Materials Characterization 119 (2016) 84–91

Contents lists available at ScienceDirect

Materials Characterization

journal homepage: www.elsevier.com/locate/matchar

Microstructure, texture, and mechanical properties of friction stir welded commercial brass alloy

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ARTICLE INFO

Article history:
Received 17 January 2016
Received in revised form 9 July 2016
Accepted 11 July 2016
Available online 12 July 2016

Keywords:
Friction stir welding
Microstructure
Texture
Mechanical properties

ABSTRACT

Microstructural evolution during friction stir welding of single-phase brass and corresponding mechanical properties were investigated. For this purpose, 2 mm thick brass plate was friction stir welded at a rotational speed of 450 rpm and traverse speed of 100 mm/min. The microstructure of the joint was studied using optical microscopy, scanning electron microscopy equipped with electron back scattered diffraction system, and scanning transmission electron microscopy. The mechanical properties were measured using hardness and tensile tests. The formation of subgrains and their transformation into new grains in conjunction with existence of A_1^*, A_2^* and C texture components revealed that the continuous dynamic recrystallization plays a dominant role in the microstructural evolution. However, grain boundary bulging, along with the formation of twin boundaries, and presence of the G texture component showed that the discontinues dynamic recrystallization may participate in the new grain formation. Furthermore, the different strengthening mechanisms, which caused the higher strength of the joint, were discussed.

1. Introduction

Friction stir welding (FSW) was developed at The Welding Institute of UK in 1991 [1]. It is a solid-state welding method without large distortion, solidification cracking, porosity, oxidation, and other defects that arise from conventional fusion welding [2]. In addition, it can improve the mechanical properties of the joints compared to fusion welding processes. Therefore, FSW has been proved a promising joining method for various metals and alloys [1,3].

Brasses, the copper and zinc alloys, have vast industrial applications, and so there is a large demand for welding of these types of alloys. Unfortunately, the conventional fusion welding of brasses has some difficulties in addition to the common problems mentioned before. The low boiling temperature of the zinc causes to its evaporation during fusion welding processes, which results in color change and formation of a porous and weak layer of copper or copper oxide. Additionally, it is notable that the zinc vapor is toxic and can be harmful to the health of welding operator. Therefore, the investigators have been encouraged to use FSW for joining of the brass alloys.

Despite a lot of investigations in the field of copper FSW, the studies in the case of brass alloys are somewhat limited [4–12]. Xie et al. [9,12] have studied the effect of FSW on the microstructure and mechanical properties of 5 mm thick 62/38 brass plates. They reported that partial recrystallization occurred during FSW, which caused the formation of different types of grains, including recrystallized, deformed recrystallized and deformed grains in the stir zone (SZ) of the joints. They also found that the high heat input conditions, i.e. higher rotational speeds and lower traverse speeds of the tool, resulted in a more homogenized structure in the SZ, but could not completely remove the partially recrystallized zone. Xu et al. [10] have used rapid cooling during FSW of 2 mm thick 70/30 brass plates to improve the mechanical properties of the welded joints. They confirmed that with rapid cooling, the grain size of 1.2 μm was achieved, and the post annealing effect, including both recovery and static recrystallization could be prohibited. Emamikhah et al. [13] have investigated the effect of tool pin profile in FSW of 3 mm thick 60/40 brass plates. Their results showed that appropriate tools can produce sufficient heat underneath the shoulder with regard to further materials stirring. Additionally, they demonstrated that a hexahedron tool caused the accumulated defects, and hence the mechanical properties weakened due to a lower heat generated.

FSW can be assumed as a kind of hot deformation processes in some aspects due to existence of heat and deformation. Thus, the restoration

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http://dx.doi.org/10.1016/j.matchar.2016.07.009
1044-5803/

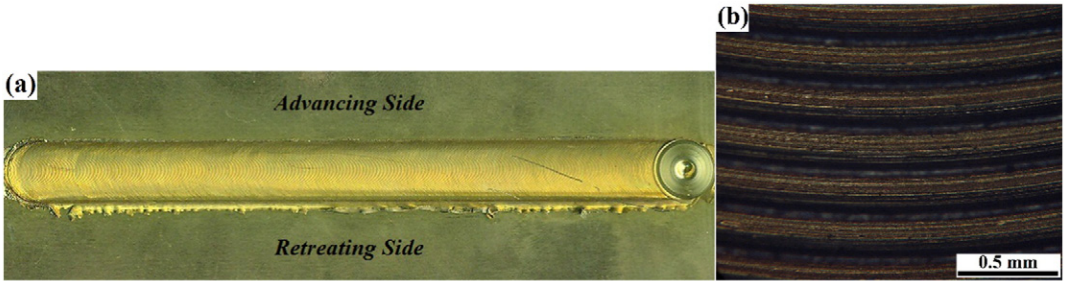

Fig. 1. (a) Surface of the joint, and (b) higher magnification of (a).

