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Ultrasound in arc welding: A review

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A B S T R A C T

During the last decade, the introduction of ultrasound techniques in arc welding with the intention of improving the operational performance and technical characteristics of the welding processes have been studied intensively. In this work is presented a broad review of the literature surrounding the utilization of this technique. Firstly, we discuss the use of traditional mechanical transducers to generate ultrasound in arc welding. Furthermore, we describe the various methods and their application in arc-welding processes. After, is presented a recent method of introducing ultrasonic energy in arc welding, which forms a potential alternative to the use of traditional mechanical type transducers. This method was originally developed in the late 1990s and is called arc with ultrasonic excitation of current. Here, the arc acts not only as a thermal source but also as an emission mechanism for ultrasound, acting directly on the weld pool. We presented and discussed various innovative concepts based on this method, which allows the introduction of ultrasonic energy in the arc welding without the need of any auxiliary device of welding. In addition, we also presented the variations of this method reported in the literature. Finally, we have described the respective effects attributed to the use of this method in the welding of different materials using various welding processes.

Contents

1. Introduction

Despite the advent of new fusion welding processes or techniques, voltaic arc remains the main heat source for promoting the fusion of metallic materials. This is due to the fundamentally unique features of electric arc welding, such as the easy and accurate control of the energy input to the workpiece, low cost, and the easiness of obtaining the arc. Nonetheless, efforts are constantly undertaken to increase the productivity of arc-welding processes, while seeking to improve the metallurgical characteristics of the welds. Accordingly, several techniques have been studied and developed to serve these purposes over the years.

Recently, a new arc-welding method has attracted attention owing to the results obtained in the welding processes in which

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it has been used. This method uses ultrasonic energy in arc welding.

The effects of ultrasound in materials processing are long known [1]; however, despite the use of ultrasound in industry, including the union of materials, ultrasound is not yet successfully applied in industrial arc-welding applications. Nonetheless, the use of ultrasound in arc welding has been studied intensively in the last decade. Several studies in the literature discuss ultrasonic welding not only from the operational point of view but also with respect to the metallurgical aspects of the resulting welds. The results of these studies highlight the potential of ultrasound in arc welding as the means to improve the performance of the welding process and the final quality of the welds.

This paper consists of two parts that are based on a comprehensive literature review, and provide a broad and updated view of the means to introduce ultrasound in arc welding with respect to the operational and metallurgical characteristics. The first part, specifically focuses on the techniques that make use of mechanical transducers for obtaining ultrasonic energy. These transducers are either piezoelectric or magnetostrictive [2], and both are widely used in material processing [3]. The second part, focuses on the new method based on the pulse of current in ultrasonic frequencies, called arc with ultrasonic excitation of current. In this method the arc acts not only as a thermal source but also as a mechanism that emits ultrasound to introduce energy in the molten pool [4]. This work does not examine the technology for obtaining the ultrasound but the development of techniques that allow the application of ultrasound in the various arc-welding processes and its effects.

