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Study on the transient impact energy of metal droplet transfer in P-MIG welding based on acoustic emission signals analysis

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A B S T R A C T

According to the structure-borne acoustic emission (AE) signals detected in pulsed metal inert gas (P-MIG) welding on aluminum alloy, the energy gradient and total energy of AE signals were used to describe the rate of impact energy and total impact energy coming from metal droplet transferred into molten pool. The results showed that there were three types of energy gradient curves according to three modes of metal droplet transfer (MDT). The characteristics of energy gradient curves had a close relation to the transient impact energy of MDT. The energy gradient of MDT decreased with the rise of pulse frequency during the impact process of not only one metal droplet but also several metal droplets within 0.04 s. So, the variation rate of impact energy was lowered with the raise of transfer frequency on the premise of one droplet per pulse mode. Total energy of AE signals coming from not only one metal droplet but also several metal droplets within 0.04 s also demonstrated a downward trend. On the premise of one droplet per pulse mode, the variation of the transient impact energy accorded with an exponential attenuation model.

1. Introduction

The metal droplet transfer (MDT) of pulsed metal inert gas (P-MIG) welding has been found to influence the weld quality, such as the weld geometry and microstructure [1]. Because the MDT of P-MIG welding has high deposition efficiency and automatable equipment with better welding quality, this welding process is widely used in manufacturing. The MDT and its stability are closely associated with the stability of welding process and weld quality. Furthermore, the pulse also affects the MDT as well as the appearance of weld seam in P-MIG welding [2,3]. So, the MDT is a very complicated problem in P-MIG welding.

A high speed video camera system was used to study the stability of gas metal arc welding (GMAW) process by Nakamura et al. The observation showed that the unstable welding behavior was due to the instability of MDT generated at the wire tip [4]. In order to promote the stability of MDT, some researchers have studied its mode and characteristics. Li et al. observed two spatter types related with MDT by using a high-speed digital camera system and analyzed the reason of droplet rebounded spatter [5]. The results provided some helpful guidance in developing dry hyperbaric GMAW process. Luo et al. proposed a new welding method called EMS-CO_2 welding, which improved MDT process, increased the stability of MDT, and delivered better control of the welding spatter [6]. Doodman Tipi et al. presented an improved dynamic metal transfer model for GMAW process, which considered the effect of melting temperature and variation of the conducting area in short circuit period [7].

A lot of process factors could affect the welding stability and weld quality in GMAW. Therefore, the real time monitoring and analysis are highly required in modern automated welding environments [8]. Current and voltage used in welding were considered to be closely related to MDT, which sensing technology was reliable, simple and competitive [9,10]. The acoustic signals produced in GMAW or pulsed GMAW are related to the behavior of the arc, the molten pool and MDT mode. Some researchers acquired acoustic signals in welding to analyze and correlate them with the MDT or the welding stability. Kamal et al. compared the acoustic signals of pulsed GMAW at various process parameters. The acoustic signals were found to be strongly related to both MDT and weld quality [11]. Saad et al. investigated the relationships between the acoustic signals and the modes of the molten pool in variable polarity plasma arc welding. The results showed that the keyhole mode can be distinguished from the cutting mode under the experiment conditions [12]. Kamal et al. used the acoustic sensor and other sensors to properly monitor the depth of weld penetration. Finally, the weld penetration monitoring was found be better with the arc sound kurtosis [13].

As the metal droplet is transferred into molten pool with momentum interchange, the impact energy is generated in a very short moment because the MDT is a transient process. The transient impact energy coming from metal droplet affects the stability of molten pool, the depth of penetration and the appearance of weld. But the method to study and the correlation researches were deficient. In this study,

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Table 1
Welding parameters used in welding experiment.

NO.	Welding current I/A	Arc voltage U/V	Pulse frequency F/Hz	Welding speed v/m min^{-1}	Heat input Q/J mm^{-1}
A01	120	16.2	–	0.32	365
A02	136	15.0	100	0.32	383
A03	142	18.6	200	0.32	495
A04	155	22.0	300	0.32	639
A05	146	25.0	400	0.32	684

according to the structure-borne AE signals detected in MIG welding on aluminum alloy, the energy gradient and total energy of AE signals were used to describe the variation rate of impact energy and total impact energy coming from the metal droplet transferred into molten pool. It was extremely important for all the specialists to have know-how about the metal transfer and its implications on the process and welding parameters in study and industrial applications of the P-MIG welding technologies.