mechanisms of hot deformation processes can occur during FSW of metals which rule the final microstructure and mechanical properties [14–16]. Some researchers [17–23] have studied the microstructural evolution during FSW of different metals and alloys. They have concluded that the dynamic recovery (DRV), discontinuous dynamic recrystallization (DDRX), continuous dynamic recrystallization (CDRX), geometrical dynamic recrystallization (GDRX) and static recrystallization (SRX) take place during FSW of various materials similar to other hot deformation processes. However, because of sharp gradients in strain, strain rate, and temperature during FSW, the restoration mechanisms will be different from conventional hot deformation processes of the same alloys, which comprise almost uniform strains and temperatures [24,25].

Although some researchers [4–12] have studied FSW of brass plates, an investigation into the deep microstructural aspects and their relation to the final mechanical properties of the joint is lacking. Therefore, the objectives of this study are to determine the type of restoration mechanisms during FSW of single-phase brass plates, and to realize the strengthening mechanisms of the welded joint.

2. Materials and methods

The single-phase brass (70% Cu and 30% Zn) plate with an initial cold worked condition was used as a base metal (BM) with dimensions of 150 mm × 100 mm × 2 mm. This composition of brasses belongs to the cartridge brass, which has a wide application among the other types of brasses. In addition, because of its single-phase microstructure, it was suitable for the aim of the present study. The BM was annealed at 500 °C for 1 h, before FSW. A H13 steel tool with a shoulder (12 mm diameter) and a simple cylindrical pin (3 mm diameter and 1.7 mm length) was used at a rotational speed of 450 rpm and traverse speed of 100 mm/min. The selection of the H13 steel tool for FSW of the brass plate was according to the literature and our previous laboratory experiences [4–12].

The macrostructure of the joint cross section was analyzed using optical microscopy (OM). The metallographic samples were cut from the section perpendicular to the welding direction, then polished and etched with a solution of 20 ml nitric acid and 10 ml acetic acid. A JEOL JSM 6500F field emission scanning electron microscopy (FESEM) equipped with electron backscatter diffraction (EBSD) system (HKL) was used for microstructural and textural characterizations. In order to produce a suitable surface finish of EBSD sample, the electropolishing was conducted in a solution including 250 ml H_3PO_4, 250 ml ethanol, 50 ml propanol, 500 ml distilled water, and 3 g urea under an applied potential of 10 V for 30 s. In addition, the microstructure of the joint was characterized using transmission electron microscopy (TEM, JEM 2200FS). For this aim, jet thinning was used to produce the thin films for TEM investigations.

In order to study the mechanical properties, the Vickers microhardness test was performed using 50 g load for 10 s. In addition, the tensile test specimens were machined perpendicular to the welding direction with a gauge size of 12 mm (length) × 3 mm (width) × 2 mm (thickness), and tensile tests were conducted at a crosshead speed of 1 mm/min.

3. Results and discussion

3.1. Microstructure

The surface of the joint is illustrated in Fig. 1a, which shows that the joint has excellent surface appearance, with regular grooves. Also, the higher magnification of the weld surface (Fig. 1b) indicated that the tool revolution per mm was approximately equal to 4.5 which confirms the used FSW parameters in this study i.e. 450 rpm and 100 mm/min.

The macrostructure of the joint is shown in Fig. 2, which indicates that the joint was defect free. Furthermore, it can be seen that the macrostructure consists of three distinct regions, including BM, thermomechanically affected zone (TMAZ) and SZ. The optical microstructure of these three regions at higher magnification are illustrated in Fig. 3. The absence of heat-affected zone (HAZ) in the macrostructure of the joint can be due to high thermal conductivity of the brass and low heat input condition of the present study. Moreover, the difference between the size and morphology of the SZ and TMAZ grains makes sharp and clear the interface of these microstructural zones.

The grain boundary maps of the different zones of the joint macrostructure are illustrated in Figs. 4-6. As well, the corresponding distribution of misorientation angle and different types of grain boundaries are shown in Figs. 7 and 8. From Figs. 4–8, the BM had a coarse grain

Fig. 2. The cross sectional macrostructure of the joint.