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EFFECTS OF ULTRASOUND VIBRATION ON MICROSTRUCTURE SUBMERGED ARC WELDING

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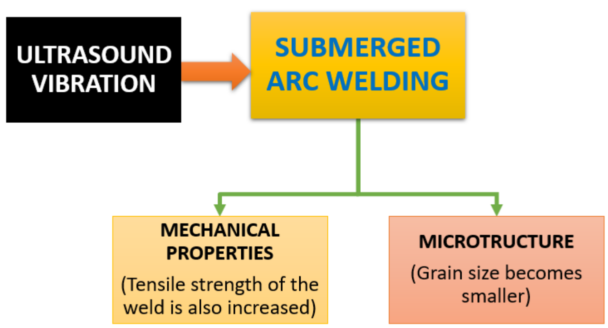
Graphical abstract



Abstract

The microstructure of the weld influences its quality, in which the grain size is one of the most important parameters affecting the mechanical properties of the weld. To change the grain size, the cooling process of the weld zone must be carefully controlled. Customarily, the weld zone is cooled down without post-treatment after the welding process, so the microstructure of the weld is similar to that of the casting. In this study, ultrasonic vibrations are used in the welding process from the beginning of the welding process until the part is completely cooled. Using the ultrasonic waves with frequency of 20kHz, power of 1500W, the researchers analyzed the weld microstructure, comparing the welds with and without ultrasonic vibrations. The results show that when ultrasonic vibrations are utilized, the grain size is changed and the mechanical properties are significantly improved.

Keywords: Ultrasonic vibration, Arc weld structure, Grain size, Frequency of 20kHz, Mechanical properties.

1.0 INTRODUCTION

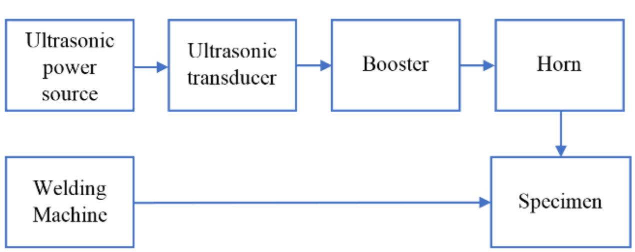
Welding is a technology that accounts for a large proportion of the manufacturing technology, especially fusion welding technology [1]. In order to improve the quality of welding processes, many studies have been conducted to improve the equipment, technology, as well as welding worker skills, and remarkably, plenty of achievements have been recorded in this field [10, 14]. However, all these things only ameliorate the welding quality such as preparation or post-processing, but do not change the characteristics of the fusion weld, which entails the features of castings and heat-affected areas. Therefore, in order to fathom the nature of the fusion weld, it is necessary to master the nature of weld formation, from melting to recrystallization, thereby directly interfering with the process to enhance the quality of the fusion weld.

Recently reported research has demonstrated that the use of ultrasonic vibrations during the welding process increases weld penetration, reduces grain structure, increases weld properties, and reduces heat-affected areas in molten welds [2, 11-13, 15-20]. Sun et al. [3] reported that using ultrasonic waves with frequency of 20.5kHz, power of 200W in the GTAW process for stainless steel results in an increase in weld penetration by 1.18 - 3.12 mm. In addition, Dai et al. [4], Dong et al. [5], and Cui et al. [6] described that using a 20 kHz ultrasonic wave with a power of 2000W in GTAW welding method for aluminum alloy 7075-56 increases significantly weld penetration (45%), reducing the grain size structure, increasing the tensile properties of the weld by 27%, and at the same time significantly reducing the heat affected zone in the molten weld. Chen et al. [7] specified that using ultrasonic waves in the welding process shortens the length and increase the width of the arc region, increasing the permeability of the weld, reducing the grain size of the martensitic structure, making the solidification process more uniform, and increasing the weld mechanical properties.

