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Friction Stir Welding of Oxygen Free Copper and 60%Cu-40%Zn Copper Alloy

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Abstract. The mechanical properties of the friction stir welds of the oxygen free copper (OFC) and 60%Cu-40%Zn copper alloy(60/40 brass) were investigated. The defect-free welds were obtained in a relatively wide range of welding conditions; the tool rotation speed had rpm of 1000 to 2000 in the OFC and 1000 to 1500 in the 60/40 brass, with the welding speed of 500 to 2000 mm/min. The SZ hardness values of the OFC welds were almost the same or slightly lower than those of the base metal. However, the SZ hardness values of the 60/40 brass in all welding conditions were much higher than those of the base metal. The SZ hardness values of both metals increase with a decrease in heat input. The tensile properties of the all-SZ showed relative correspondence to the variation of the SZ hardness values.

1. Introduction

In many studies [1-3], it has been proved that friction stir welding (FSW) [4] can produce low distortion, high-quality, and low-cost welds of aluminum alloys, even for those difficult to weld by conventional fusion welding process. FSW process can also be applied to copper and copper alloys [5-8], which are also known to be difficult to weld. Since FSW is essentially a solid-state process, it doesn't cause great distortion, solidification cracking, porosity, oxidation, and other defects, which result from conventional fusion welding.

Although there are several reports [5-8] on the applicability of FSW to copper alloys, not much has been published concerning the metallurgical and mechanical properties of the welds. The feasibility of FSW of a 50 mm thick OFC was demonstrated by Anderson et al. [5, 6]. Okamoto et al. [7] reported that OFC intended for backing plates was successfully welded by FSW and that the welds improved in mechanical and metallurgical properties compared to those made from electron beam welding. However, it was shown that some different results existed concerning the mechanical properties in the welds [8]. Moreover, the effect of welding conditions on the formation of welds, and the variation of microstructures and mechanical properties of the welds at various welding conditions for copper alloys are still unclear. Thus, the objectives of this study are to clarify the appropriate welding conditions for producing sound welds, defects formation and the mechanical properties of the welds in a wide range of the welding conditions for the OFC and 60/40 brass.

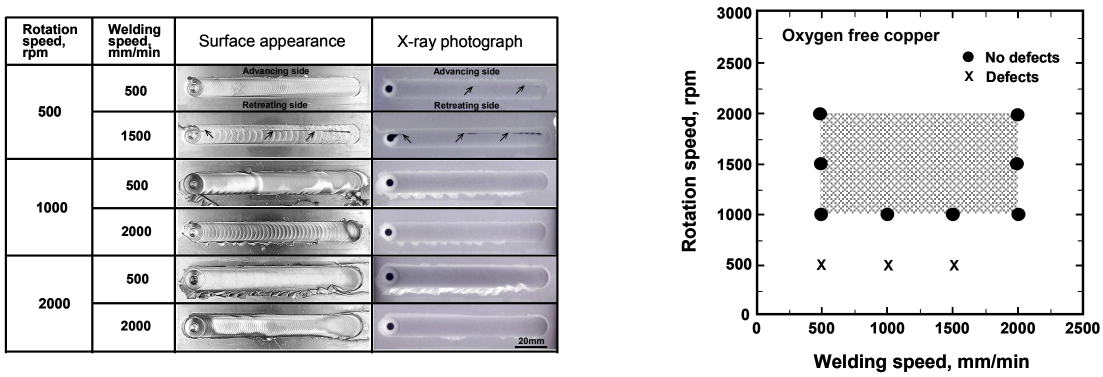
2. Materials Used and Experimental Procedures

Friction stir welds were produced in the OFC and 60/40 brass plates with a thickness of 2 mm. The OFC used was a commercial JIS alloy No. C1020P-1/2H, which is more pure than 99.99 mass% Cu. The 60/40 brass used was a commercial JIS alloy No. C2801-1/4H, which has chemical compositions of 60.89%Cu-39.10%Zn (mass%). The bead-on-plate and square (I-type) groove butt joint welds were made by FSW on a 50 mm wide x 150 mm long plate and two plates of 100 mm in width x 150 mm in length, respectively.

The process parameters varied from 250 to 2000 rpm in counter clockwise tool rotation speed and from 500 to 2000 mm/min in welding speed. The tilt angle for all welds was maintained at approximately 3°. The diameters of the shoulder and the probe of the tool used in this FSW were 12 and 4 mm, respectively. The length of the probe was 2 mm. The hardness measurements were performed along the centerline in the cross section of the welds by using a Vickers hardness tester with a 0.49N load. The tensile tests with two different configurations of specimens machined out from welded plates were carried out at a crosshead speed of 1.67×10^{-2} mm/s at room temperature. The principal axis of the transverse specimens of the FSW joints was perpendicular to the welding direction. The longitudinal specimens of the all stirred zone (all-SZ) had its principal axis parallel to the welding direction.

