STUDY ON WELDABILITY OF CU (OFC) BY FRICTION STIR WELDING

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Abstract

The microstructure and mechanical properties of friction stir welded OFC plates with 2mm in thickness were examined with the changing welding parameters such as welding speed, rotation speed in this study. The sounding welding conditions was acquired at the optimum welding conditions of the 41mm/min to 61mm/min of welding speed at 1250 rpm of rotation speed.

The microstructure of weld zone was divided into four parts such as the base metal region (BM), thermal mechanical affected zone (TMAZ), heat affected zone (HAZ), stir zone (SZ). The grain size in the SZ and the width of weld nugget were increased with increasing welding speed

The hardness profiles of the base metal were distributed about 80HV. The HAZ is a slightly softened region of about 60~75 HV relative to the base metal. The hardness profiles of the SZ were higher than that of base metal.

The tensile strength was increased with increasing welding speed. In case increasing rotation speed, tensile strength was decreased. The maximum tensile strength was about 220MPa which was 110% of joint efficience of that of base metal at 41mm/min of welding speed, 1250rpm of rotation speed.

Keywords: FSW, OFC, welding speed, rotation speed

1. Introduction

FSW was invented at TWI and patented in 1992. Since 1992 the applications of FSW have been made in implementing FSW in production of aluminum structure including decks for ferry boats and fuel tanks for space launch vehicles.[1],[2] Advantages of FSW include good strength and ductility along with minimization of residual stress and distortion These characteristics of FSW are generally attributed to the solid state nature of the process and a supposed low energy input to the welding[3].

Recently the applications of FSW have been reported in many industrial parts especially transportations including ships, railway cars and rockets.[4] But the applications of joints of friction stir welded copper have a little cases which are applied industry. Especially, friction stir welded joint of copper among friction stir welded materials will anticipate to applying many industrial sections. Copper is excellent for electric conductivity, corrosion oxidation and corrosion resistance. So copper widely applies to electric materials, heat conductivity materials, semiconductor, sputtering equipment, ships parts, atomic power plant. Generally oxygen free copper (OFC) and tough pitch copper (TCu) have a little damage of pore by welding. But in case OFC and TCu by fusion welding, it is easy to generate defect such as deformation and pore by welding heat, blowhole and crack. Therefore, settlement for defect is necessary, presents FSW that is solid state joining.[5]

The technique of FSW is rapidly to pay attention to parts of transportation such as railway, ships and rocket, actively goes on applications at U.S, Japan, Europe. Recently the tendency of study of Al alloys and Mg alloys is presented, but study of copper and copper alloy is not presented. Also study of that is nearly not present at foreign state. Therefore in this work, industrial applications of FSW to the heat exchanger and the fabrication of copper containment canisters for nuclear waste are presented. [6] The optimum weld conditions (RPM, travel speed, insert depth), mechanical and metallurgical properties of friction stir welded joints were investigated.

2. Experimental procedures

In this study OFC plates (thick 2mm) were used for FSW, the copper plates conform to C1020. The dimension of the plate was 70mm in width, 140mm in length and 2mm in thickness. The details of the FSW parameter such as tool rotation speed, welding speed and tool angle are shown table 1. After the specimen was polished and etched, metallurgical change was observed on a cross section of the weld joint with optical microscopy. The etching solution used α etchant which was consisted of distilled water(50ml), ammonia water(50 ml) and hydrogen peroxide(5ml).

The measurement of hardness distribution was observed on the center of the cross section at the weld joint vicinity by Micro Vickers hardness test measured at the condition (100gf, 10second). The tensile strength tests to welding direction of the weld joint were carried to evaluate the mechanical properties. The tensile strength tester was used an Instron type machine with crosshead speed of 1mm/min.

3. Results

Figure 1(a), (b) shows the top, rear surfaces and the macro image of the bead of as-welded specimens after FSW. The qualities of both the weld top and rear surfaces were very smooth regardless of welding speed and rotation speed, but the width of bead slightly was increased with increasing welding speed and the flash of the weld joint was markedly increased with increasing welding speed in fig 1(a). In case the change of rotation speed the appearance of the top and rear surface was nearly same in fig 1(b). The surrounding of the weld bead was generated the change of color from red to blue in relation with excessive heat input and the differential of heat propagation.

Optical micrographs of the welds were shown in figure 2, 3. The stir zone (SZ), thermal mechanical affected zone (TMAZ), heat affected zone (HAZ), base metal region (BM), onion ring correspond to the locations shown as ‘a’, ‘b’, ‘c’, ‘d’ and ‘e’ in figure 3. The SZ has a fine equiaxed grain structure in figure 2(a). That seems to be generated by the dynamic recrystallization, which was caused by frictional heat and deformation, and the regions include the onion ring in figure 2(e). But the SZ had a grain growth structure over 41mm/min of welding speed as known figure 3. It seems that the excessive friction heat is generated in the SZ.

