Friction Stir Welding of Copper and Copper Alloys†

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Abstract

The characteristics of structure and mechanical properties of friction stirred welds of 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 and tool rotation speeds from 1000 to 1500 rpm. The microstructures of stirred zones (SZ) of OFC and 60/40 brass showed grains a little smaller and grains a great deal finer compared with those of the base metals respectively. The mean hardness values within the SZ of OFC welds were almost the same or slightly lower than that of the base metal. On the other hand, the hardness values for 60/40 brass were much higher than that of the base metal. The maximum hardness values in the SZ increased with a decrease in heat input. The tensile properties of all SZ showed a relative correspondence to the variation of the hardness values in the SZ.

KEY WORDS: (Friction Stir Welding), (Copper Alloy), (Structure), (Mechanical Property)

1. Introduction

In many studies, it was mainly demonstrated that friction stir welding (FSW) [1] produces low distortion, high-quality, low-cost welds on aluminum alloys even for those difficult to weld conventionally. The process can also be applied to copper and copper alloys [2-4], which were also known as being difficult to fusion welding, since it is essentially solid state process without large distortion, solidification cracking, porosity, oxidation, and other defects resulting from conventional fusion welding. Although there are several reports [2-4] on the weldability of FSW for copper alloys, not much has been published concerning the detail of the metallurgical and mechanical properties of the welds. Moreover, it was shown that there were many mismatched results in the mechanical properties in the welds.

The objectives of this study were to clarify appropriate welding conditions for sound welds, examine the behavior of defect formation, detail of microstructures and correspondence between the mechanical properties and microstructural changes in a wide range of welding conditions for copper and copper alloys.

2. Experimental

Friction stir welds were produced in oxygen free copper (OFC) and 60%Cu-40%Zn copper alloy (60/40 brass) plates with 2 mm thickness. Bead-on-plate welds and I groove butt joints were made by a single pass of FSW. The dimension of the plate for bead on plate and I groove butt welding were 50 (w) x 100 mm (l) and two plates of 100 (w) x 150 mm (l), respectively. The process parameters varied from 500 to 2000 rpm in counter clockwise tool rotation speed and from 500 to 2000 mm/min in welding speed. The diameter of shoulder and probe of the tool used were 12 and 4 mm respectively. The characteristics of friction stirred welds were investigated by visual inspection, transparent X-ray tests, macro and microstructural observations, measurements of hardness, tensile tests, and fractography for the tensile fracture surfaces.

3. Results and discussions

In both welds of OFC and 60/40 brass, defects of the groove type were observed at the advancing side at a tool rotation speed 500 rpm. The generation of defects was increased with increasing welding speed. However, the defect free welds were obtained over the relatively wide range of 500 to 2000 mm/min and 1000 and 1500 rpm. The welding conditions resulting in sound welds are summarized in Fig. 1.

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Figure 2 shows an example of typical macro and micrographs of the FSW welds of 60/40 brass. The microstructures of 60/40 brass welds showed recrystallized fine grains with a portion of deformed grains in the SZ and the elongated grains in TMAZ. However, the HAZ was not clearly characterized by microstructures compared with the base metal. The microstructures in SZ of OFC consisted of equiaxed grains like that of the base metal. However, the size of the grains in the SZ is a little smaller than those in the base metal. The grains in the SZ seem to be generated and to be grown by dynamic recrystallization due to frictional heat and deformation.

In OFC welds, the mean hardness values of SZ were almost the same or slightly lower than that of the base metal for all the optimum welding conditions. The maximum hardness values in the SZ increased with a decrease in heat input. However, in 60/40 brass welds, the mean hardness values within the SZ were much higher than that of the base metal. The variation of the maximum hardness values in the SZ showed the same tendency as that of OFC welds. The variations of the

