Materials Letters 159 (2015) 253–256

Contents lists available at ScienceDirect

Materials Letters

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

Microstructure and strain in protrusions formed during severe plastic deformation of aluminum

Cai Chen [a,b], Yan Beygelzimer [b,c], Laszlo S. Toth [a,b,*], Jean-Jacques Fundenberger [a,b]

[a] Laboratoire d'Etude des Microstructures et de Mécanique des Matériaux (LEM3), UMR 7239, CNRS / Université de Lorraine, F-57045 Metz, France
[b] Laboratory of Excellence on Design of Alloy Metals for low-mAss Structures (DAMAS), Université de Lorraine, Metz, France
[c] Donetsk Institute for Physics and Engineering named after O.O. Galkin, National Academy of Sciences of Ukraine, 36 Vernadsky St., Kyiv 03142, Ukraine

ARTICLE INFO

Article history:
Received 12 June 2015
Accepted 2 July 2015
Available online 3 July 2015

Keywords:
Severe plastic deformation
Protrusion
Aluminum
Ultrafine grain
Texture

ABSTRACT

The protrusions formed during twist extrusion of commercially pure aluminum were characterized in terms of microstructure, texture, strain and Vickers-hardness. Ultra-fine-grained structure was found with grain sizes down to 610 nm. The texture was identified as a shear texture with oblique shear plane with respect to the plane of the protrusion. The amount of strain was estimated theoretically and was also obtained by comparing the disorientation distribution in the protrusion with that observed in high pressure tube twisting.

1. Introduction

Ultrafine grained (UFG) materials can be readily obtained using severe plastic deformation (SPD) techniques [1]. SPD processes are characterized by the application of extreme large strains and hydrostatic pressures which generally result in protrusions. This paper reports about protrusions obtained with a split-die during Twist Extrusion (TE) [2]. Because of the specific form of the observed protrusions, we call them fins in the present work. We examine the formation of the fins and show that the governing deformation mode is simple shear (like in Equal Channel Angular Pressing (ECAP) [3]). The results of the study can be useful when the fins are desired as final products because the strain in them is very large so that UFG structures are formed. Similar ideas have been expressed previously in relation to some other SPD processes in Refs. [4,5].

2. Experimental procedure

As-received commercially pure 1050 aluminum was processed in twist extrusion with length of 60 mm, diameter of 20 mm and with a cross-section thickness of 12 mm as shown in Fig. 1a. The twist angle was 45°. A split-design die was used which led to significant protrusions, because of the insufficient lateral force to close the die, see Fig. 1b. The larger fin was 0.68 mm thick and about 1850 mm^2 surface which was examined in detail. Electron back scatter diffraction (EBSD) technique was used for detailed examination of the microstructure. For data acquisition, the HKL software was used. Further processing was done with the JTEX software [6]. Hardness was measured using a CSM nano-indentation instrument; the obtained nano-hardness values were transformed into equivalent Vickers hardness quantities. High Pressure Tube Twisting (HPTT) [7] tests were also done on the same material to obtain reference data for large strain shear deformation.

3. Results and discussion

The results of the Vickers hardness measurements show that the material was substantially hardened during the formation of the protrusion: in the initial state, the hardness was 44 HV, while in the protrusion it varied between 77 HV and 108 HV. This relatively large variation is due to the very local measurement technique; the effective zone in the nano-indentation test was in the order of the grain size, so it reflects the grain-orientation dependence of strain hardening. This hardness is much larger than the hardness measured in the bulk twist-extruded part of the specimen, which was 61 HV. The microstructure was investigated by EBSD in the bulk twist-extruded part as well as in the fin. The observed microstructure revealed a very fine grained structure in

---

[*] Corresponding author at: Laboratoire d'Etude des Microstructures et de Mécanique des Matériaux (LEM3), UMR 7239, CNRS / Université de Lorraine, F-57045 Metz, France. Fax: +33387315366.
E-mail address: laszlo.toth@univ-lorraine.fr (L.S. Toth).

http://dx.doi.org/10.1016/j.matlet.2015.07.008
0167-577X/

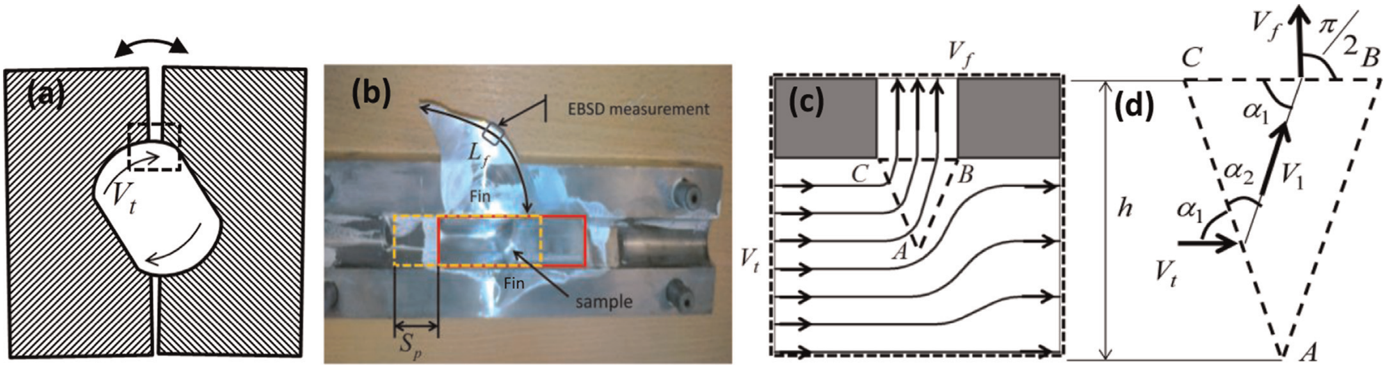

Fig. 1. (a) Cross-section of the die; (b) Sample and fin; (c) Metal flow near the gap (dotted line square region in (c) is the same as in Figure (a)); and (d) A kinematically admissible velocity field for the triangular area bounded by a dotted line in the Figure (c).

