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Study of metal transfer in CO_2 laser+GMAW-P hybrid welding using argon–helium mixtures

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ABSTRACT

The metal transfer in CO_2 Laser+GMAW-P hybrid welding by using argon–helium mixtures was investigated and the effect of the laser on the mental transfer is discussed. A 650 nm laser, in conjunction with the shadow graph technique, is used to observe the metal transfer process. In order to analyze the heat input to the droplet and the droplet internal current line distribution. An optical emission spectroscopy system was employed to estimate default parameter and optimized plasma temperature, electron number densities distribution. The results indicate that the CO_2 plasma plume have a significant impact to the electrode melting, droplet formation, detachment, impingement onto the workpiece and weld morphology. Since the current distribution direction flow changes to the keyhole, to obtain a metal transfer mode of one droplet per pulse, the welding parameters should be adjusted to a higher pulse time (*TP*) and a lower voltage.

1. Introduction

Laser+GMAW-P hybrid welding is an increasingly accepted joining technology for a variety of industrial sectors [1,2]. The main advantages are the wider gap tolerance, higher welding speed, and controlling the bead humping defect, improving the weld metal microstructure by using filler materials [3,4].

In order to achieve a stable and repeatable welding process, it is essential to select optimum combinations of parameters for a controlled metal transfer process over wide ranges of heat and mass input levels. GMAW-P which is a modified spray transfer process provides the best of both short-circuiting and spray transfer, by using a low base current to maintain the arc and a high peak current to melt the electrode wire and detach the droplet [5–7]. Although pulsed GMAW is capable of reducing spatters and improving arcing stability through obtaining spray transfer, such capability is conditional [8]. So far, no one welder specifically designed for hybrid welding. Thus, it is not easy to attain the repeatability and controllability in Laser+GMAW-P hybrid welding.

The plasma characteristics and metal transfer process must be affected by the additional laser beam. A number of experiments have been conducted to investigate the behavior of droplet transfer in laser or hybrid welding [2,9,10–12]. Liu et al. investigated a direct-current GMAW CO_2 laser hybrid welding, it was found that the droplet transfer mode is changed from globular transfer to spray transfer with the increasing distance between laser and arc [11]. Campana et al. found that spray transfer is more appropriate than short circuiting transfer for hybrid welding [13]. Roepke et al. found that low laser powers produced the large globular/short circuiting transfer in the arc, while high laser powers produced the mid frequency small globular free flight transfer [12]. Huang and Zhang found the laser affect the metal transfer process as an additional detaching force [14,15]. However, GMAW-P often referred to as synergic power supplies, the pulse welding process parameters only aimed at specific parameters and shielding gas [16]. In case of hybrid welding, the changing of shielding gas and energy input to the plasma would given the mental transfer a destabilizing effect [2,17]. This is due to the droplet transfer mode related to both arc power and laser power affects droplet transfer in laser-GMA hybrid welding process. Therefore, the pre-selected conventional GMAW-P pulse parameters need to be optimized before use.

Appropriate selection and matching of the shielding gas and the welding parameters will contribute to refinements in Laser+GMAW-P hybrid welding. However, no attention has been paid to study how to obtain a metal transfer mode of one droplet per pulse up to now. Therefore, the primary objective of this investigation is to compare the effect of laser-induced plasma on the metal transfer in Laser+GMAW-P hybrid welding, and find the appropriate sets of pulse parameters to achieve the transfer mode

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of one-droplet-per-pulse. Finally, we given a guide on how to design specifically welder for hybrid welding. The arc plasma and the metal transfer was observed by a high speed video camera. The plasma temperature, electron number densities distribution was estimated by an optical emission spectroscopy system, respectively. On the basis of the measured results, the heat content and force, which exerts a great influence on the droplet transfer, was discussed.

2. Theoretical background

How much the heat content of droplet and how the forces act on the droplet were the major factors affecting the type of droplet transfer. In the conventional GMAW-P progress, Heat content of droplet is composed of the heat input by the Joule heating, H_J, and arc heating H_A [18]. In the case of hybrid welding, an additional laser plume radiation heat input H_L must be considered.

$$H_J = f((I_{rms}/S)^2 l/v) \tag{1}$$

H_J is a function of $(I_{rms}/S)^2\ l/v$, where S is the cross section of electrode, l the electrode extension, v the electrode feeding rate, and I_{rms} is the effective current.

$$H_A = E_A = U \bullet I \tag{2}$$

where U is the equivalent melting voltage, and I the average current.

$$H_L = f(L_P, DLA, V) \tag{3}$$

H_L is a function of (L_p, DLA, V),where L_p is the laser power, DLA the distance between laser and arc, V the welding speed. This can be reflected by plasma profile and temperature.