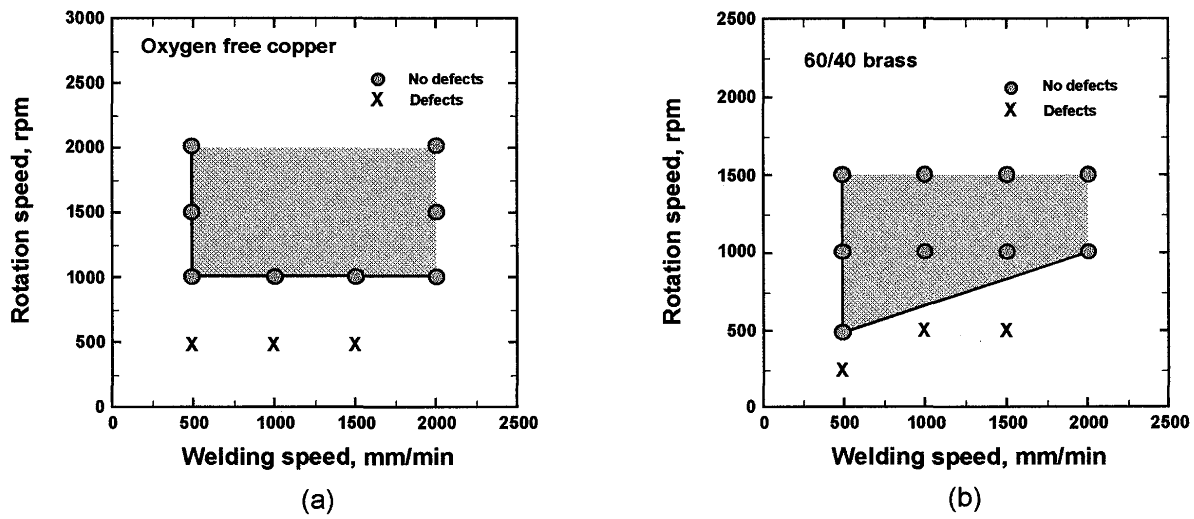

Fig. 1 Optimum welding conditions for OFC (a) and 60/40 brass (b).

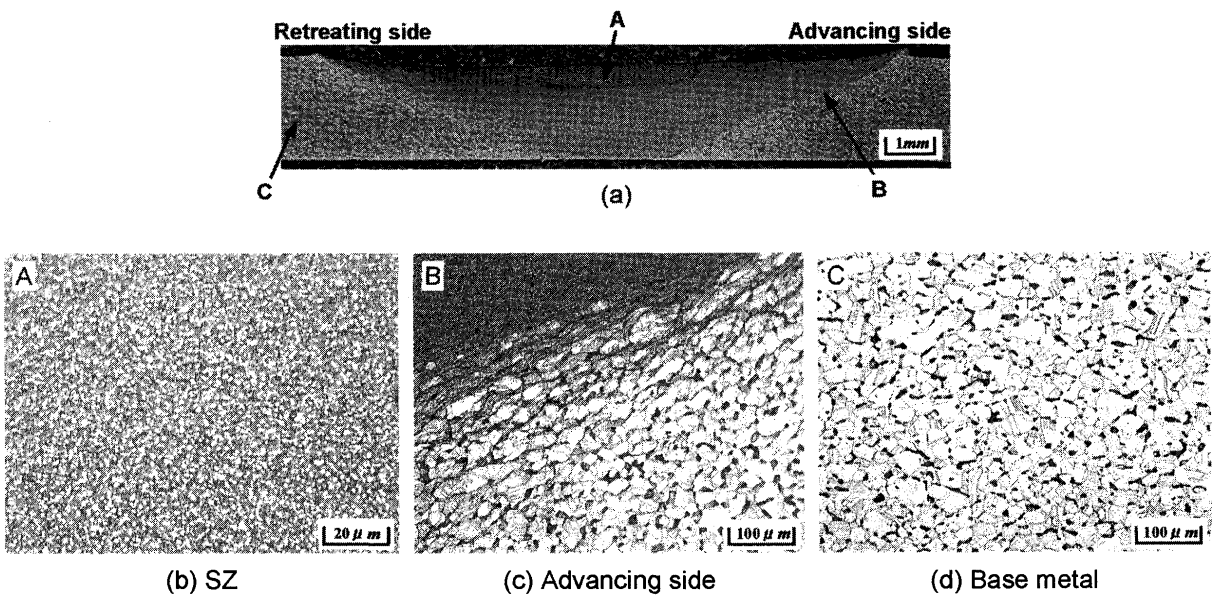

Fig. 2 An example of macro and microstructures in the cross section of the FSW welds for 60/40 brass.

maximum hardness values in the SZ in both materials are shown in Fig. 3.

The tensile properties for the specimens longitudinally cut off from all the SZ are shown in Fig. 4, which also includes the base metal properties. In the SZ of OFC, the tensile strengths of all SZ including all the optimum welding conditions were nearly the same or slightly lower than that of the base metal. On the other hand, in 60/40 brass, the strengths were much higher than those of the base metal. In both materials, the tensile strengths increased with decreasing heat input. In particular, the tendency was clearly revealed in 0.2% offset strengths.

In observation of the fracture surface of OFC base metal, fracture mainly occurred by the partial contraction mechanism, which was characterized in pure metals with high ductility. The fracture surface of base metal of 60/40 brass showed a dimple pattern across the whole width of the specimen. The fracture surfaces of all SZ specimens in both materials showed nearly the same features as the base metals. However, in 60/40 brass, the size of the dimples was a great deal smaller than that of the base metal.