2. Experiment details

Several factors including welding parameters and materials properties affect the characteristics of metal transfer. Aluminum alloy is a lightweight metal material with low melting point. The types of metal transfer mode in welding process are various for aluminum alloy, which makes things difficult for the design of welding process in production. So, the experiment design about metal transfer was made by aluminum alloy and welding parameters. Responding to the industry demand, 2024 aluminum alloys of 4 mm thin sheets and ER4043 aluminum welding wire of 1.2 mm diameter were chosen in experiment. The inert gas used in welding was high purity argon. DC MIG machine with pulsed welding function was used to weld 2024 aluminum alloy. The other factors influencing the MDT mode are the welding parameters, such as arc voltage, welding current and pulse frequency. When altering the values of these main welding parameters, the mode of metal transfer is changing. So, the welding parameters were designed to achieve various transfer types. On the other hand, the transfer mode of one droplet per pulse was the most favorable transfer mode in pulsed MIG welding because of its high welding stability. So, one droplet per pulse mode was chosen in experiment. In other words, the transfer frequency of metal droplet was consistent with the pulse frequency used in welding experiment. Table 1 showed the welding parameters used in welding experiment. NO.A01 was MIG welding with no pulses, and the others were P-MIG welding. From NO.A02 to NO.A05, the pulse frequency used in welding increased from 100 Hz to 400 Hz. In order to obtain enough experiment data, each welding experiment in Table 1 was repeated for three times.

As metal droplet transfers into molten pool during MIG welding, AE signals are released because of the transient impact energy of metal droplet. The characteristics of AE signals are in accordance with the transient impact energy. As not only the transfer mode but also the materials are various, the transmutation of transient impact energy is complicated. So, the transient impact energy of metal droplet was monitored by detecting the AE signals released in MIG welding.

The AE signals released in welding process were monitored in real-time, which were detected by the piezoelectric sensor mounted on the workpiece. So, it was called structure-borne sensing. As the workpiece was used as transmission medium, the losses of AE signals during welding process were less. The experimental equipment was shown in Fig. 1. The harmonic frequency of piezoelectric sensor used in experiment was 150 kHz. The AE signals detected during welding process were amplified by the preamplifier, processed by the signal conditioner and transferred to the computer by data acquisition unit for further processing and analysis.

3. Experiment results

Fig. 2 showed the weld appearance of MIG welding for 2024 aluminum alloy and the AE signals corresponding to welding process. It was clearly that there was a mapping relation between the process of the weld formation and the waveforms of AE signals. In order to analyze the details of AE signals, area A in AE signals was amplified as shown in Fig. 3. It was observed that the waveforms of AE signals were composed of several AE events. Because the welding current used in MIG welding was direct current, the AE event came from the transient impact energy of the metal droplet transferred into molten pool. So, the AE event was called metal droplet transfer event (MDT event). Obviously, the MDT events reflected a mass of transient information about metal droplet transfer. The cycle of MDT event, represented by symbol T, was just the cycle of the metal droplet transfer. Accordingly, it was possible to study the transient impact energy of MDT by the analysis to the AE signals detected in MIG welding experiment.

Fig. 4 showed the waveforms of AE signals detected within duration of 0.5 s. The MDT events of MIG welding as shown in Fig. 4a were distinguishable. The amount of MDT events increased with the raise of pulse frequency as shown in Fig. 4b, c, d and e, which indicated that the MDT

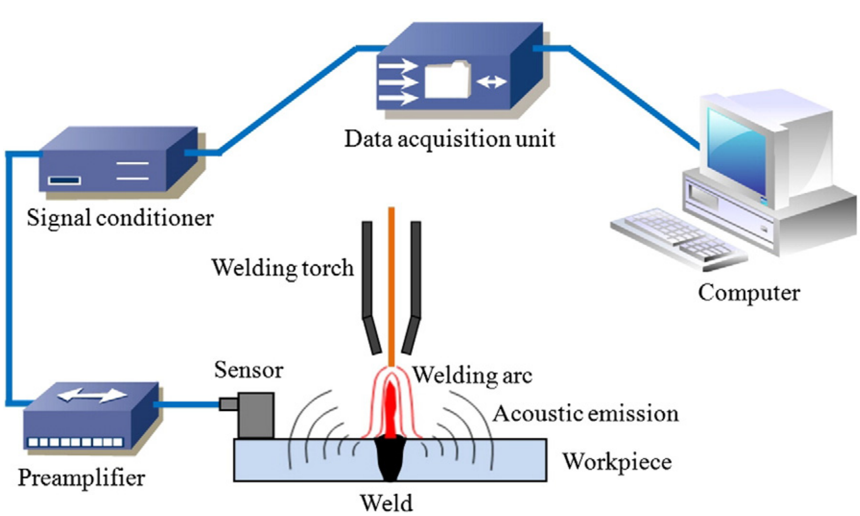

Fig. 1. Schematic diagram showing experimental equipment.