EBSD analysis of texture produced by abnormal grain growth in friction-stir welded aluminum alloy 1050
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1. Introduction
Friction stir welding (FSW) is an innovative solid-state joining technique having very large industrial potential. The essential drawback of FSW, however, is low stability of the welded material against abnormal grain growth during subsequent annealing [1]. This undesirable effect has been observed to occur in various aluminum alloys [2] and is considered as a significant problem in the FSW field.

Attemping to obtain an additional insight into this phenomenon, the crystallographic orientations of the abnormal coarse grains which evolved in an FSWed material was examined in this work. To the best of the authors’ knowledge, this has never been studied before.

2. Experimental
The material used in the present investigation was aluminum alloy 1050 supplied as 2-mm-thick sheets. The received material was friction-stir welded in a bead-on-plate configuration at a tool rotational speed of 2000 rpm and a travel speed of 10 mm/s. The welding tool was fabricated from a tool steel and had a shoulder with a diameter of 12 mm and a threaded cylindrical pin 5 mm in diameter and 1.7 mm in length. The reference directions used in this study were denoted as welding direction (WD), normal direction (ND) and transversal direction (TD). Following FSW, the obtained welds were cross-sectioned perpendicular to the WD for annealing experiments and microstructure examinations. The selected samples were isothermally annealed in an air furnace for up to 3.6 ks at temperatures ranging from 573 to 773 K and subsequently quenched in ice water. The microstructure and texture which evolved during FSW and subsequent annealing were studied by using the electron backscatter diffraction (EBSD) technique.

3. Results and discussion
A composite EBSD map illustrating the microstructure observed in the transversal cross section of the FSWed material is shown in Fig. 1a. In the figure, individual grains are colored according to their crystallographic orientations relative to the TD; an orientation code triangle is given in the bottom left corner. An evident variation of preferential grain orientation is seen. To illustrate the texture distribution within the stir zone, orientation data were derived from the five locations indicated on the map and arranged as 111 and 110 pole figures in Fig. 1b. To a first approximation, the textural peaks in the pole figures may be interpreted in terms of the \( \mathbf{B}\mathbf{F} /\{112\}<110> \) ideal simple shear texture. Formation of this texture is frequently reported in FSWed aluminum alloys.

Composite EBSD maps illustrating the microstructure distribution in the annealed samples are summarized in Fig. 2. Again, individual grains in the maps are colored according to their crystallographic orientations relative to the TD; orientation code triangle is shown in the bottom left corner. In all cases, the retreating side (RS) of a particular weld is on the left and the advancing side (AS) is on the right.

It is evident that the material annealed at 673 K for 0.6 and 1.2 ks experienced abnormal grain growth. It was initiated at the stir zone periphery (upper and bottom surfaces) and was more pronounced on the RS. It should be also pointed out that the crystallographic orientations of the abnormal coarse grains were often distinctly different from those of the fine-grained matrix. In the material annealed for a longer time...
and/or at higher temperatures, the abnormally coarse grains occupied almost the entire stir zone. Hereafter, these samples are referred to as fully annealed ones. Even in these cases, however, a few surviving fine grains were seen in the stir zone, confirming the abnormal nature of the grain growth.

Textural analysis of all fully annealed samples showed that the texture distribution in all seven cases was broadly the same. To ensure better statistics, all EBSD data taken from the fully annealed samples were combined into a single data set, the obtained cumulative orientation data being shown in Fig. 3.

As follows from the pole figures in Fig. 3b, the texture induced by the abnormal grain growth is not random. It is close to the initial $B/\overline{B} \{112\}<110>$ texture rotated by $\sim25-35^\circ$ around $<111>$, as shown in the figure. In the rotated state, the $\{110\}$ plane is nearly parallel to the simple shear plane and $<112>$ direction tend to be aligned with the shear direction. Therefore, the preferential crystallographic orientation of the abnormally coarse grains is therefore close to $\{110\}<112>$ in the simple-shear reference frame (Fig. 3b).

This effect indicates that abnormal grain growth was related with catastrophic growth of the grains misoriented by $\sim30-40^\circ<111>$ from the $B/\overline{B}$ grains.

In face-centered cubic metal (including aluminum alloys), the grain boundaries having misorientations close to $30-40^\circ<111>$ are well known to be highly mobile [3]. The dominating crystallographic orientation in the stir zone was $B/\overline{B}$ simple shear texture component, as shown in Fig. 1b. Thus the grains misoriented by $\sim30-40^\circ<111>$ from the $B/\overline{B}$ orientations should have an advance in grain growth.

Therefore, the abnormal grain growth was related with catastrophic growth of the grains misoriented by $\sim30^\circ<111>$ from $B/\overline{B}$ simple shear texture which developed in the stir zone. This effect was attributed to high mobility of the 30-40$^\circ<111>$ grain boundaries in FCC metals.

References