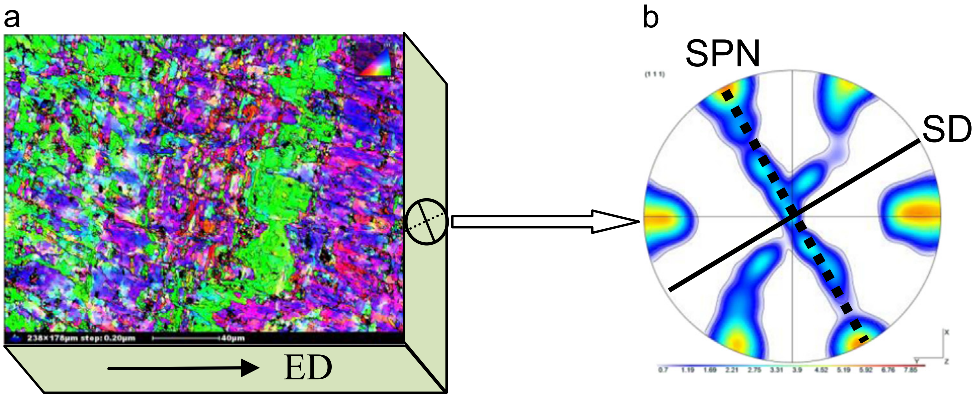

Fig. 2. (a) Inverse pole figure map obtained by EBSD from the large fin in the plane of the fin. (b) {111} pole figure obtained from the IPF map.

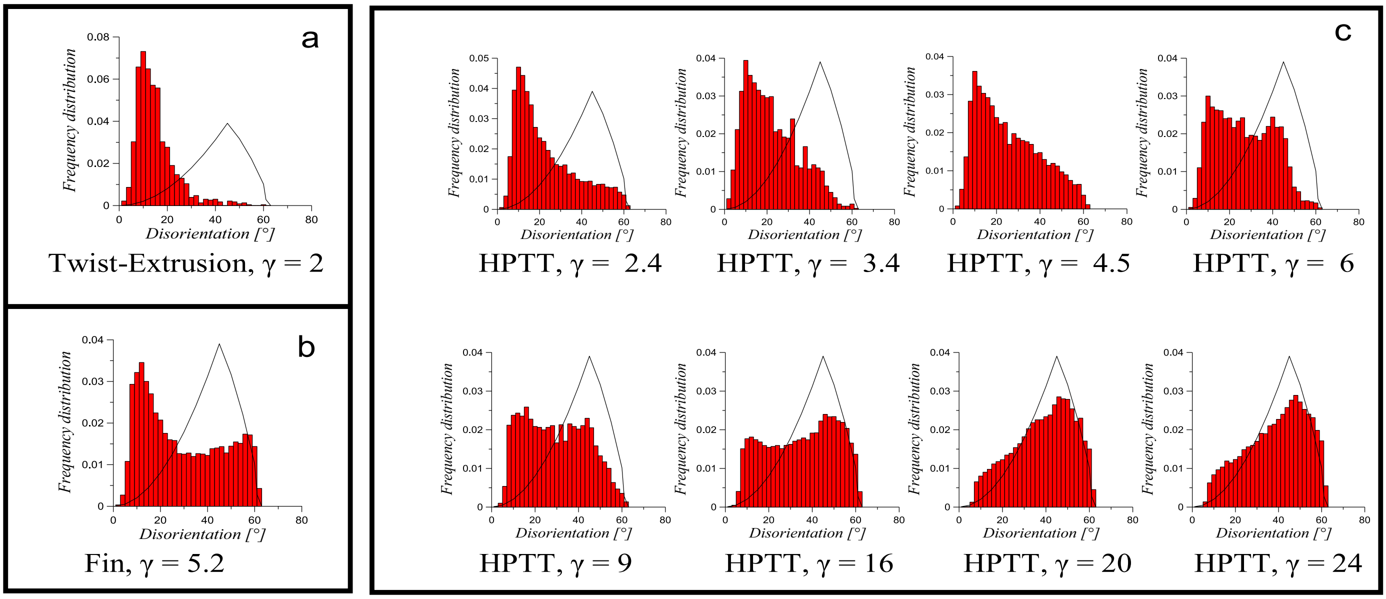

Fig. 3. Comparison of the disorientation distribution measured in the fin (b) with the disorientation distributions obtained in one-pass Twist Extrusion (a) as well as with HPTT (c) as a function of shear strain. The continuous function is the random Mackenzie distribution.

the fin, an example is shown in Fig. 2a. The average grain size was 1.36 µm in this map, other measurements showed similar values, however, in some regions the grain size was only 610 nm. Grain orientations were defined as the average of the pixel orientations constituting the grain and then disorientation angle between adjacent grains was obtained using these average values. This procedure leads to the next-neighbor grain to grain disorientation distribution of the microstructure [8]. The disorientation distributions obtained in this way are presented in Fig. 3, for the bulk twist-extruded part (3a), for the fin (3b) and for HPTT (3c) in comparison with the random case (the Mackenzie-curve [9]). In general, the distributions show two characteristic peaks, one at low and another at high angles. The low angle peak can be identified with the ongoing grain fragmentation of the initial grains while the high angle peak is the result of the orientation change of the already fragmented grains. In the following, the percentage