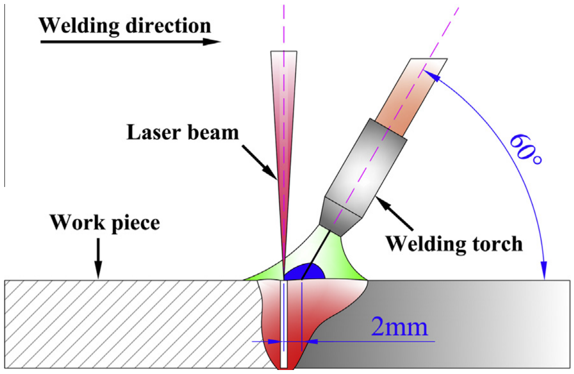

Fig. 2. Schematic diagram of experimental set-up.

Table 3
Welding parameters of LCHW, LPHW and LSHW.

Welding parameters	LCHW	LPHW	LSHW
Laser power, *P* (kW)	6.0	6.0	6.0
Welding speed, *v* (m/min)	1.0	1.0	1.0
Wire feed rate, *r* (m/min)	9.0	9.0	9.0
Current, *I* (A)	198	204	235
Voltage, *U* (V)	14.9	22.8	23.8
Focal length, (mm)	250	250	250
Defocused distance (mm)	−2	−2	−2

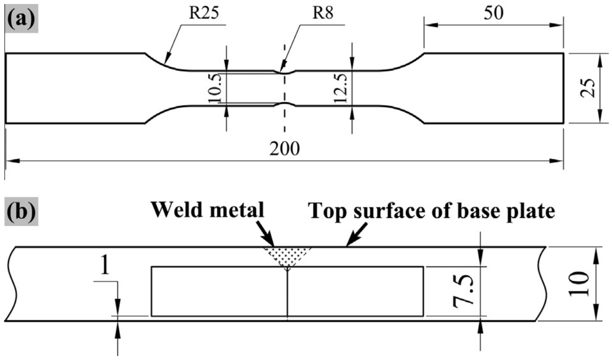

Fig. 3. Geometry design of (a) tensile specimens and (b) impact specimens.

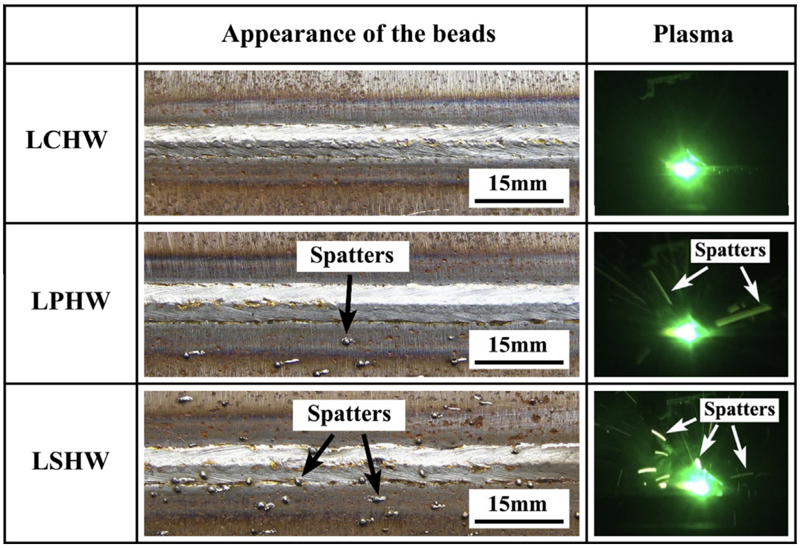

Fig. 4. Bead appearance and plasma characterization of three hybrid welding processes.