3. Results and Discussion

Figure 1 (a) shows the surface appearances and the X-ray radiographs of the bead-on-plate welds of the OFC. The defects, which are indicated by arrows in the figure, were observed as a groove-like defect occurred linearly along the weld line in an advancing side at a low tool rotation speed of 500 rpm, and became apparent with increasing welding speed. The defect-free welds were obtained in all welding speeds at rotation speed higher than 1000 rpm, as summarized in Fig. 1 (b). In the 60-40 brass welds, the groove-like defect were also observed at low tool rotation speeds of 500 and 250 rpm, and the sound welds were made at 500 rpm-500 mm/min and at rotation speed higher than 1000 rpm. Hence, it is found that sound welds of the OFC and 60/40 brass can be made by FSW in a relatively wide range of welding conditions.



(a) (b)

Fig. 1 Surface appearances and X-ray radiographs of welds (a), and optimum FSW conditions for sound welds (b) of OFC

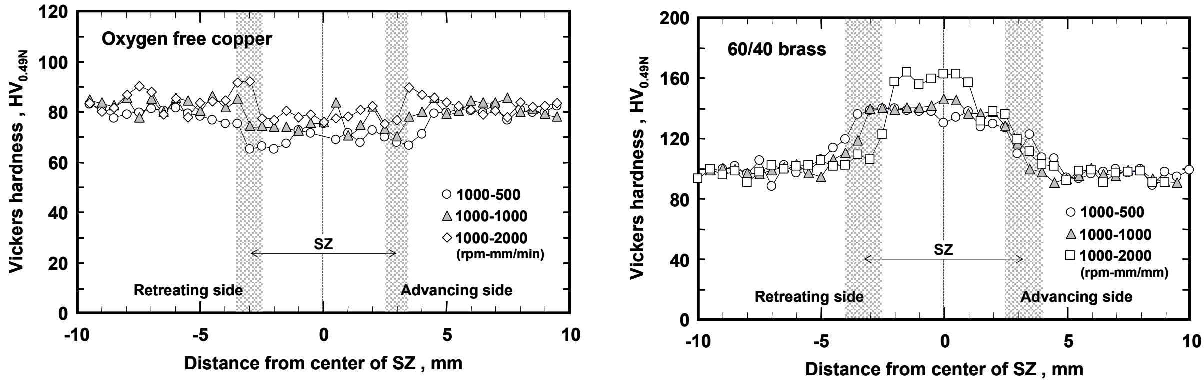


Fig. 2 Hardness profiles in cross section of welds at different welding speeds with constant rotation speed of 1000 rpm

Figure 2 shows the hardness profiles along the centerline on cross section of the welds at the rotation speed of 1000 rpm. The hardness values of SZ of the OFC ranged from HV65 to 75; which

were slightly lower than that of the base metal (HV81). Since the OFC used in this study is a 1/2H hardened material, the hardness decrease in the SZ is due to the recrystallization during the FSW. However, in the 60/40 brass welds, the hardness values within the SZ including all the welding conditions were much higher than those of the base metal. The mean hardness value in the SZ of both materials tends to increase with an increase in welding speed. It is considered that the variation of hardness is related to the microstructural changes in the SZ induced by welding conditions.
The tensile properties for the as-welded joints at the different welding speeds with the constant rotation speed of 1000 rpm are shown in Fig. 3. In the OFC welds, the weld tensile strengths are quite similar to those of the base metal in any welding conditions. It is, however, shown that the joint efficiency in the offset yield strength is lower than that of the tensile strength. In the 60/40 brass welds, the tensile strength and offset yield strength are almost the same as those of the base metal. This means that the strength at the SZ and the TMAZ is higher than the base metal. This also matches well with the result of the hardness distribution of the welds as shown in Fig. 2.

