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Effect of acoustic field parameters on arc acoustic binding during ultrasonic wave-assisted arc welding

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ABSTRACT

As a newly developed arc welding method, power ultrasound has been successfully introduced into arc and weld pool during ultrasonic wave-assisted arc welding process. The advanced process for molten metals can be realized by utilizing additional ultrasonic field. Under the action of the acoustic wave, the plasma arc as weld heat source is regulated and its characteristics make an obvious change. Compared with the conventional arc, the ultrasonic wave-assisted arc plasma is bound significantly and becomes brighter. To reveal the dependence of the acoustic binding force on acoustic field parameters, a two-dimensional acoustic field model for ultrasonic wave-assisted arc welding device is established. The influences of the radiator height, the central pore radius, the radiator radius, and curvature radius or depth of concave radiator surface are discussed using the boundary element method. Then the authors analyze the resonant mode by this relationship curve between acoustic radiation power and radiator height. Furthermore, the best acoustic binding ability is obtained by optimizing the geometric parameters of acoustic radiator. In addition, three concave radiator surfaces including spherical cap surface, paraboloid of revolution, and rotating single curved surface are investigated systematically. Finally, both the calculation and experiment suggest that, to obtain the best acoustic binding ability, the ultrasonic wave-assisted arc welding setup should be operated under the first resonant mode using a radiator with a spherical cap surface, a small central pore, a large section radius and an appropriate curvature radius.

1. Introduction

Arc welding, characterized by advantages such as simple operation, high production efficiency and being prone to automation, has been extensively applied in welding manufacture industries, including automobile, aviation, shipbuilding, national defense, petroleum, electron. As the technology and the theory develop, welding has become a systematic discipline [1]. However, with the continuous development of modern industry and the variation in the diversity of products, materials, and their service conditions, the requirements for welding quality becomes more strict. Excellent welding technology of high efficiency and low consumption is an inevitable development trend in the field. Considering the advantages of ultrasonic such as mechanical effect, acoustic streaming and cavitation effect, many researchers have done some distinctive work to introduce ultrasound in the process of arc welding. Dai [2] imposed the ultrasonic frequency vibration with 2 kW output power and 20 kHz output frequency to the side surface of workpiece to be welded in the tungsten inert gas (TIG) welding of 7075-T7 aluminum alloy and found that the grain size in the overheated and heat affected zones decreases. By exerting ultrasonic to the back of the workpiece of AL-6XN austenitic stainless steel, Cui et al. [3] thought that the joint corrosion resistance could be improved by applying the ultrasonic with 1.5 kW output power and 20 kHz output frequency to the shielded metal arc welding process of super-austenitic stainless steel. In conventional metal inert gas (MIG) welding, Watanabe et al. [4] introduced ultrasonic energy into the weld pool by the ultrasonic frequency oscillation of filler metal, the output power and the frequency of the ultrasonic vibration system used in that study were 600 W and 19 kHz, respectively. They found that the elongation of the stainless steel joint increases by more than 40% comparing with those obtained in conventional MIG welding. Wu et al. [5] reported this arc ultrasonic as the result of excitation of arc by high frequency current, and the frequency can be artificially adjusted from 10 to 100 kHz by a pulse exciting supply. He et al. [6,7] and Morisada et al. [8] has also demonstrated the effectiveness of this method in improving performance of the joint. Yang et al. [9,10]

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proposed the ultrasonic wave-assisted arc welding method, where non-contact ultrasonic vibration is imposed along the coaxial direction of arc to form an acoustic radiation field in arc zone. The acoustic radiation field can act on arc and weld pool. The welding equipment and the action principle of acoustic wave are illustrated in Fig. 1. This equipment includes two parts: acoustic radiation equipment and welding equipment. The former is constituted of ultrasonic power and ultrasonic transducer. The transducer produces co-frequent mechanical vibration, which is amplified through amplitude transformer and then radiated to surrounding space in the form of ultrasonic waves through acoustic radiator. The whole equipment is similar to a single axis acoustic levitation system applying the workpiece to be welded as the acoustic reflector [11]. With the ultrasonic force, the welding arc is compressed and therefore generates certain arc acoustic binding effect (Fig. 2) [12,13], the droplet transfer frequency increases [14]. Compared with the conventional arc welding, when the ultrasonic of 100 W output power and 20 kHz frequency is applied, the weld penetration increases (Fig. 3) [14,15], the grains are obviously refined in the weld [16]. Therefore, it is helpful in improving the welding efficiency and joint performance, its application potential is as wide as to cover all arc welding processes. Especially, it may find the most attractive applications in welding other positions except for the flat welding with the small welding gun and few process parameters.