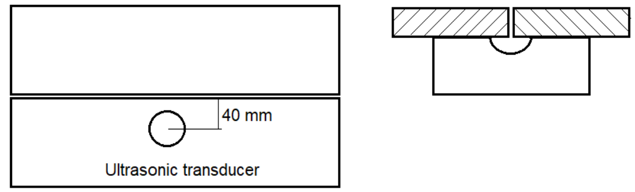
The essence of an arc weld is the crystallization of liquid metal in the weld region to form a weld joint. Therefore, welds that are characteristic of casting are dendrites and are pearlite plates. The above organization is of poor mechanical properties and makes the weld joint easily damaged under the impact of external forces. The ultrasonic waves applied in the crystallization process of the weld will destroy the original organization, creating a smaller, finer structure and improving the weld's mechanical properties. Kolubaev etc [8] reports the application of ultrasound during laser welding of low-carbon steel significantly affected the weld pool solidification conditions. Ultrasonic vibrations create ultrasonic cavitation in the melted metal thanks to high pressure and shock waves. The cavitation reduces the level of dendritic segregation and inhibits the growth of Widmanstätten ferrite crystals that significantly reducing the strength of the weld. Although the welding process with the employment of ultrasonic vibration has been studied for decades, the data on microstructure and mechanical properties of welded components under the submerged arc welding process is not readily available. Among steels, SAE 1040, a carbon steel, is widely utilized for general structural and constructional purposes such as the construction of factories, bridges, boats, rails, trucks, and the building of seawater tanks [9]. In this study, SAE 1040 carbon steel was selected as a material for investigation. The submerged arc welding process was performed under various conditions. The properties and mechanical properties of welded samples with and without the assistance of ultrasonic vibration were scrutinized within the context of microstructure and tensile strength.

2.0 METHODOLOGY

The material used in this research was steel plate SAE 1040. The nominal chemical composition of the SAE 1040 steel (weight %) is composed of C (~0.40), Mn (~0.70), S (≤ 0.050), and P (≤ 0.050). The experiment would be conducted on a carbon steel sheet with different thicknesses. Figure 1a presents the flowchart of the experimental process and Figure 1b shows the workpiece was correlatively installed with ultrasonic transducer. Ultrasonic vibration was generated at the frequency of 20kHz, the power of 1500W, and the vibration amplitude from 30µm to 50µm. The experimental setup model is shown in Figure 2. After the welding process, the welded samples with their microstructures and tensile strength were properly examined to investigate the effects of the ultrasonic vibration on the microstructure and properties of the materials. The welding process parameters is presented in Table 1, and the weld speed 0.4 m/min, wire supply speed 0.4 m/min, wire diameter 2 mm were used the same for all the welding process.



a.The flowchart of the experimental process

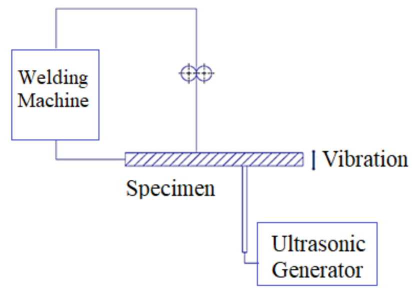


b. The position of Ultrasonic transducer

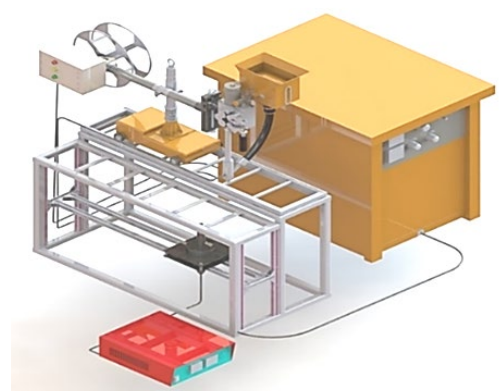
Figure 1 The welding experimental process

Table 1 Welding process parameters.

Workpiece 4 mm thick	Workpiece 6 mm thick	Workpiece 8 mm thick
Current: 235-250A Voltage: 25-28V	Current: 250-270A Voltage: 27-30V	Current: 280-320A Voltage: 31-35V



