Journal of Manufacturing Processes 32 (2018) 522–529

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

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

Analysis of welding process stability and weld quality by droplet transfer and explosion in MAG-laser hybrid welding process

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ARTICLE INFO

Article history:
Received 20 December 2017
Received in revised form 16 March 2018
Accepted 18 March 2018

Keywords:
Hybrid welding
Welding process stability
Weld quality
Droplet transfer
Droplet explosion

ABSTRACT

The metallic vapor and molten pool include plenty of welding information in the manufacturing process of MAG (Metal Active Gas Arc Welding)-laser hybrid welding. In this work, double high speed cameras are used to take the real-time images of the top-vapor and bottom-molten pool in the hybrid welding process. In order to monitor welding process status and weld quality, this paper proposes a method which combines the period of droplet transfer and droplet explosion. In time domain, the morphological features include the area of top-vapor, area of spatters, number of spatters and the average gray value of the bottom-molten pool, those features are used to research the stability of short circuiting transfer as well as the mechanism of the welding process. Besides, the welding process stability and weld quality are analyzed by features including the period of droplet transfer and droplet explosion in time and frequency domain. The experimental results show the period of droplet transfer and droplet explosion can effectively reflect welding process and weld quality. It provides a basis for monitoring and controlling MAG-laser hybrid welding process status.

1. Introduction

The idea of laser-arc hybrid welding was first proposed by Steen [1]. The laser-arc hybrid welding has many advantages, such as improved welding speed [2,3] and weld quality [4], deep weld penetration [3], reduction of porosity formation and cracks [4]. So hybrid welding has been widely used in manufacturing industry such as automotive body manufacture, shipbuilding, oil pipeline and aerospace [5–7]. However, laser-MAG hybrid welding is not only superimposition of two heat sources [8]. Therefore, some researchers have focused on the mechanism of the hybrid welding process. Liu showed laser induced attraction and constriction of hybrid arc root make the synergy affect between laser and MAG arc which increased by electron temperature and density [9]. Gao and Wu built a three-dimensional numerical model to analyze keyhole behaviors and fluid flow during droplet transfer in laser-MAG hybrid welding [8,10]. Liu reported the transition mechanisms of arc characteristics, the droplet diameter and droplet transfer behaviors in laser-MAG hybrid welding processes combined with voltage and current signals [11]. For further research on the advantage of hybrid welding and the stress distribution in the joints, the microstructure of weld bead has been observed [12,13].

However, there were few researchers have been studied the relationship between signals and laser-MAG weld quality [14]. Signals can directly reflect the welding status. For example, Wang built an imaging system and measure the weld pool shape to provide feedback information for the automated welding robot system to control the welding quality [15]. Therefore, signal sensing technology has been widely used in welding process monitoring, such as microphone [16], vision sensor [14,16,17], spectrometer [9,21], laser lines [18]and so on. It is easily understood that stable welding process corresponds to a regular signal and unstable welding process corresponds to a mutation or singularity signal and it has been extensively researched in laser welding [17] and arc welding [16]. Hence, for the development of welding automation, it is necessary to analyze the laser-MAG welding stability combined with signal to evaluate weld quality. The best monitored sensor is vision sensor [19] and double high-speed cameras system was proposed in our previous research [20].

Droplet behavior and fluid flow phenomenon have been investigated from different standpoint [10,21–24]. Cai comparatively investigated the transfer frequency and landing location of the droplet by changing welding current wave, transfer sequence of a droplet and morphology of plasma [21]. Zhang reported that the laser-induced plasma plume changes the conductive path and

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https://doi.org/10.1016/j.jmapro.2018.03.024
1526-6125/

