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Technical Paper

Comparison of mechanical properties of pure copper welded using friction stir welding and tungsten inert gas welding

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ABSTRACT

The objective of this research is to investigate the mechanical properties including bonding, tensile strength, and impact resistance of pure copper welded using friction stir welding (FSW) method and compare them with that of tungsten inert gas (TIG) welding. Micro-hardness tests are performed on pure copper, TIG welded copper and FSW welded copper to determine the effect of heat on the hardness of welded coppers. Tensile strength tests and notch tensile strength tests are performed to determine the mechanical properties of different weld process.

In this experiment, it is found that the notch tensile strength and the notch strength ratio for FSW (212 MPa, 1.10) are significantly higher than those (190 MPa, 1.02) of TIG welding. For the impact tests, the weld zone and heat-affected zone energy absorption values for FSW (2.87 J, 2.25 J) are higher than those (1.32 J, 0 J) of TIG welding. XRD tests are performed to determine components of copper before and after welding process for TIG and FSW.

1. Introduction

Pure copper is a tough, malleable, and ductile metal. Copper metal has been utilized to manufacture many things since the beginning of human civilization. Nowadays, the consumption of copper in quantity is the second among all kinds of metal. Copper is a good conductor of electricity and heat, thus it is widely used as the electric conducting and wiring material for electronic devices, communication products and power transmission lines. Due to its excellent heat conductivity, copper is also used in many appliances such as refrigerators, evaporators, and heating coils. It is a situation which occurs frequently in the product manufacturing processes to weld pieces of copper together.

However, pure copper is a challenge for traditional welding process like brazing because oxygen is present during the extraction of pure copper. At above 400 °C, hydrogen atoms in the reducing gas rapidly diffuse into the solid metal and react with the Cu_2O to form H_2O. Sufficient local pressure is built up by the vapor that is formed through the aforementioned reaction and creates internal holes; these holes make a porous structure which reduces malleability and strength [1] of the material.

Tungsten inert gas (TIG) welding is an inexpensive welding process that produces good quality welds. It has been adopted for welding copper since 1940s. However, the welding of copper is usually difficult because copper has a high thermal diffusivity, which is about 10–100 times higher than those of many steel and nickel alloys. The heat dissipates faster than almost any other material thus results in low welding speed. To overcome these problems, friction stir welding (FSW), a solid-state welding technique, has become a better option to TIG [2,10].

Compared to traditional welding method or TIG, FSW has a lower heat input, less welding distortion, zero pollution, and higher welding performance. Therefore, it is now widely used for welding of aluminum, magnesium, copper, zinc, lead, low-carbon steel and aluminum matrix composites [3,4]. The thickness of welds varies from 1 to 50 mm and applications range from small cooling components to ship construction [5,6]. Welds with a thickness of 50 mm for nuclear waste disposal canisters have been achieved [7]. Previous studies [8–11] have investigated the effect of welding speed on the microstructure and mechanical properties of pure copper. It is found that the grains decreased and became finer with increasing welding speed, resulting in enhanced mechanical properties. Khodaverdizadeh et al. [12] used hardening and strain hardening indices to explore the influence of stir revolutions and feed speed on the strain hardening behavior of pure copper. He et al. [13] used FSW and TIG welding to investigate the annealing of cold-pressed and hot-pressed plates of the alloy Al–Mg–Mn–Sc–Zr. A comparison of the welding properties and microstructure indicated that the hardness of the alloy with FSW was higher than that of the alloy with TIG welding. Liu et al. [14] studied the TIG welding of magnesium alloys and investigated the characteristics

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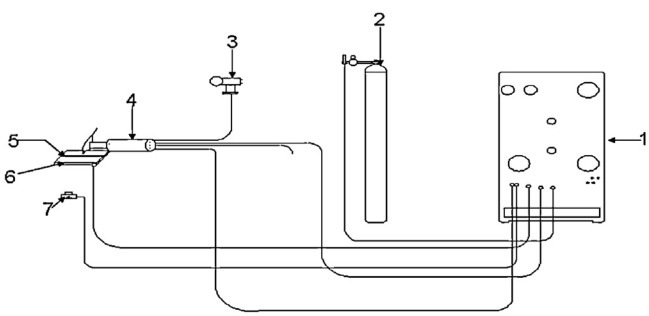
of metal compounds at the joined surface. They showed that the metal compounds become brittle after welding process. Squillac et al. [15] compared the electrochemistry characteristics of welds created using TIG welding and FSW. The present study primarily focuses on investigating the mechanical properties of pure copper with FSW and TIG welding, including the microstructure of the welding joint, tensile strength, and impact resistance.

