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Analysis of droplet transfer mode and forming process of weld bead in CO_2 laser–MAG hybrid welding process

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ABSTRACT

In this paper, CO_2 laser–metal active gas (MAG) hybrid welding technique is used to weld high strength steel and the optimized process parameters are obtained. Using LD Pumped laser with an emission wavelength of 532 nm to overcome the strong interference from the welding arc, a computer-based system is developed to collect and visualize the waveforms of the electrical welding parameters and metal transfer processes in laser–MAG. The welding electric signals of hybrid welding processes are quantitatively described and analyzed using the ANALYSATOR HANNOVER. The effect of distance between laser and arc (D_{LA}) on weld bead geometry, forming process of weld shape, electric signals, arc characteristic and droplet transfer behavior is investigated. It is found that arc characteristic, droplet transfer mode and final weld bead geometry are strongly affected by the distance between laser and arc. The weld bead geometry is changed from "cocktail cup" to "cone-shaped" with the increasing D_{LA}. The droplet transfer mode is changed from globular transfer to projected transfer with the increasing D_{LA}. Projected transfer mode is an advantage for the stability of hybrid welding processes.

1. Introduction

Recently, laser–gas metal arc (MAG) hybrid welding technology has been widely studied and some successful applications have been seen [1,2]. The process combines two heat sources, i.e. a laser and an electric arc, and forms one molten pool between two pieces of metallic material to be welded. The main advantages of laser–MAG hybrid welding are its high welding speed and the high gap bridging capabilities as well as the high penetration compared to conventional processes [3]. Nevertheless, only after optimizing the process parameters, these advantages of laser–MAG hybrid welding can be obtained for the efficient welding of thicker work-pieces. In order to achieve a stable, repeatable and productive process, investigation of processing parameters of laser–MAG hybrid welding is very necessary.

In general, these parameters include distance between laser beam and arc (D_{LA}), focused position of laser beam [4], arc voltage and welding current, laser power [5], shielding gas composition and the shielding gas flow [2,6]. Much research in laser–arc hybrid welding has been done to study coupling of laser welding process and arc welding process [7], and the influence of the parameters mentioned above on process stability, weld profile as well as weld penetration. The stability of hybrid welding process is dependent on droplet transfer mode. The droplet transfer mode is affected by the type of the voltages and current intensities' range, electrode polarity, filler wire, D_{LA} and shielding gas. Droplet transfer modes are closely related to electrical signals. The electric signals, such as arc voltage and welding current, contain a quantity of information in hybrid welding process. Every welding process carries the particular characteristic of the electric signal. For laser–MAG hybrid welding, transport phenomena of liquid drop and electric signals of welding arc involve complex interactions between different physical phenomena. There are limited literature focusing on the study of the complicated physical phenomena, such as melt flow, energy transfer in keyhole and weld pool, characteristic of electrical signal, and interactions between droplets and weld pool. Zhou and Tsai [8] reported that developed model can be used for further parametric studies or optimization of the hybrid laser–MIG welding process. Also, mathematical models have been developed to investigate the transport phenomena in a hybrid laser–MIG welding process. The complicated velocity and temperature distributions caused by the impingement of filler droplets are calculated. Gao et al. [9] proposed that the laser beam and arc couple effect was introduced into mathematical model by the plasma width during hybrid welding. Transient weld pool shape and complicated liquid metal velocity distribution from two kinds of weld pool to a unified weld pool were calculated. However, understanding these transport phenomena and electric signals is critical for fundamentally understanding and optimizing the hybrid laser–MIG/MAG welding

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process. For example, in order to achieve stable process and good weld shape of high strength steel weld by adding filler metal in laser–MAG hybrid welding, it is necessary to understand how well the droplets can transfer and diffuse into the weld pool, and how well the D_{LA} affects the weld bead geometry and electrical signal.

In this paper, a computer-imaging-based system is used to sense and visualize the electric signals and metal transfer modes in real-time. The effects of D_{LA} and welding current on the formation process of weld shape, arc characteristic, electric signals and behavior of droplet transfer were further investigated.

2. Experimental method

2.1. Materials

High strength steel plates with the dimension of 150 mm × 30 mm × 7 mm were used in the study. The specimen surfaces were chemically cleaned by acetone before welding to eliminate surface contamination. Austenitic stainless steel (ASS) filler wire with 1.2 mm in diameter was used. The chemical compositions of the base metal and the filler wires are shown in Table 1.