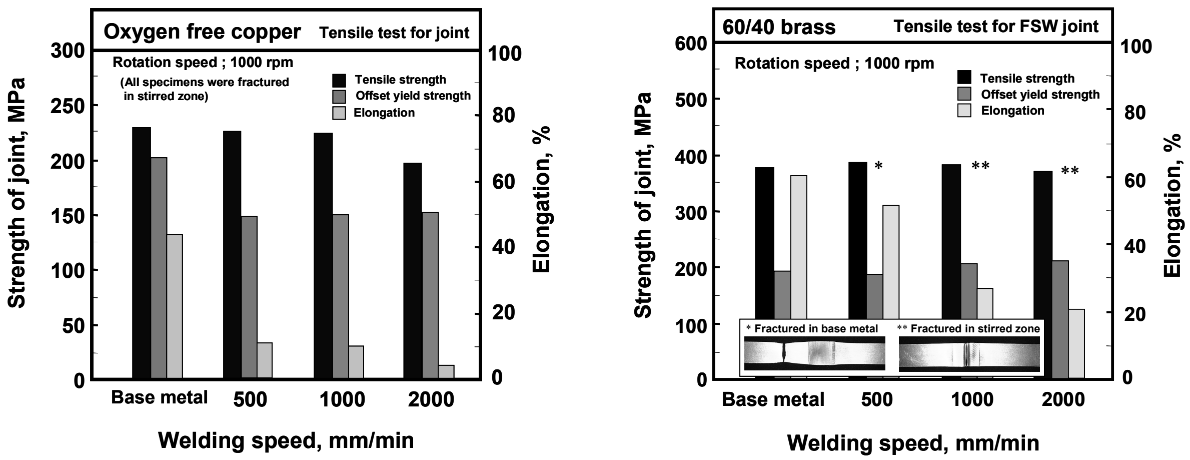


Fig. 3 Transverse tensile properties to welding direction of weld joints at different welding speeds with constant rotation speed of 1000 rpm.

The tensile properties for the longitudinal specimens, consisting of all-SZ, are shown in Fig. 4. In the OFC welds, the tensile strengths of the all-SZ are nearly the same or slightly lower than those of the base metal. The tensile strength increases with increasing welding speed. This tendency is clearly seen particularly in the offset yield strengths. This outcome complements the result

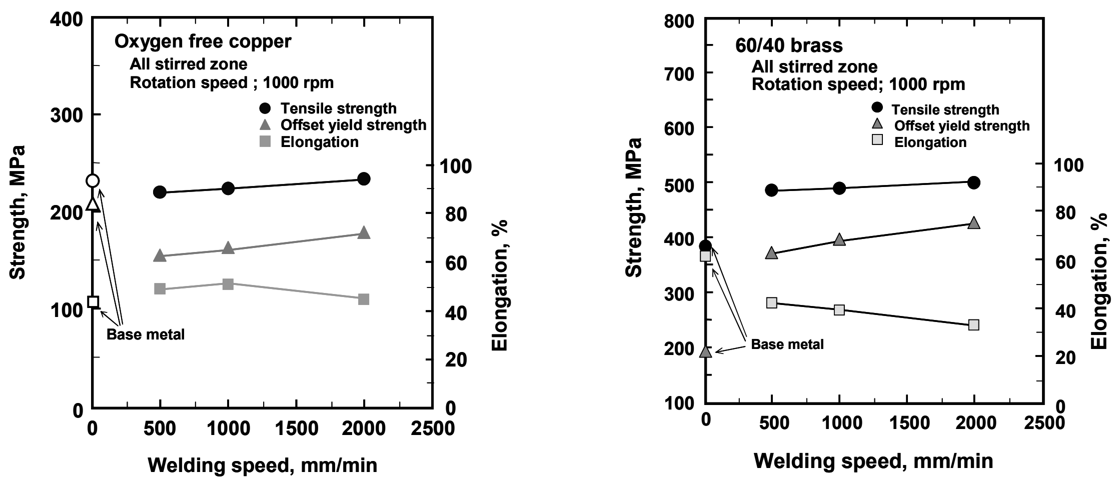


Fig. 4 Tensile properties of all-SZ at different welding speeds with constant rotation speed of 1000 rpm.

of hardness change for welding speed, because a close relationship between the hardness and offset yield strength is well known. In the 60/40 brass welds, the tensile strengths and offset yield strengths of the SZ are much higher than that of the base metal. The strengths of the SZ increase with increasing welding speed, and the tendency is clearly revealed particularly in the offset yield strengths. The tensile properties in the OFC and 60/40 brass showed a relative correspondence to the variation of hardness values in the SZ.

4. Summary

The feasibility of FSW and mechanical properties of the welds of the OFC and 60/40 brass were investigated in a wide range of the welding conditions. The main conclusions are summarized as follows:

(1) The defect-free welds of both materials were obtained in a relatively wide range of welding conditions, 1000 to 1500 rpm in rotation speed, with a welding speed of 500 to 2000 mm/min.

(2) In the OFC welds, the hardness values in the SZ including all the optimum welding conditions were slightly lower than those of the base metal. In the 60/40 brass welds, however, the hardness values in the SZ were much higher than those of the base metal. The mean hardness values in the SZ of both materials increased with an increase in welding speed.

(3) In the tensile test for the all-SZ of the OFC welds at the rotation speed of 1000 rpm with different welding speeds, the tensile strengths of the SZ were almost the same or slightly lower than those of the base metal. In the 60/40 brass welds, the tensile strength and offset yield strength of the SZ were much higher than those of the base metal. The strengths of the all-SZ in both materials increased with increasing welding speed, and the tendency was clearly revealed particularly in the offset yield strengths.

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