2. Experimental methods

The experiment apparatus layout for TIG is shown in Fig. 1a, the FSW apparatus picture is shown in Fig. 1b. The operation parameters for TIG are listed in Table 1. Fig. 1c is the schematic plot of the FSW welding layout. For FSW, the ambient temperature of operation is 25 °C. The operation parameters are described later in the text.



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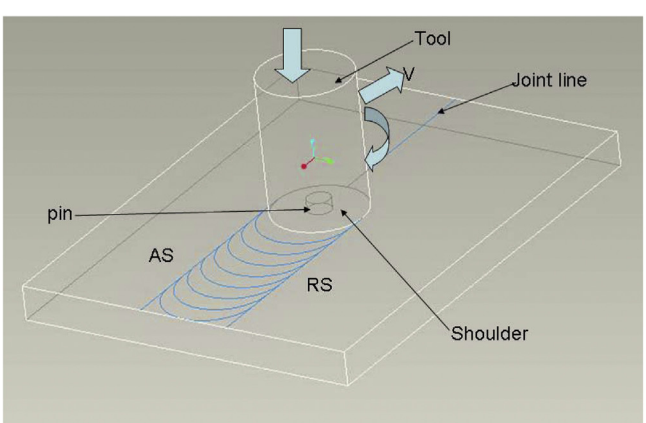
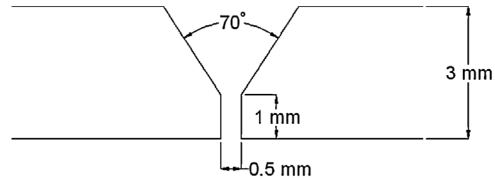
(b)



(c)

Fig. 1. (a) Schematic drawing of TIG. (1) AC/DC welder, (2) argon gas supply, (3) water supply, (4) welding torch, (5) filler wire, (6) base metal, and (7) foot operated current control. (b) Photograph of friction stir welding. (c) The schematic plot of the of FSW welding layout



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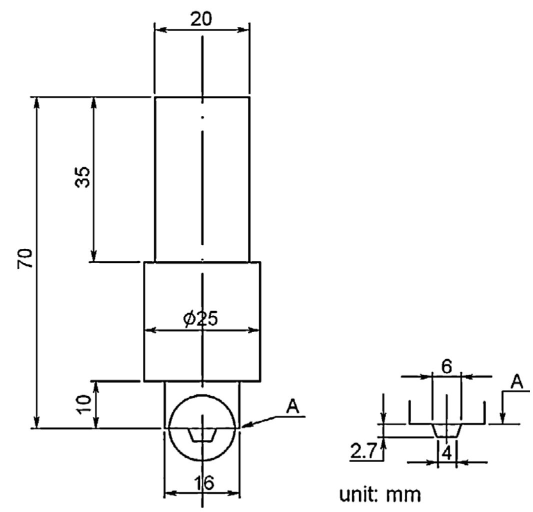

(b)

Fig. 2. (a) The dimensions of V notch cut for TIG. (b) The dimensions of friction stir tool head.

Pure copper (C11000) was processed to the desired dimensions of 300 mm × 50 mm × 3 mm. A V shape notch was then made between the joint of two pure copper plates for TIG welding, as shown in Fig. 2a. In this experiment, the filler wire was fed manually for the welding process. In order to increase the strength of the weld, two-pass welding was used. To avoid distortion and rapid cooling of the metal during the welding process, the copper plates were fixed and pre-heated before welding. Oxygen-free copper wires with a diameter of 2.4 mm were used as filling material and high-purity argon gas was used as shielding gas. The welding parameters are listed in Table 1. The stir tool used in this process is a JIS SKH55 standard stir head, the dimension of it is shown in Fig. 2b. The stir head is machined into a cone shape in order to obtain a better welding result. The FSW process is affected by the rotational speed and translational speed of the stir tool, and friction tool pressure (axial force). In the FSW experiment, the rotational speed of the stir head is 1100 rpm, the translational speed is 25 mm/min, the axial force exerts on the stir head is 10 kN, and the backward inclination angle of the stir head is 2.5°. The shoulder of the rotating tool was pushed below the level of the copper surface for 0.2 mm.

After welding, three tensile test specimens were cut out from each welded plates in accordance with ASTM E8M-9 [16] standards by longitudinal metal production, as shown in Fig. 3a and b. Fig. 3c is the specimen dimensions for notch tensile strength test. The number of specimens for tensile strength and notch tensile test are 3 for base metal, 3 for TIG, and 3 for FSW, respectively. The base metal was used to compare two specimens. The unnotched specimen was used to analyze yielding strength, tensile strength, cross-sectional elongation, and reduction. The notched specimen was used to analyze the notch tensile strength (NTS) and notch strength ratio (NSR). A 100-kN tensile tester (Instron, 5582, USA) was used for the tensile test.