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Correlation between microstructure, tensile properties and fatigue life of AA1050 aluminum alloy processed by pure shear extrusion

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ABSTRACT

This research is focused on the influence of multiple passes of pure shear extrusion (PSE) on grain refinement and evolution of tensile properties in AA1050 alloy. It is observed that the average cell size reduces and the misorientation angle increases with increasing number of PSE passes. High fractions of elongated grains are observed in the microstructures of the samples deformed by 1, 2 and 3 PSE passes. However, the fraction of elongated grains reduces by increasing number of PSE passes and diminishes at the 4-pass of PSE. In fact, by increasing the number of PSE passes, more homogeneous grain refinement occurs which is evidenced by formation of equiaxed cell structures with remarkable percentage of high angle grain boundaries. The most significant increase in yield and tensile strength occurs at the first pass of PSE. Strengthening continues with further PSE processing while elongation gradually improves which is attributed to reducing cell size and increasing the fraction of high angle grain boundaries. Despite of increasing elongation and strength, the fatigue life of the samples continuously reduces with further PSE processing. This is attributed to occurrence of cyclic softening in deformed samples with ultra-high strength.

1. Introduction

Producing bulk nanostructured materials by means of severe plastic deformation (SPD) has been a challenging research topic in materials science. In severe plastic deformation (SPD), a remarkable plastic strain is induced into a bulk material in order to produce an ultra-fine grained structure [1–4]. Numerous SPD techniques, such as high pressure torsion (HPT) [5,6], twist extrusion (TE) [7], equal channel angular pressing (ECAP) [8] and simple shear extrusion (SSE) [9], have been developed to produce ultra-fine grained Al alloys. It should be taken into attention that these processes are mainly based on simple shear. However, it has been proved by Segal [10] that the mode of shear deformation, i.e., simple or pure, can have significant effects on the development of microstructure. Although the effect of the mode of shear deformation is deeply investigated in this research [10], however, the used technique to provide pure shear was conventional rolling which is inherently concerned with imposing redundant work and an inhomogeneous deformation. Therefore, it cannot be certified whether it is the net effect of the mode of deformation which is causing the differences in microstructural evolution or it is the redundant work causing the outcome. In order to remedy this situation, a new approach based on pure shear, called pure shear extrusion (PSE), was developed [11–13]. The superiority of this method is that the dominant deformation mode is pure shear while no redundant work is inherently concerned.

It should be added that as a consequence of variations in the microstructures of the samples by SPD processing, a significant variation in mechanical properties is as well expected. Therefore, the main goal of this research was to investigate the effect of PSE deformation on the variation of microstructure and its consequent effect on mechanical properties, among which, tensile and fatigue properties are of quite high importance. For this purpose, the influence of multiple PSE passes on the development of microstructure and the evolution of tensile and fatigue properties of AA1050 aluminum alloy are investigated. In fact, purpose was to find the most homogenous nano-structure yielding the most homogeneous mechanical properties.

2. Experimental procedure

The chemical composition of AA1050 aluminum alloy used in this work is shown in Table 1. Al slabs were subjected to machining in order to produce rectangular samples of 19.8×19.8×100.0 mm^3. Afterwards, machined samples were fully annealed at 500 °C for 1 h to eliminate the influence of previously induced strains and residual stresses.

In order to facilitate removing the samples from the PSE die channel as well as minimizing the stress concentration at the die

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Table 1
Chemical composition of the AA1050 used in this investigation.

Element	Cu	Mg	Si	Fe	Mn	Zn	Ti	Al
wt%	0.03	0.03	0.25	0.3	0.05	0.06	0.04	Balance

channel corners, a split die was designed and used. The entrance of PSE die channel was a 20 mm side square cross section with the length of 120 mm and the height of the exit channel was 20 mm. The deformation zone included two sections of 25 mm in height. A 10 mm long relaxation zone was designed between the two upper and lower deformation zones. It should be noted that extrusion process was carried out by a hydraulic press of 50 t capacity.

Electron backscatter diffraction (EBSD) analysis was carried out using a JEOL 6500 scanning electron microscope (accelerating voltage: 25 kV; working distance: 25 mm; tilt angle: 70°; step sizes: 0.5 µm) in order to examine the structure of the samples after each pass of PSE. In addition, TSL analyzing software was used for interpreting orientation contrast data. Also by considering 2° and 15° as the minimum misorientation angles of low angle grain boundaries (LAGBs) and high angle grain boundaries (HAGBs) respectively, grains and subgrains were traced and detected.

Longitudinal cross section of each specimen along the long diagonal of the rhombic was considered for samples preparation. Subsequently, section of the specimen for EBSD observation was polished mechanically and then electrolytically in a 700 ml CH_3OH +300 ml HNO_3 solution at approximately 243 K with a voltage of 20 V. It should be noted that all samples for EBSD observation and tensile testing were extracted from the surface of PSE specimen.

For tensile testing, round 100 mm long samples were prepared. Subsized specimens were prepared according to the ASTM B557M standard with a gage length of 45 mm and diameter of 9 mm. Tensile testing was performed using a Universal Instron testing machine with a 5 mm/min speed.