a) Design model



b) 3D model

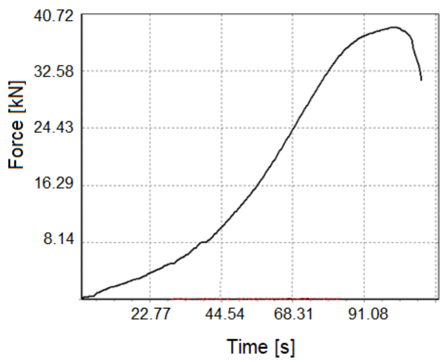
Figure 2 Experimental setup model

Analysis of Microstructure

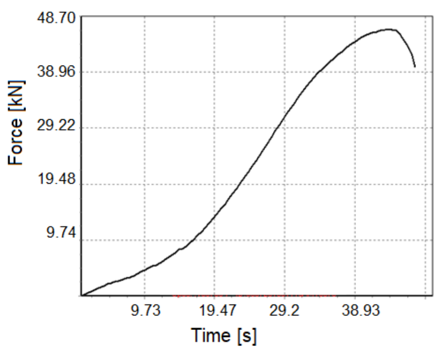
Microstructure analysis samples were obtained from welded samples. The samples were cut axially, then the sample was ground with grit sandpapers from P100 to P2000. The samples then were polished using aluminum oxide solution. The sample surface was cleaned with distilled water and 90o alcohol and then dried before etching. Samples were etched with Nital solution (100 ml ethanol and 5 ml nitric acid) with an etching time of 15 seconds. The sample was cleaned with 90^{o} alcohol and dried. Optika microscopes with magnifications from 50x to 500x were used to observe microstructure.

3.0 RESULTS AND DISCUSSION

The tensile strength of the welded sample is shown in Figure 3. The results show that it was improved with the help of ultrasonic vibration during welding process. The tensile strength increased from 0.350 kN/mm^2 to 0.381 kN/mm^2 (equivalent to 8.9%), from 0.364 kN/mm^2 to 0.393 kN/mm^2 (equivalent to 7.9%) and from 0.342 kN/mm^2 to 0.364 kN/mm^2 (equivalent to 6.4%) in the cases of plate steel 4mm, 6mm and 8mm, respectively.



a) Without ultrasonic vibration assistance



b) With ultrasonic vibration assistance

Figure 3 The graph of force versus time in the tensile strength test in the test of steel 6mm

The cross-section of welded joint can be divided into four different zones which are fusion zone, weld interface, heat-affected zone, and the base metal (Figure 4). Due to the thermal influence of the welding process, the microstructure and mechanical properties of these regions are completely different. Therefore, the influence of the ultrasonic oscillation on these different areas of the weld also differs. Such discrepancy could be noticed when we compared the microscopic structure of the welds without and with the impact of ultrasonic vibrations. The results are shown in Figures 5, 6, and 7.

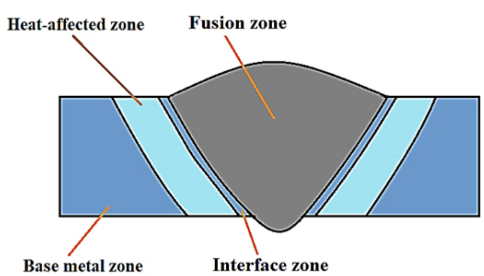
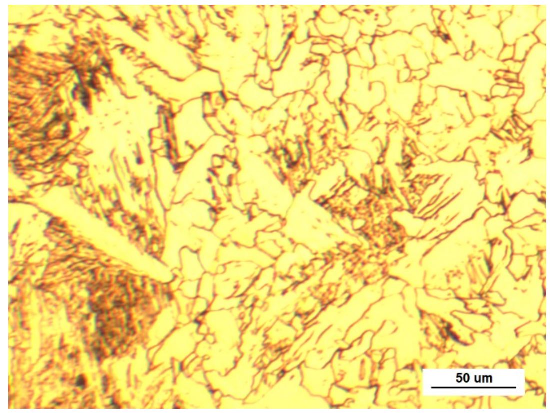
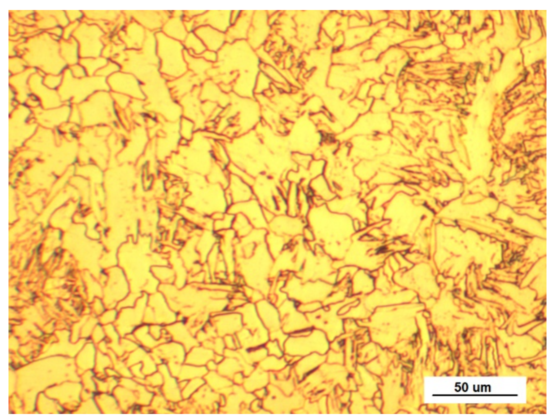


Figure 4 The cross-section of welded joint

Figure 5 illustrates the microstructure of the fusion zone of the welded samples. Figure 5a shows that the microstructure of the fusion zone is completely coarse, grain size is large and the dendritic structure is observed. This structure has poor mechanical properties, many defects and it directly affects the quality of arc welds. In Figure 5b, when ultrasonic vibration is supported, the coarse grain organizations become finer, the dendritic structure is broken and anisotropic arrangement contributes to the increase of weld properties [8, 10, 11, 12]. Average grain size reduces from 11.52 µm (Figure 5.a) to 9.21 µm (Figure 5.b).