Acoustic force mainly refers to acoustic/ultrasonic radiation force, which is firstly applied in acoustic levitation. There are two different types of waves used in levitation, corresponding to the standing and progressive waves, respectively. Here, the radius of the objects, R_S, should be smaller than the sound wavelength λ. It is shown the force produced by a standing wave is much larger than that produce by a progressive wave, because the former is of the order of $(R_S/\lambda)^3$ whereas the latter is of the order of $(R_S/\lambda)^3$. A most notable aspect of the acoustic radiation force is the possible sign change depending on the densities and compressibilities, which determines the direction of the force and thus whether the particle will move towards the standing wave pressure node or the antinode. Generally, gases [17,18] and liquids [19] can be served as the transport medium and the force acted on solid particles or gas bubbles is primarily focused in prior research. However, the presence of particles or bubbles may also reduce the levitation ability. More attention is paid to enhancing the levitation force and stability in terrestrial laboratories [20,21], whereas the optimization of acoustic levitation device is one of the solutions. The number of the prototypes of levitation device can be remarkably reduced through optimizing the geometric parameters of levitation device by using linear numerical simulation prior to the design of levitation device. Combined with Gor'kov theory [22], Barmatz et al. [23] developed a method to evaluate levitation force and stability of levitated spheres in various acoustic fields by time-averaged potential. Their method is simple and convenient, but the concrete form of acoustic field needs to be known in advance, while as for the complex form acoustic field, it is often difficult to obtain the analytical expression and acoustic radiation and scattering should be involved into the analysis. Compared with the other methods [24–26], boundary element method is commonly applied to analyze acoustic field, especially for the external acoustic field [27–29]. Xie et al. [27,28] employed this method to explore the influence of acoustic field parameters on the acoustic levitation force. In their study, the iridium with density of 22.6 g/cm^3 was successfully suspended by optimizing the geometric parameters of reflector. There are many literatures focused on the optimization design of reflector, while the optimization design of acoustic radiator is rarely reported. This is mainly because that the shape and dimension of radiator must meet the requirements for matching with transducer, which means that the choice range of radiator is greatly limited. Whereas, the design of reflector is out of these restrictions to free variation its geometrical parameters. During the process of ultrasonic wave-assisted arc welding, the geometric parameters are constant with the welding workpiece as reflector, and the existence of arc plasma also has some negative influences on the space distribution of acoustic field [30–32]. Thereby, the acoustic binding capability can be further enhanced only by optimizing the parameters of acoustic radiator.

In this paper, we firstly establish a double cylinder model for ultrasonic wave-assisted arc welding devices. Then based on Barmatz's approach, the resonant modes, the acoustic radiation force, and the restoring force constants are analyzed on the basis of the time-averaged potential, during which main attention is focused on the influence of the parameters of acoustic radiator with concave radiation surface on acoustic binding force (radial and axial acoustic radiation force). Finally, in order to verify the reliability of this model, acoustic binding experimental results for arc plasma are also presented accordingly. The purpose of this paper is to clarify the possibility and feasibility of improving an acoustic field's capabilities of ultrasonic wave-assisted arc welding device by optimizing radiator's geometric parameters and enhance the acoustic energy utilization.

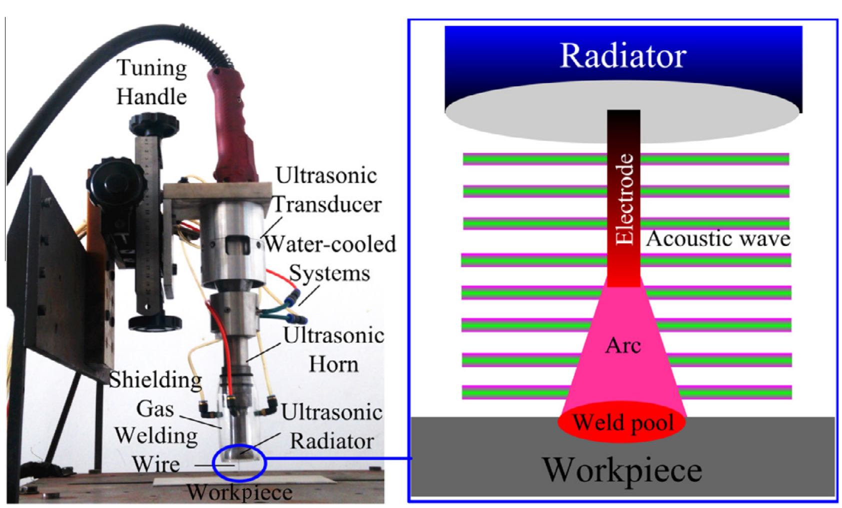

Fig. 1. Device of ultrasonic wave-assisted arc welding.