Bending fatigue test was performed according to ASTM E-1150-87 standard. The samples were 100 mm long with a diameter of 6.67 mm, according to DIN 50113 standard. The rotation speed was 2900 revolutions per minute (RPM) and a bending stress of 52 MPa was applied.

3. Results and discussion

3.1. Microstructure

3.1.1. Evolution of microstructure during PSE

The microstructures of the samples after 1, 2, 3 and 4 PSE passes are illustrated in Fig. 1. It should be noted that these microstructures are extracted from the surface of PSE specimens.The lines marked in red are attributed to low angle grain boundaries (LAGBs) with misorientation angle range of 2° to 15°; whereas high angle grain boundaries (HAGBs) with minimum misorientation angle of 15° are outlined in black. From Fig. 1(a) and (b), it can be clearly observed that elongated grains are produced by application of first and the second passes of PSE. As shown in Fig. 1(a) and (b), a high density of LAGBs, can be seen in the inner space of elongated grains which can be correlated to the lattice microstrains as well as residual stresses. In addition, large variations throughout the microstructures of the samples after the first and second passes of PSE, may be attributed to the inhomogeneity in material flow [14]. However, after the third PSE pass, elongated grains would be intensely broken-up and transformed to fine and spherical grains while a small fraction of the microstructure still includes elongated grains having significantly high density of LAGBs. By continuing deformation, i.e., by application of the 4th pass, the microstructure develops with equiaxed grains and elongated grains can be hardly found. In other words, the equiaxed

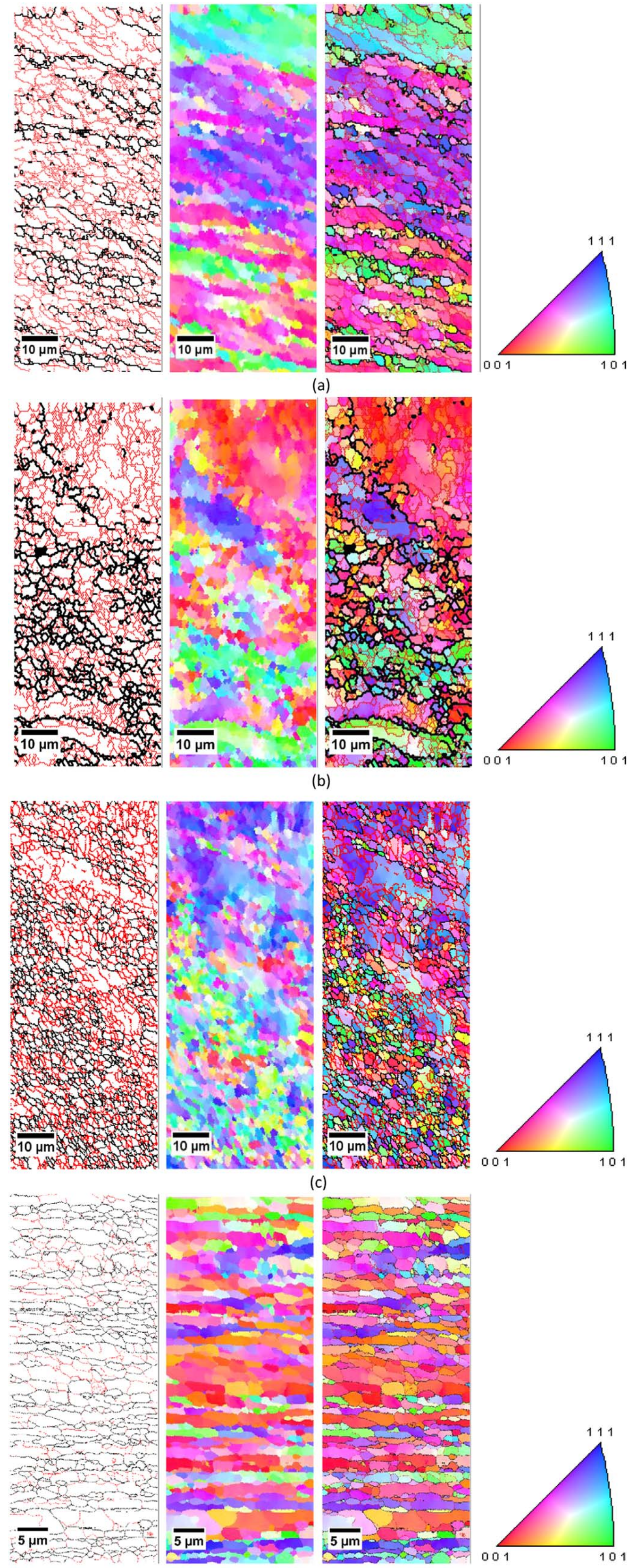

Fig. 1. EBSD maps of AA1050 alloy after (a) 1, (b) 2, (c) 3 and (d) 4 passes PSE. (For interpretation of the references to color in this figure , the reader is referred to the web version of this article)