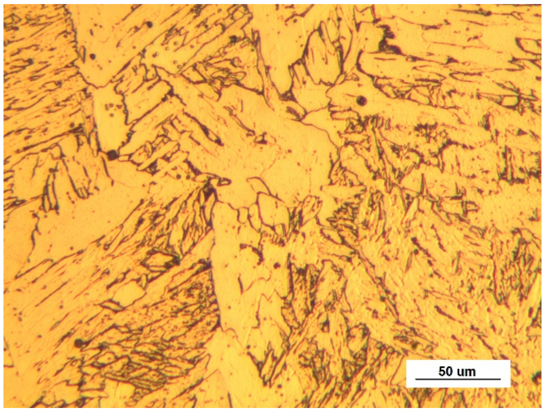
a. Without ultrasonic assistance



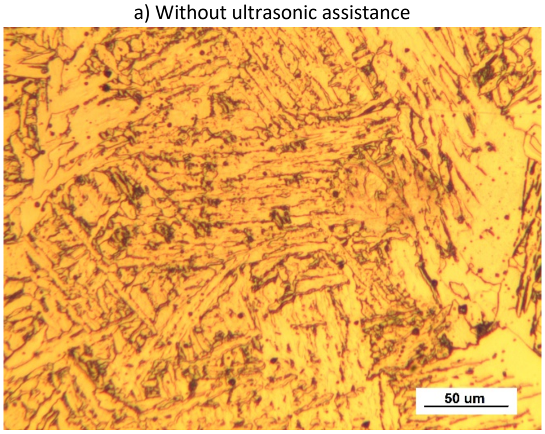
b. With ultrasonic assistance

Figure 5 The microstructure of the fusion zone of the welded samples

Figure 6 presents the microstructure of weld interface of the welded samples. This section has the fastest cooling rate in the weld pool and is the area where the nucleation is born and grows fastest. The section is mainly structured with long, thick dendrites and points towards the center of the weld pool in the arc welding. The complete melting area has coarse grain and the dendritic structure is often formed here (Figure 6a). Nevertheless, thanks to the ultrasonic vibration that brings energy and creates vacuum bubbles, the micro-vortex phenomenon has caused the organization of dendrites to be significantly reduced. Moreover, ultrasound creates pressure on the surface of the gas welding tank, increasing the convection in the molten weld, which improves microstructure and the solubility of the welding components.



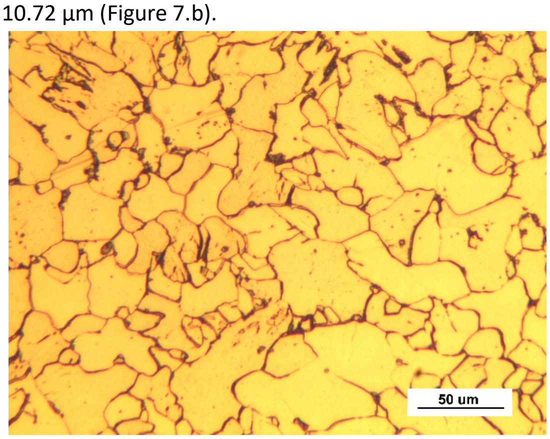
a) Without ultrasonic assistance



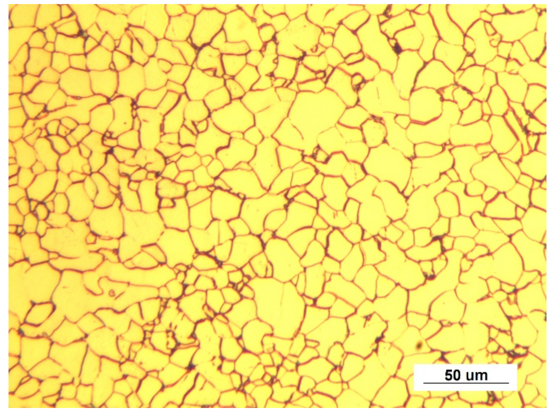
b) With ultrasonic assistance

Figure 6 The microstructure of the weld interface of the welded samples

The heat-affected zone of the welded samples is illustrated in Figure 7. This is the area that causes poor mechanical properties. Although it retains the chemical composition of the base metal, under the effect of heat during welding, this area is affected by residual thermal stresses and recrystallization when heated above the crystallization temperature. Recrystallization is similar to the crystallization in liquid metal, which also involves germination and germ development. The ultrasonic vibration transmitted inside the weld also exerts an impact on this region. Specifically, in case of a weld with ultrasonic vibration support, the microstructure becomes smaller and more uniform than that in case of a conventional welding process. Average grain size reduces from 18.92 µm (Figure 7.a) to 10.72 µm (Figure 7.b).