In the conventional GMAW-P progress, the metal transfer was considered in a state of force balance and thermal equilibrium to achieve one droplet per every pulse. However, the application of the laser destroyed the balance of welding progress. In the case of hybrid welding progress, a large amount of laser-induced plasma energy is continuously put into the electrode. The additional laser power changed the arc profile, electron density, current density and other parameters of conventional GMAW. Which finally changed either the direction or size of the force acted on the droplet. The major forces acting on the droplet include the gravitational force, electromagnetic force (Lorentz force), aerodynamic drag force, surface tension, and vapor jet force. These forces are shown in Fig. 1.

According to the static-force balance theory, the balance of these forces determines the metal transfer process, i.e., droplet formation, size, and frequency. Detaching force and retention force occur in hybrid welding process. Detaching forces include gravitational force, plasma drag force, and electromagnetic force, while retention forces include surface tension and vaporization force.

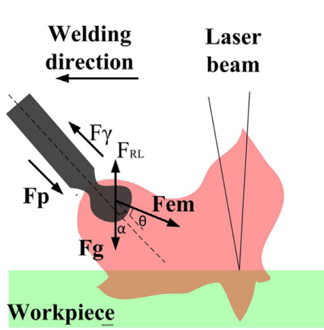

Fig. 1. Schematic of forces affecting droplet in hybrid welding.

The force due to gravity can be expressed as

$$F_g = \frac{4}{3}\pi R^3 \rho_d g \tag{4}$$

where R is the droplet radius, ρ_d is the droplet density, and g is the acceleration of the gravity. This force is higher with higher droplet radius.

The surface tension is given as

$$F = 2\pi a\gamma \tag{5}$$

where a is the electrode radius, while γ is the surface tension coefficient. The surface tension mainly determined by the diameter of the wire.

The aerodynamic drag force can be expressed as;

$$F_d = C_D A_p \left(\frac{\rho_f v_f^2}{2}\right) \tag{6}$$

where C_D is the aerodynamic drag coefficient, ρ_f and v_f are the density and fluid velocity of the plasma, A_p is plasma acting area. This force is higher with higher droplet radius and plasma velocity.

The electromagnetic force, F_{em}, is given by [19]

$$F_{em} = \frac{\mu_0 I^2}{4\pi}\left(\frac{1}{2} + \ln\frac{r_i}{r_u}\right) \tag{7}$$

where μ_0 is the magnetic permittivity, I is the welding current, r_i is the exit radius of the current path, and r_u is the entry radius of the current path. However, in case of hybrid welding, the category of electromagnetic force is changed with changing current line distribution in the droplet.

The vapor jet force is given by [20]

$$F_{RL} = \begin{cases} \frac{1}{4\pi R_h^2} C_D A \rho_m^2 V_o^2 \left(\frac{N_a K_B T_s^{3/2}}{M_a B_o}\right) \exp(-U/T_s) \exp(-{D_{LA}}^2/2R_h^2) & (D_{LA} \le R_h) \\ 0 & (D_{LA} \ge R_h) \end{cases} \tag{8}$$

where R_h is the metal vapor distribution parameters, C_D is the aerodynamic drag coefficient, A is plasma acting area, ρ_m and is the density of the plasma, V_o is constant $(3.4 \times 10^2\ \mathrm{m\ s^{-1}})$, N_a is Avogadro′s constant, K_B is Boltzmann constant, T_S is the surface temperature of melted zone. D_{LA} is the distance between laser and arc. As can be seen, this force is mainly related with the D_{LA}.

As can be seen, in case of hybrid welding, both the heat content and the forces of droplet are different from conventional GMAW-P progress.

3. Experimental set-up and procedure

The experimental setup is shown in Fig. 2. It composed of five main sections: (1) the welding torch with power supply and the system of gas flow control, (2) the welding parameter data acquisition system, (3) the high speed camera, (4) the high power laser and (5) the spectrometer system. These sections are described in later paragraph.

3.1. The welding process

A welding arc is generated at atmospheric pressure by a plasma torch, with 45 degree angles to a workpiece. Electrical power, gas flow and wire feed control are performed by a Fronius machine TPS5000. The power source is operated with positive polarity on the wire. The wire is steel CHW-50C6, and is 1.2 mm in diameter. It is fed at a velocity of $4\ \mathrm{m\ min^{-1}}$. A 10 mm thick steel (E36) workpiece was employed. The chemical compositions (percent by weight) of the workpiece and the wire are given in Table 1. Shielding gas are argon–CO_2 (80% Ar + 20% CO_2) and argon–helium mixtures (50% argon + 50% helium), flowing at $40\ \mathrm{L\ min^{-1}}$.