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The ultrasonic characteristics of high frequency modulated arc and its application in material processing

He Longbiao [a,*], Yang Ping [a], Li Luming [b], Wu Minsheng [b]

[a] National Institute of Metrology, Beijing 100013, China
[b] Tsinghua University, Beijing 100084, China

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ABSTRACT

To solve the difficulty of introducing traditional ultrasonic transducers to welding molten pool, high frequency current is used to modulate plasma arc and ultrasonic wave is excited successfully. The characteristics of the excited ultrasonic field are studied. The results show that the amplitude-frequency response of the ultrasonic emission is flat. The modulating current is the main factor influencing the ultrasonic power and the sound pressure depends on the variation of arc plasma stream force. Experimental study of the welding structure indicates grain refinement by the ultrasonic emission of the modulated arc and the test results showed there should be an energy region for the arc ultrasonic to get best welding joints.

1. Introduction

Traditional ultrasonic generation ways include mechanical-type, piezoelectric transducer, magnetostriction transducer, and electromagnetism-type laser ultrasonic, in which piezoelectric transducer and magnetostriction transducer are extensively used in materials processing [1], such as ultrasonic welding [2,3] and refining cast structure by power ultrasonic [4]. Quite a few researchers studied on the effect of ultrasonic during the solidification of molten metal [5,6], but the previous methods of ultrasonic generation could not be introduced into welding pool effectively [7,8]. As a special casting bath, welding pool has a tiny capacity and strong corrosive ability to amplitude transformer. The vibrations of welding wire and work-piece were studied [9–11] to make the molten pool oscillate, but the devices were complex. Mazzola and Molen [12] and Alexeff [13] pointed out that the arc could act as a loudspeaker, which showed welding arc with good dynamic characteristic in audio frequency. As a dynamic load, welding arc is believed to be able to emit ultrasonic under high frequency current modulation [14]. This paper presented the characteristics of ultrasonic generation by high frequency modulated welding arc and carried out the experiments of grain refinement effect with the ultrasonic treatments.

2. The experiment setup

To modulate welding arc and gather the ultrasonic signals, a pulse exciting supply and a continuous exciting supply were founded respectively, as well as the collection and analysis system, as Fig. 1 shows. The power device adopted metallic oxide semiconductor field effect transistor module with the frequency adjustable from audio frequency to 500,000 Hz. With the frequency increased, more energy would be consumed on the transmission lines due to their inductance, so the exciting experiments were carried out below the frequency of 100 kHz. The microphone was B&K 4939L and the PZT transducer was V30 made by Vallen Corp. The exciting source could be coupled freely with a conventional dc or ac welding power through transmission lines. Considering that tungsten inert gas (TIG) welding process was steady, TIG arc was chosen to make exciting experiments. Compared to the parameters normally used in welding process the high frequency modulation energy used to excite the ultrasonic was weak. The added exciting source did not change the conventional technique of welding or its basic specification.

3. The characteristic of high frequency modulating arc

3.1. Acoustic emission of arc with pulse energy modulated

As shown in Fig. 2, the welding arc generated sound wave after it was modulated by the pulse energy. Channel 1 was the sound signal and channel 2 was the pulse signal. The distance from arc

* Corresponding author. Tel.: +86 10 64524630; fax: +86 10 64218628.
E-mail address: helb@nim.ac.cn (H. Longbiao).

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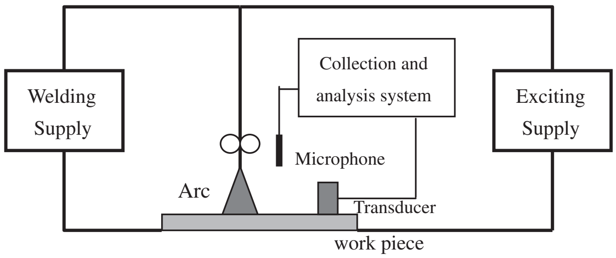

Fig. 1. Schematic experimental setup.

to the microphone was about 100 mm and the delay of the sound signal compared with the pulse signal is about 290 μs, so the speed of the sound emission in the atmosphere can be calculated, namely 344 m/s, which matched with the sonic speed. The sound emission of pulsed arc suggested that arc can response with high frequency modulated current.

3.2. Acoustic characteristic of continuous modulated arc

Fig. 3 showed the arc voltage wave forms. When modulated by high frequency square wave, continuous ultrasonic emission generated, as showed in Fig. 3(c). Channel 1 was the sound signal received by PZT sensor, and channel 2 by microphone. The frequencies of sound signals were the same as exciting signal. The parameters of welding arc were, arc voltage 25 V, arc current 100 A, tungsten cathode with 2 mm in diameter, and argon flow 10 L/min.