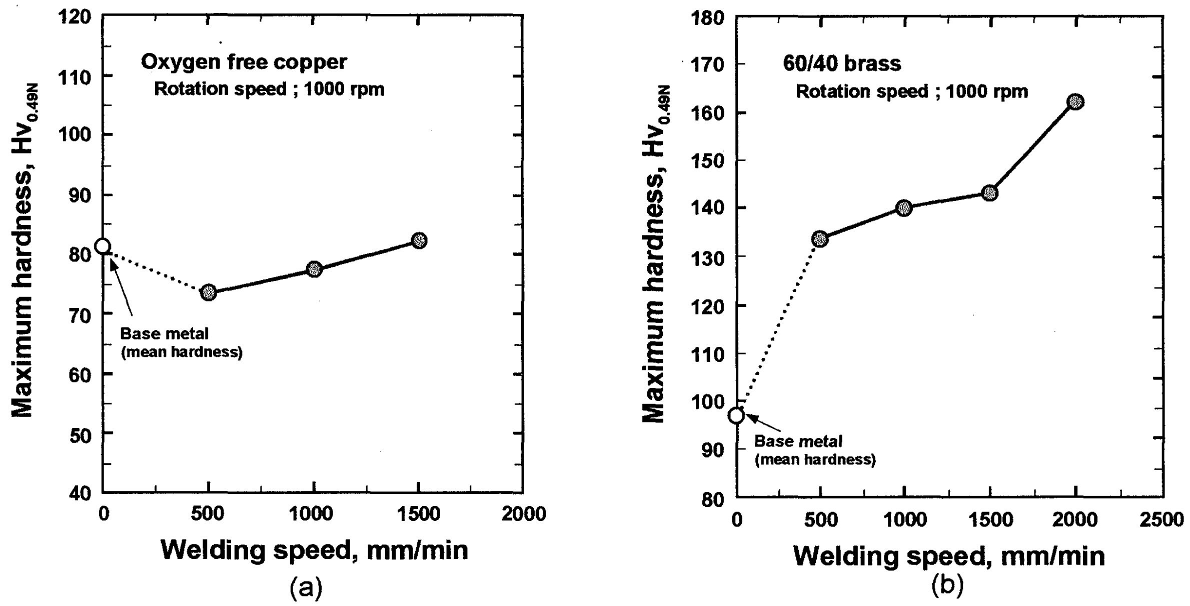

Fig. 3 Variations of the maximum hardness values in SZ in both materials OFC (a) and 60/40 brass (b)

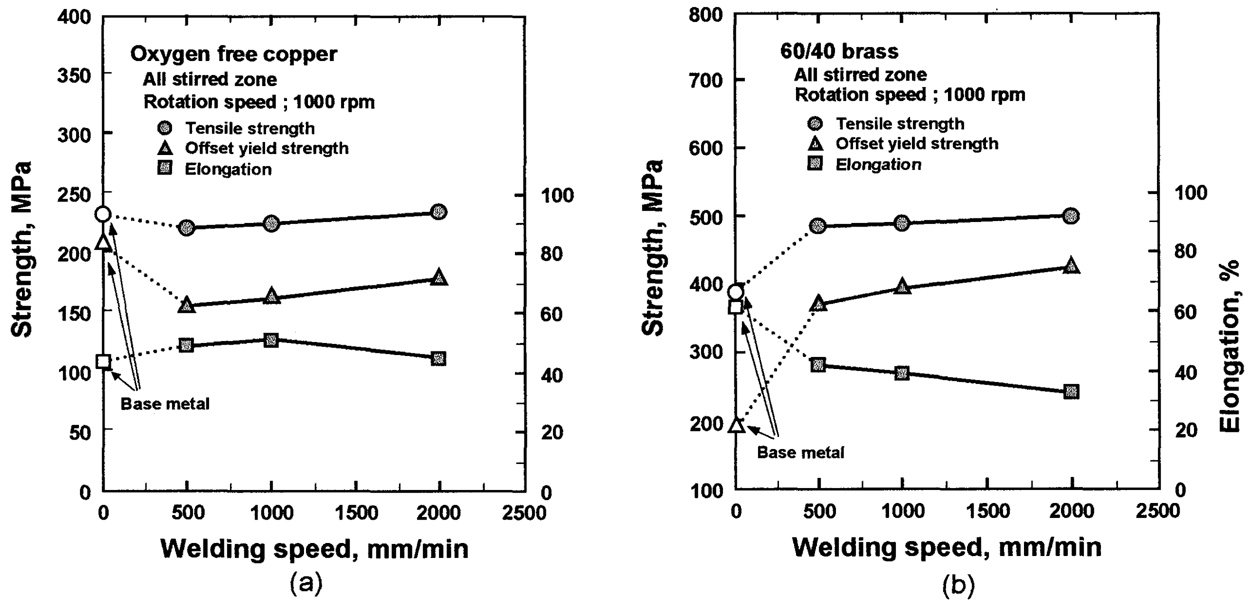

Fig. 4 Tensile properties of all SZ specimens in both materials OFC (a) and 60/40 brass (b) at different welding speeds.

4. Conclusions

The characteristics of structure and mechanical properties of friction stirred welds of oxygen free copper and 60/40 brass were investigated. The main conclusions obtained are as follows:

(1) The defect free welds were obtained over a relatively wide range of welding conditions of tool rotation speed from 1000 to 1500 rpm with welding speed from 500 to 2000 mm/min.

(2) The microstructures in the SZ of OFC and 60/40 brass showed grains a little smaller and grains a great deal finer compared with those of the base metals, respectively.

(3) The mean hardness values in the SZ of OFC welds were almost the same or slightly lower than those of base metal for all the optimum welding conditions. On the other hand, the hardness values of 60/40 brass were much higher than those of base metal. The maximum hardness values in the SZ increased with a decrease in heat input. The tensile properties of all SZ showed a relative correspondence to the variation of the hardness values in the SZ.

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