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Influence of shielding gas on undercutting formation in gas metal arc welding

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ABSTRACT

Two sets of vision-based sensing systems were established to investigate the behavior of droplet transfer, arc shape and molten metal flow by varying shielding gas mixtures. Orthogonal experiments and analysis of variance indicated that the CO_2 content in shielding gas was the major welding parameter compared with welding current and arc voltage, which affected the size of undercutting defects. Results demonstrated that the suppression of undercutting defects was mainly caused by the reduction in backward flow velocity of molten metal in weld pool due to the lowering in droplet impact and arc force when CO_2 content increased from 10% to 100%. Non-dimensional fitting method was used to establish the relationships between welding parameters and undercutting defects. It showed that appropriate pulse welding current could suppress undercutting and spatter with high CO_2 content in shielding gas.

1. Introduction

Gas metal arc welding (GMAW) is an arc welding process where a welded joint is produced by melting base metal and filling welding grooves with consumable electrodes. GMAW is the most widely used technology in welding construction industries, because of its high flexibility, easy operation, low cost and considerable potential for automation. Undercutting defects, which appear as grooves at weld toes in high-speed GMAW process, are of serious concern en route to improvement of quality and productivity in manufacturing. Several methods to resolve this problem have been proposed in the past. For example, exploitation of composite shielding gas, control of welding electric parameters, adoption of hybrid welding technology, application of external magnetic field etc. were employing separately.

Suban and Tusek (2001) studied TIME process and reported improvement in production efficiency by increasing the wire melting rate. The TIME process used expensive shielding gases and increased the welding cost. Praveen et al. (2005) achieved better control of the GMAW-P technology and improved the weld bead appearance using an intelligent current waveform in conjunction with automatic feedback systems. The high-cost of the intelligent microprocessor control system curtailed its extension and application. TIG-GMAW hybrid welding investigated by Mishima et al. (2014) and Meng et al. (2014) showed that the TIG arc could stabilize the GMAW arc and increase the welding speed. Tandem MAG welding offered benefits in both welding productivity and quality by improving the arc interaction and molten metal flow in the weld pool, reported by Chen et al. (2015). Both TIG-GMAW and tandem MAG hybrid welding processes were complicated for workers to optimize the welding parameters under practical circumstances. Wang et al. (2015) reported the effect of external magnetic field on weld pool behavior and increased the welding speed up to 2.0 m/min without humping and spatters (92% Ar + 8% CO_2). The external magnetic field required excitation power supply and its performances were susceptible to work space.

It is meaningful to develop cost-effective methods to improve the transitional GMAW process by simplifying the welding parameters and suppressing undercutting defects to increase the welding speed. Studies have been carried out to establish the relationships among shielding gas compositions, droplet transfer, arc shape, weld pool behavior, and their influences on undercutting defects.

Rhee and Kannatey-asibu (1992) observed the weld bead formation under different shielding gas mixtures. They found high reinforcement and bad wetting characteristics by using pure argon shielding gas, which in turn caused severe undercutting defects as a result of high surface tension. Nguyen (2005) proposed a curved

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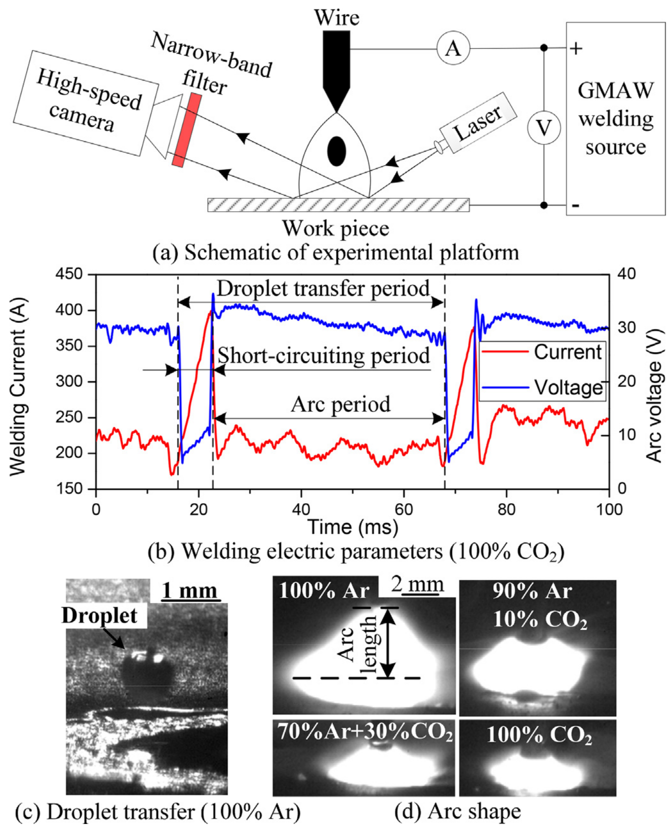

Fig. 1. Observation of droplet transfer and arc shape.