2. Use of mechanical transducers

2.1. Ultrasound in GTAW welding

With the objective of introducing ultrasound in GTAW welding, Sun et al. [5,6] proposed a system consisting of ultrasonic vibration excitation through a piezoelectric ultrasonic transducer made of titanium wire and attached axially to the tungsten electrode used in the GTAW process. Thus, during welding, ultrasonic vibrations are directionally applied to the axial axis of the electrode and transmitted to the molten pool, independently of the waveform and polarity of the welding current. By using this method and based on the results obtained in the welding of AISI type 304 stainless steel, Sun et al. [7,6] showed that the use of ultrasound might significantly increase the weld penetration as well as the relative depth and bead width. According to the results, an increase of 1.18 mm to 3.12 mm and 1.20 mm to 3.71 mm in the penetration welds performed with a current of 100 A and 150 A, respectively, was achieved by using an electrode vibration frequency of 20.5 kHz and a power of 200 W [7] (Fig. 1). This increase in penetration weld of AISI 304 stainless steel is also reported by Fan et al. [8] and by Sun et al. [9] by employing ultrasonic vibration power of up to 1 kW. In addition, under the same conditions, when the depth–width relation is considered, there is an increase of about 235% in welds when using a current of 100A and 380% in welds when using a current of 150 A relative to conventional GTAW welds [6]. According to these authors, this is attributed to the greater penetration of the ultrasonic field owing to the longitudinal oscillation of the electrode, which seems to increase the pressure of the plasma jet in the molten pool. In this context, Sun et al. [10] stated that the pressure in the arc welding when using ultrasonic vibration has a peculiar behavior. Unlike what happens in conventional GTAW welding, where the arc pressure continuously decreases with increasing distance between the electrode and the workpiece, using the ultrasonic vibration the maximum value of arc pressure reaches an intermediate distance of 4.4 mm.

Wen [11] also reported a similar increase in weld penetration by directly applying ultrasonic vibrations perpendicular to the workpiece surface. According to the results obtained in the GTAW welding of aluminum alloy 7075-T6 using a vibration frequency of 20 kHz and resonator power of 2 kW, there was an increase in the penetration of up to 45% and a grain-size reduction of the next line melting up to 42% compared to conventional GTAW welding.

Using the same concept of vibration system employed by Wen [11], Dong et al. [12] introduced the ultrasonic vibration welding of Al–Mg alloy with galvanized steel and Al–Mg with stainless steel, both in lap joints. Both materials could be welded. In the case of the galvanized steel, there was significant grain refinement in the microstructure of the weld, associated with the decrease in Fe–Al intermetallic compounds and the increase in the tensile strength of the welded joint from 115 MPa to 146 MPa, an increase of 27%.

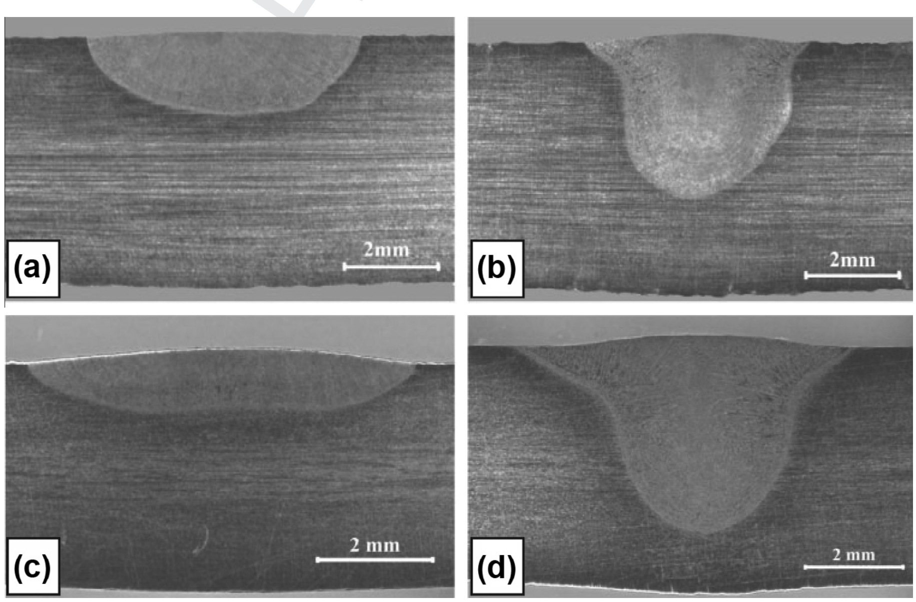

Fig. 1. Macrograph of the cross section of the welds made in AISI 304 with a current of (a) 100 A without ultrasound, (b) 100 A with ultrasound, (c) 150 A without ultrasound, and (d) 150 A with ultrasound. Adapted from Sun et al. [7].

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