The TMAZ is characterized by transition region, where the grain structure was transformed from the equaxed grain structure to that of base metal. The elongated and recovered grain structures caused by the distinction of friction heat were observed in the TMAZ. On the other hand, the HAZ had no difference in the microstructure compared with the base metal. It is reason that the mechanical and thermal effects in the HAZ are not sufficient to promote deformation and the grain growth. So the HAZ is identified only by hardness results.

Figure 4(a), (b) was shown the change of the width of weld nugget with increasing welding speed, rotation speed. The width of weld nugget nearly did not change at the range of welding speed from 22mm/min to 31mm/min in figure 4(a) and the onion ring pattern was observed in the SZ at these conditions. But the width of weld nugget was increased over welding speed 41mm/min and onion ring pattern was not examined. It is supposed that heat input at the weld nugget steeply increases over 31mm/min. So the width of weld nugget was increased in accordance with the excessive heat, the grain size in the SZ also increases. In case the change of rotation speed the width of weld nugget was nearly changeless in figure 4(b). In the welding condition (1600 rpm, 31mm/min) the weld defect is observed at the SZ as known figure 5. It is thought that sufficient plastic flow is not generated.

Horizontal hardness profiles were measured along the centerline of the cross section in the weld zone shown in figure 6(a), (b). The hardness of the base metal was about 80HV. The HAZ is a slightly softened region of about 60~75 HV relative to the base metal. The total softened range is between 15mm and 20 mm with the change of welding speed and rotation speed. Firstly in case the variation of welding speed, the softening range had been 20mm from the center of SZ with travel speed (22mm/min), but had been 15mm at weld speed (41mm/min) as known figure 6(a). Secondly on the occasion the change of rotation speed the softening zone had been the range about 17mm in figure 6(b).

The effect of welding speed and rotation speed on the tensile strength were shown in figures 7(a), (b). The tensile strength was increased according to increasing travel speed. In case the change of rotation speed, the tensile strength was decreased with increasing rotation speed. The highest tensile strength was acquired when the welding speed was 41 mm/min, which was 110% of that of the base metal.

4. Conclusions

In accordance with the variables of welding speed and rotation speed, this study was examined the microstructure and the mechanical properties of OFC. The conclusions obtained are as follows,

(1) The OFC was successfully joined by FSW and had no welding defect in the all welding condition except for the welding condition of 1600 rpm, 31mm/min

(2) The grain size of weld zone was shown fine equaxed grain structure below the 31mm/min welding speed regardless of tool rotation speed. But that of weld zone slightly grew over the 41mm/min of welding speed

(3) The total softened range is between 15mm and 20 mm with the change of welding speed and rotation speed.

(4) In this work, the highest tensile strength was acquired 220MPa at the welding condition (1250 rpm, 41mm/min). The optimum welding conditions was 1250 rpm of rotation speed, from 41 to 61mm/min of welding speed.

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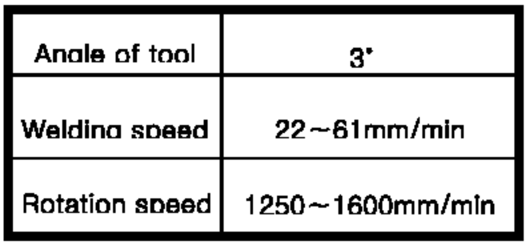