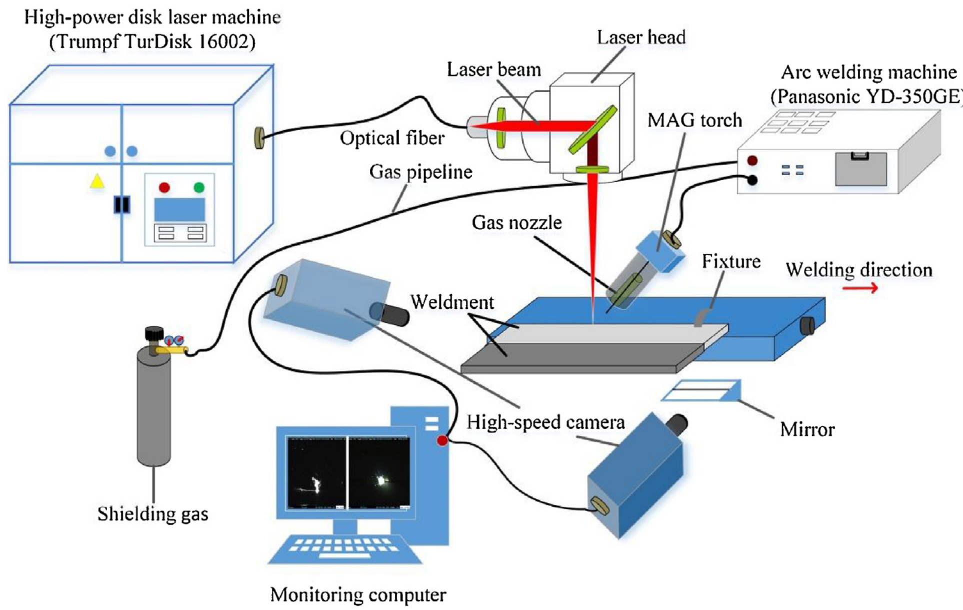

Fig. 1. Schematic diagram of experimental system.

forces affecting on the droplet and has an impact on the arc droplet formation, detachment, and impingement onto the workpiece [22]. Xu's model which took into account the coupling of gas, liquid and metal phases indicated an anti-clockwise vortex is generated and improve the stability of keyhole depth. Besides, the effects of laser power on different driving forces of fluid flow in the weld pool were also discussed [23]. Bunaziv illuminated that the cause of coarse porosity is the closures of keyhole during welding due to flow of liquid metal, which after some time generates swelling [24]. However, these researchers only pay attention to the mechanism analysis. Unlike their research, this paper aims to evaluate process status and weld quality by investigating emphatically the relationship among visual information, short circuiting transfer, and droplet explosion based on feature analysis during the MAG-laser hybrid welding process. On the one hand, this method analyzes the instantaneous status of short circuiting transfer with top and bottom visual features and researches the mechanism of MAG-laser hybrid welding process in time domain. On the other hand, the continuous analysis methods of short circuiting transfer and droplet explosion are used in frequency domain. Finally, the relationship among mutative signals, process stability, and weld quality is built. The work in this paper supplies basis for the study on welding stability and weld formation evaluation in real-time.

2. Experimental setup

The structure of MAG-laser hybrid welding system is illustrated in Fig. 1 which consists of high-power disk laser device (Tumpf-16002), MAG/MIG arc welding machine (Panasonic YD-350GE), six-axis robot, gas shielding device and image capture system. The butt-joint weldment is consist of 316 austenitic steel and 400 mild steel. In order to capture the status of top-vapor, spatters and bottom-molten pool, two high-speed cameras are utilized to capture the information in hybrid welding process. The monochrome high-speed camera A (CA) with infrared-visible optical filter is installed above the weldment and takes the images of metallic vapor and spatters. A visible optical filter is fitted in front of the color high-speed camera B (CB). The CB is placed under the weldment to indirectly capture the images of bottom-molten pool from the mirror. The camera frame rate is 2000 fps and the image resolution is 512 pixel × 384 pixel. The monitoring computer records

Table 1
Experimental conditions.

Welding parameter	No.1	No.2	No.3	No.4	No.5	No.6
Laser power/(kW)	2	3	5	3	3	3
Arc current/(A)	100	100	100	130	100	100
Arc voltage/(V)	10	10	10	10	13	10
Welding speed/(m/min)	0.5	0.5	0.5	0.5	0.5	0.5
Current waveform	pulse	pulse	pulse	pulse	pulse	continuous

images during welding process and image processing method is used to extract feature. In the experiment, the 80%Ar + 20%CO_2 mixture shield gas flow rate is 40 L/min from MAG touch. The angle between the gas nozzle and the horizontal plane is 45°. The welding parameters during the experimentation are shown in Table 1. In particular, continuous waveform is used in No.6 and the other welding processes use pulse waveform. Laser wavelength is 1 030 nm and focuses 2 mm below welding surface, the wire-length is 15 mm, the distance between laser and touch is 2 mm, the welding speed is 0.5 m/min. The size of weldment is 150 mm × 60 mm × 6 mm.

As shown in Fig. 2, the cross-sectional views of the weldment during welding process are presented. Previous research has shown that weld penetration was mainly affected by laser power [3], so the statuses of bottom-molten pool are different with the change of laser power. According to the statuses of bottom-molten pool, the welding process can be presented as three different penetration situations. Fig. 2(a) shows that lower laser power is not sufficient to get a fully-penetrated weld seam in 6 mm thickness of weldment. With the increase of laser power, the status of weldment is full penetration which is shown in Fig. 2(b). In this situation, there are two kinds of phenomena. As the bottom side of keyhole is opening, the inner pressure of the keyhole force the metallic vapor occasionally erupts from the bottom side. And spatter can be occasionally observed. In Fig. 2(c), laser power is not only strong enough for over-full penetration but also keeps the bottom side of keyhole always opening. Most of the metallic vapor erupts from the bottom of the weld beam and it reduces the top of metallic vapor. However, the droplet transfer will influence the fluid flow and constantly change the status of penetration in every welding parameter. And different statuses of penetration have influence on weld quality.