2.2. Welding equipments and conditions

Bead-on-plate welds were made using a 5 kW CO_2 laser (DC050; Rofin Sinar GmbH) in combination with a power supply (YD-350A G2HGE; Panasonic Ltd.). The CO_2 lasers with an emission wavelength of 10.64 μm can deliver in continuous wave (CW) mode. Laser beam passed through focusing mirror with the focal length of 350 mm and was finally focused as a spot of 0.3 mm in diameter. The focus position was kept on the top surface of specimens. A welding head combined a CO_2 laser beam and a MIG/MAG torch was developed, which is shown in Fig. 1. The welding direction was arc leading. Shielding gases for laser co-axial nozzle consists of helium and argon (30%He+70%Ar) with flowing velocity of 25 L/min from a coaxial nozzle in diameter of 5 mm. But shielding gas used for arc torch is the mixture of carbon dioxide and argon (20% CO_2+80% Ar), flowing velocity of which is 16 L/min. The welding parameters are shown in Table 2.

A CMOS CR5000 high-speed color camera (Optronis, Germany) was used for observing and recording the welding phenomena. The observation was focused on metal transfer, weld bead forming and arc characteristic. The high speed camera had a zoom lens. Fig. 1 shows the experimental setup for the observation. The high-speed color camera was placed on the side of the hybrid welding head. During hybrid welding the transport phenomena was video-graphed with the help of a high speed camera recorded at the speed of 5000 frame per second. To collect shape and transfer mode of droplets, an LD Pumped green laser was used as backlight source. The LD pumped laser with an emission wavelength of 532 nm can deliver in continuous wave (CW) mode. The interference filter with wavelength of 532 nm was installed in front of high speed camera for filter out most of the arc light, which is shown in Fig. 1.

The ANALYSATOR HANNOVER was used to sample the current and voltage during hybrid welding process. Fig. 2 shows the schematic drawing of droplet transfer sensing and visualizing system for hybrid welding. A sampling rate of 5 kHz was selected for this work. The ANALYSATOR HANNOVER based on the modern

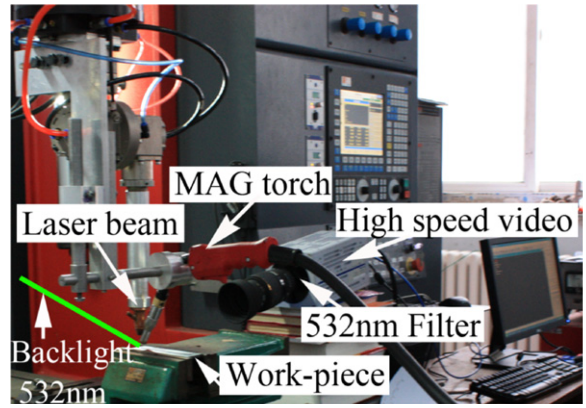

Fig. 1. Set-up of CO_2 laser–MAG hybrid welding.

Table 2
Welding parameters.

Welding speed v (m/min)	1.2
Angle of welding torch θ (deg.)	60
Defocusing amount Δf (mm)	0
Extension length L (mm)	12
Laser powder P (kW)	2.0
MAG current I (A)	140–220
MAG voltage U (V)	24–28
Distance between laser and arc D_{LA} (mm)	0–6

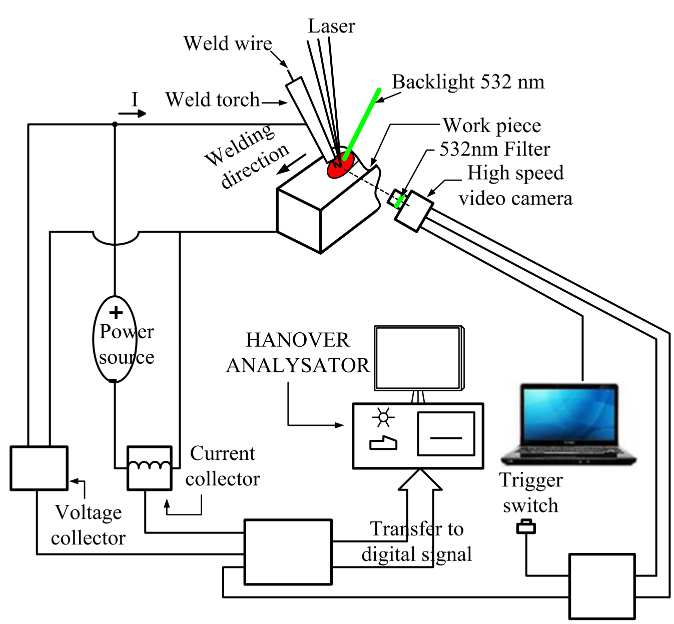

Fig. 2. Schematic drawing of droplet transfer sensing and visualizing system for hybrid welding.

Table 1
Chemical compositions of high strength steel and filler wires (wt%).

Materials	Chemical composition (wt%)										
	C	Cr	Ni	Mn	Mo	Si	V	Cu	S	P	Fe
Base metal	0.11	0.60	0.95	1.4	0.5	0.28	0.1	0.32	0.008	0.002	Bal.
ASS	0.09	21	9	1.6	0.37	–	–	–	0.01	0.02	Bal.