Angle of tool	3°
Welding speed	22～61mm/min
Rotation speed	1250～1600mm/min

Table 1. Parameters of FSW

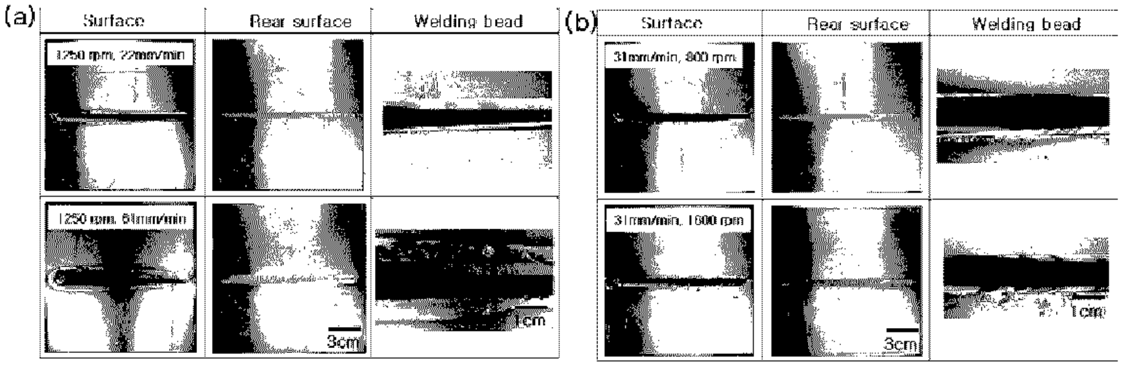

Fig. 1 Macro image of as welded specimen with

(a) the change of welding speed, (b) the change of rotation speed

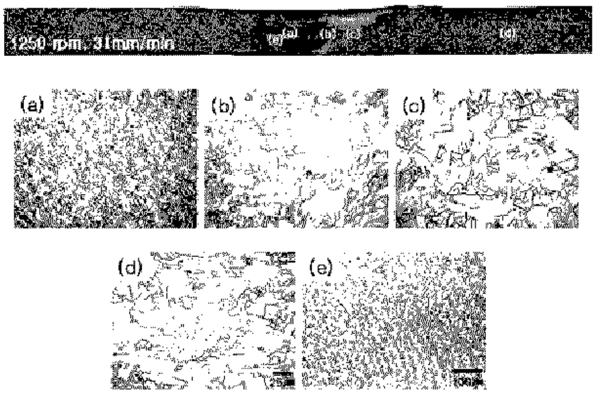

Fig.2 Microstructure of (a) SZ, (b) TMAZ, (c) HAZ, (d) BM and (e) Onion ring

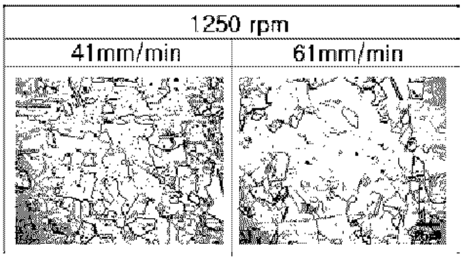

Fig. 3 Microstructure of the SZ

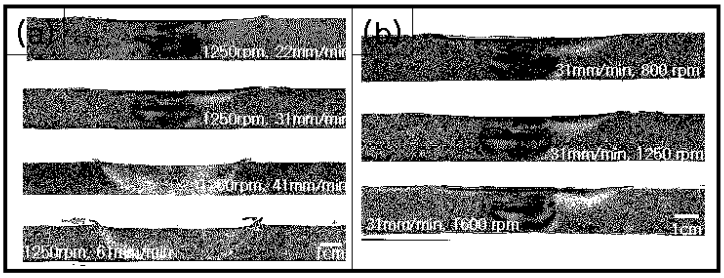

Fig.4 Macro image of weld nugget according to

(a) the change of welding speed ,(b) the change of rotation speed

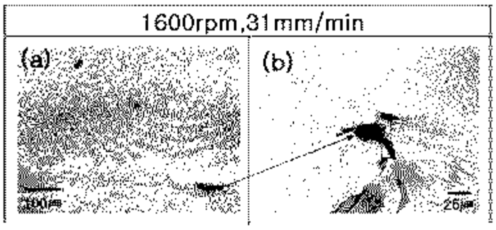

Fig.5 Optical image of weld defect in the SZ

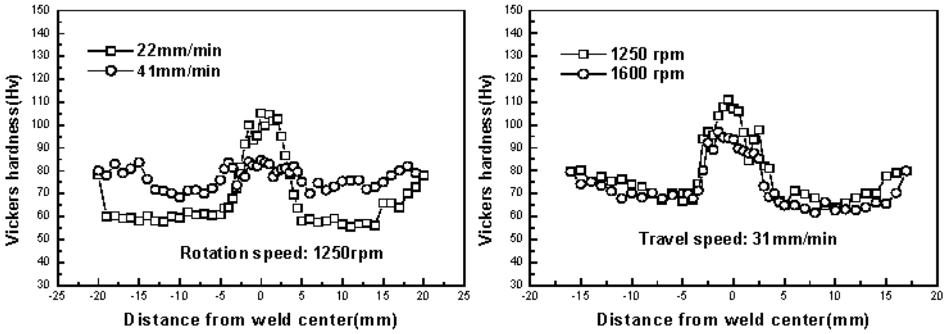

Fig. 6 Distributions of hardness at near weld center with

(a) variations of welding speed(left side), (b) variations of rotation speed(right side)

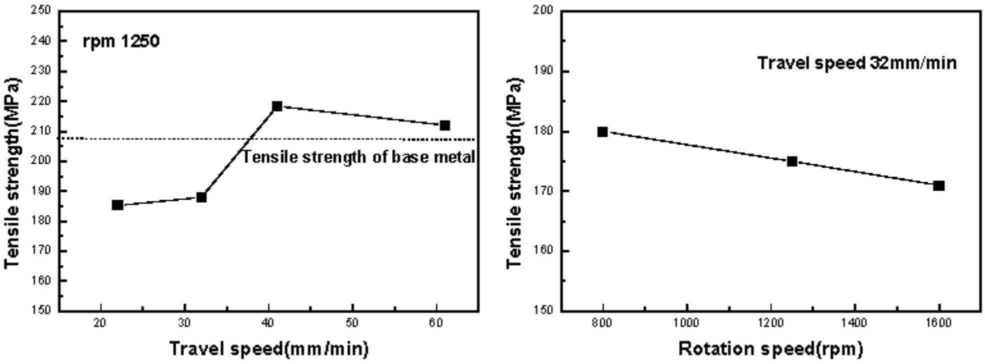

Fig. 7 Relation between tensile strength

and (a) travel speed(left side), (b) rotation speed(right side)