As thermal plasma, welding arc includes lots of electrons and ions, which are the substance base to produce vibration. The state of the particles would be changed when they are disturbed by additional energy, and the particles around them were forced into oscillation. The mechanical vibration of particles was propagated into the welding pool and the technology is called arc-ultrasonic welding technology.

Acting as an ultrasonic transducer, the sensitivity and frequency response are its key points. Because of the high temperature of the work-piece, it is easier to get the ultrasonic signal from the microphone instead of the PZT sensor. Also for the high temperature, the distance between the microphone and the arc is set as 50 cm. To evaluate the frequency response of the transducer, the measured sound pressure is traced to the emitted point. As we know, the attenuation coefficient varies with frequency and the ultrasonic pressure could be described as formula (1),

$$p = p_0 e^{-\alpha x} \quad (1)$$

where α is the attenuation coefficient, x is the propagating distance.

When the arc is excited by 50 kHz current and the current was maintained at 5 A, the measure sound pressure is 1.837 Pa at 50 cm

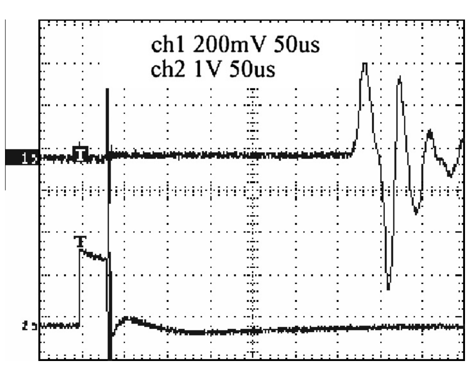

Fig. 2. Acoustic emission of pulsed arc.

from the arc, and 0.918 Pa at 100 mm distance, according formula (1), the attenuation coefficient could be calculated as 0.0175 Np/cm. Then the emitted ultrasonic pressure could be calculated. Frequency response of the airborne ultrasonic is shown in Fig. 4. The TIG welding arc shows flat response from 30 kHz to 100 kHz. At higher frequency, the disturbance of the switch signal from the power devices gets larger and the ultrasound signal is weak to collect. If the exciting source could be improved, the frequency response could be obtained in wider range.

The overall presentation of arc plasma is electrically neutral, while at local positions the charge is always unbalanced and there are oscillations of electron and ion in the plasma. The eigenfrequency of arc plasma is about 1000 MHz to 10,000 MHz, which means arc could make response to the exciting signal under the eigenfrequency. The arc ultrasonic frequency range is decided by the min. response time of the plasma inner particle. But higher frequency needs improved supply and more energy will be lost in the transmission lines.

Directivity is another property of a ultrasonic transducer. The volume of welding arc is small and it contacts with welding piece directly. The directivity test was carried by the plasma spray arc instead of the TIG welding arc. When TIG welding arc was impressed further it will be plasma spray arc, their characteristics should be similar. The plasma current was about 500 A and the modulating current 15 A. The test structure was shown in Fig. 5(a) and the distance L was 80 cm, the sound pressure in front of the arc was measured. In the axis of the arc, the pressure is the largest, and the pressure reduced when it is far from the axis, as shown in Fig. 5(b). It showed that different zones in the welding pool were applied with different energy ultrasonic. It may affect the solidification process of the welding joint in different zones.

3.3. The influencing factors of arc-ultrasonic

For TIG welding arc, the factors of arc-ultrasonic intensity include modulating current, modulation degree (the ratio of the modulating current to welding current), arc length and the flow velocity of shielding gas. Set I_p as the peak value of modulating current and I_b as the welding current. The ratio of I_p to I_b is the modulation degree.

3.3.1. Modulating current

I_b was kept as 50 A and I_p was varied from 2.3 A to 11.7 A, the result showed that for both airborne ultrasonic and ultrasonic in the work-piece, the sound pressure is almost linear proportion to the modulating current, as Fig. 6. The measured value of PZT sensor may influenced by some reflected wave, but the trend is still linear.

3.3.2. Modulation degree

The arc-ultrasonic is excited by the modulating electric current based on the welding current. To describe the influence of different modulation degrees, the modulating current was keep as 10 A, and the welding current varied from 20 A to 80 A with the step of 20 A. The test result was shown as Fig. 7. With the increasing of modulation degree, the airborne ultrasound increased from 5.0 Pa to 7.5 Pa, while the ultrasound in the work-piece almost kept the same.

3.3.3. Welding voltage/arc length

Long arc length means high welding voltage, so the arc length could be described as welding voltage. The test results shown in Fig. 8 indicated that, with the increasing of the welding voltage, ultrasonic in the work-piece almost kept the same pressure while for the airborne ultrasonic the sound pressure is raised. It indicated that the airborne ultrasonic and the ultrasonic in the work-piece were decided by two different mechanism.