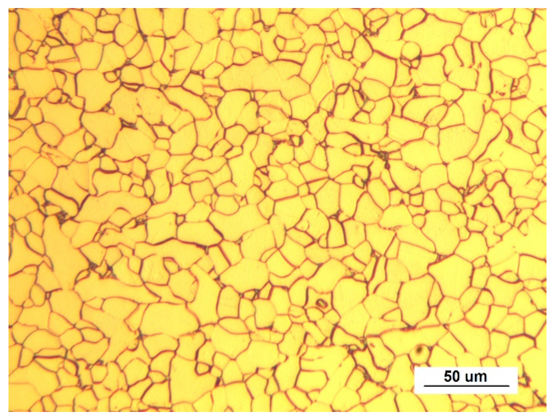
a) Without ultrasonic assistance



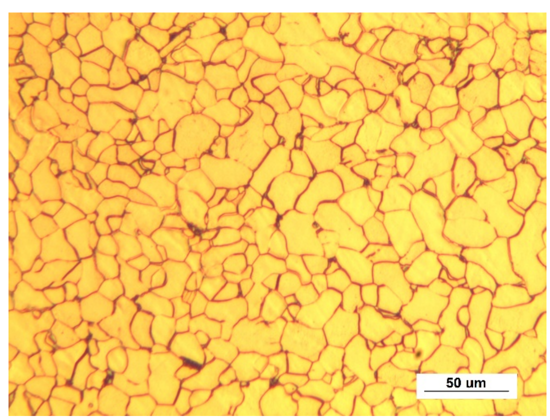
b) With ultrasonic assistance

Figure 7 The microstructure of the heat-affected zone of the welded samples

The unaffected base metal zone is presented in Figure 8. This zone neither is not melted nor does not undergo any changes in microstructure; hence, the ultrasonic vibration does not influence this zone during the welding process. Average grain size is about 10 µm (Figure 8.a and Figure 8.b).



a) Without ultrasonic assistance



b) With ultrasonic assistance

Figure 8 The microstructure of unaffected base metal zone of the welded samples

To sum up, it can be asserted that ultrasonic vibration increases heat conduction in the weld. When the ultrasonic vibration propagates into the welding crystalline network, the lattice undergoes constant compression and reduction, resulting in changes in the lattice density. During compression, the lattice volume diminishes, leading to an increase in temperature. By contrast, during reduction, the lattice volume increases, leading to a decrease in temperature. This change leads to the heat transfer in the crystal lattice from the high temperature to the low temperature, causing changes in the heat distribution in the weld. On the other hand, when the crystallization takes place, the germs in solid objects form, but under the effect of tensile-compressive ultrasonic pressure they cannot grow up, and ultrasonic vibration carries the stimulating energy. Considering germination in solid objects in the same space, the proliferation of germs leads to limited development space, resulting in finer grains in the organization of this section than those of the original organization.

The results of this study are used to reduce the grain size in the welding zone, reduce the thermal effect, and limit or eliminate the boundaries of the regions. This method is applied to improve the quality of arc welded structures in manufacturing, ships, and aviation applications. In the next research, the improvement of mechanical properties and fatigue strength of the welded parts are investigated. Besides, the effects of ultrasound on other types of arc welding methods also are considered.

4.0 CONCLUSION

The microstructure and mechanical properties of the welded SAE 1040, a carbon steel under different submerged arc welding process conditions were investigated. Ultrasonic energy reduces the time and temperature during the solidification of the weld. This leads to certain changes in the microstructure of welds, i.e. reducing dendritic type formation, disrupting inherent dendritic organization; and making grain size becomes smaller, finer, and more homogeneous in distribution. Experimental results also show that the tensile strength of the weld is also increased under the effect of ultrasonic vibration (20kHz, 1500W) on a carbon steel: with the 4mm sample increased to 8.9% and the 6mm sample increased to 7.9%.

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