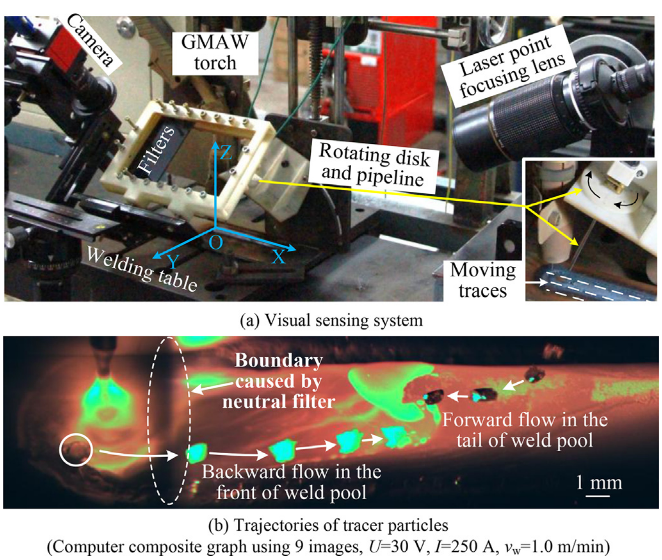

Fig. 2. System used to observe fluid flow on weld pool surface in GMAW process.

wall jet model of humping (serious undercutting defects appeared when humping occurred) in high-speed GMAW. The backward flow of molten metal caused by the momentum of the droplets was the principal physical phenomenon responsible for the formation of humping and undercutting during high-speed GMAW. Mendez and Eagar (2003), investigating high-current arc welding process, found that the molten metal under the arc would turn into a thin film (gouging region) under the action of high arc force. They proposed that the depression of weld pool was the direct factor to invoke several welding defects such as humping, undercutting, split bead, parallel humping, and tunnel porosity.

The above studies provided qualitative explanations to the formation of undercutting defects by analyzing the influences of shielding gas mixtures, droplet transfer and arc force on weld bead formation. The effect of droplet transfer and arc shape on the molten metal behavior in the weld pool, which has significant influence on undercutting formation, requires experimental verification by using different shielding gas mixtures.

Orthogonal experiments were used to investigate the effect of CO_2 content in shielding gas on the size of undercutting defects i.e., depth, width, length and volume. Two sets of vision-based sensing systems were used to observe the droplet transfer, arc shape and molten metal flow on top surface of weld pool. The influence of shielding gas on the undercutting formation was investigated by analyzing the variations in droplet impact, arc force and molten metal behavior. A pulse welding current and appropriate CO_2 content in shielding gas were used to study the influence of shielding gas on the undercutting formation which would aid in realizing high-speed welding without undercutting defects and welding spatters.

2. Visual inspection of GMAW process

2.1. Observation of droplet transfer and arc shape

Schematic of the first set of vision-based sensing system, used for visualizing droplet transfer and arc shape during welding, is shown in Fig. 1(a). The current and voltage sensors with a sampling rate, 25 kHz were used to measure welding current and arc voltage between the contact tip of GMAW torch and work-piece. Fig. 1(b) shows the variations in welding current and voltage during welding. An MV-D1024E-160 high speed CCD camera with a sampling rate, 2 kHz was employed to capture images of droplet and arc shape. An 808 nm narrow-band filter, placed in front of the camera, was used cooperatively with an 808 nm semiconductor illuminating laser to reduce arc interference. The illuminating laser light was reflected by the work-piece and created a shadow image of droplet on the CCD plane. Fig. 1(c) and (d) shows the droplet transfer and arc shape images captured by the sensing system.

2.2. Observation of fluid flow on weld pool surface

Fig. 2(a) illustrates the second set of vision-based sensing system, used for observation of fluid flow on weld pool surface. It consisted of three parts: (1) DS-UN1401-USB3.0 color camera and composite optical filters, (2) delivery device of tracer particle, (3) 3-D coordinate transformation algorithm assisted by structured light.

The work-piece was moving at a welding speed (v_w) while the GMAW torch was stationary. This sensing system was defined by a world coordinate system with its origin (point *O*) being the point where an extrapolated line of welding wire intersected the work-piece surface. The world coordinate system had its *X*-axis opposite to the welding direction, *Y*-axis perpendicular to *X*-axis on the work-piece surface, and *Z*-axis vertically upward, as shown in Fig. 2(a). The principal optic axis of the color camera was fixed on the *OYZ* plane at a depression angle 45°. The framing rate of the camera was 100 Hz. A narrow-band filter with central wavelength 630 nm and bandwidth 40 nm was placed between the lens and CMOS sensor of the camera to reduce arc interference. A neutral filter was positioned in front of the lens only for the central area of arc to further lower the arc interference as shown in Fig. 2(a). High resolution images of weld pool and arc, as illustrated in Fig. 2(b), were captured simultaneously.

Silicon carbide (SiC) particles, of diameter 0.5–1.0 mm were used as tracer to characterize the fluid flow on weld pool surface