Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Study on the post-rolling direction of severely plastic deformed Aluminum-Manganese-Silicon alloy

Mohammad Reza Jandaghi [a,*], *Hesam Pouraliakbar* [b], *Gholamreza Khalaj* [a], *Mohammad-Javad Khalaj* [a], *Akbar Heidarzadeh* [c]

[a] *Young Researchers and Elites Club, Saveh Branch, Islamic Azad University, Saveh, Iran*
[b] *Department of Advanced Materials, WorldTech Scientific Research Center (WT-SRC), Tehran, Iran*
[c] *Department of Materials Engineering, Azarbaijan Shahid Madani University, Tabriz, Iran*

ARTICLE INFO

Article history:
Received 30 November 2015
Accepted 19 June 2016
Available online

Keywords:
CGP
Post-rolling
XRD
Microstructure
Mechanical properties

ABSTRACT

Constrained groove pressing (CGP) as a severe plastic deformation (SPD) technique was applied on Al-Mn-Si sheets. In the following, direct- and cross-rolling were employed as supplementary processing in order to investigate the rolling-direction effect on CGPed sheets. The in-depth characterization of microstructural evolutions were employed using polarized light microscope and scanning electron microscope. Williamson–Hall analysis method was applied on X-ray diffraction (XRD) patterns of specimens. Analysis of XRD results revealed that post-rolling of CGPed sheets induced dynamic recrystallization (DRX) due to massive dislocations' accumulation which follows by crystallite growth. The largest crystallite size which was 619 nm achieved after direct-rolling through the rolling strain of 1.27. Maximum acquired peak intensity ratio for rolled sheets was for (220) crystallographic plane similar to annealed one. Also, post-rolling had altered the distinguished plane from (111) for CGPed sheets into (220). Mechanical characteristics of specimens were examined using hardness and tension tests. Based on the obtained results, direct-rolling of CGPed samples was more susceptible for strength enhancement compared to cross-rolling. Optimum achieved values for yield and ultimate tensile strength were 155 and 197 MPa, respectively. Rolling in the both longitudinal and cross directions had almost similar effect on the final attained hardness.

* *Corresponding author*. Tel.: +98 912 7325658.
E-mail address: mrj.sharif86@gmail.com (M.R. Jandaghi).
http://dx.doi.org/10.1016/j.acme.2016.06.005

1. Introduction

Ultra-fine grained (UFG) materials have got significant attraction in recent years since they have had unique combination of physical and mechanical properties compared to those of coarse-grained [1]. Approaching to nanostructure have remarkable effect on mechanical strength enhancement; especially in the case of light metals such as aluminum alloys whereby the grain refinement lead to ennoblement of the strength to weight ratio and makes them susceptible more than ever to be employed in transportation and aerospace industries [2]. For this purpose, different SPD methods such as, equal channel angular pressing (ECAP) [3], high pressure torsion (HPT) [4], accumulative back extrusion (ABE) [5], tubular channel angular pressing (TCAP) [6], accumulative roll bonding (ARB) [7], repetitive corrugation and straightening (RCS) [8], multi directional forging (MDF) [9] have been investigated broadly in the recent years. However, some of the mentioned techniques practically ineffectual for the manufacturing of plate-shaped products. ARB and CGP are two versatile SPD techniques for consolidation of metallic sheets. CGP induces the repetitive shear deformation under plane-strain condition utilizing the successive pressings with asymmetric grooved and flattened dies [10]. More details on CGP could be found in literature [10,11].

Cold rolling is known as one of the most advantageous metal working processes for continuous production of bulky materials having shapes such as plate, sheet and bar. Literature claims suggest that the rolled structures usually have lamellar structure with low-angle grain boundaries while the ultra-fine grained structures owing to severe straining are often granular-type containing mainly high-angle grain boundaries [12]. Also, more recent works [13–15] highlighted that further rolling of severely deformed samples spread the high-angle boundaries within the structure resulted in uniform ultra-fine grained material achievement. Hansen et al. [16–18] provided a thorough study on the cold-rolling effects on mechanical and microstructural characteristics of commercial pure aluminum up to the large strains. Likewise, the influence of post-rolling on the nature and behavior of SPDed materials have been studied scarcely. Attention has been focused on steels, copper, aluminum, magnesium, titanium and their alloys [15,19–22]. It was ascertained that exertion of subsequent rolling on SPDed matter could accelerate the grain refinement and improve the material strength. Beside, often it has been reported that this enhancement was attended by drop in ductility [21]. Of course, carry on rolling to the elevated strains exclusively might break the material's resistance due to micro-cracks propagation since their formation is elucidated to be inevitable in such large deformations. This threat is contingent when the archetypal has a thickness within low range scales.

Despite of the investigation into the cold-rolling influence on some SPDed alloys, regardless of the type of alloy and the utilized method, no render has been reported previously about the lattice transformation while rolling as the terminal processing of CGPed materials. Briefly explained reasons beside profuse unanswered questions about the rolling-direction effects on microstructural and mechanical characteristics of already strained aluminum alloys by CGP method was motivated the authors to inquire the correlation of lattice parameters and achieved material properties for Al-Mn-Si alloy in hypothesized deformation paths.

2. Materials and methods

Pieces with 84 mm × 70 mm × 3 mm dimensions were cut and prepared from Al-Mn-Si sheet which was pre-annealed at 723 K for 3 h in order to survey the impact of CGP and subsequent rolling processes. Fig. 1 illustrates the corrugating and flattening CGP dies used in the present study.

The width of dents in corrugating dies was identical to sheet thickness which lead to impose highly-pure shear stress while processing. The pressing force was supplied via a 100 kN hydraulic pressing machine equipped with a digital force-meter with constant ram displacement speed of 0.1 mm s^{-1}. The applied pressing load was 45–50 kN which was around 45–50% of nominal machine capacity. In order to extenuate the tangible friction between the processing die and specimens, Teflon tape as lubricant wrapped around the aluminum sheets rigorously. Already, analysis of force diagrams was revealed that friction could have ascertained influence on the deformation force [23].

In the following, two-pass CGPed Al-Mn-Si specimens were direct- and cross-rolled at room temperature by the strains of 0.47, 0.8 and 1.27. A laboratory 200 kN rolling machine with cylindrical rolls (ϕ = 150 mm) and feeding speed of 30 rpm was utilized. Comparing the primary and final sheet thicknesses,

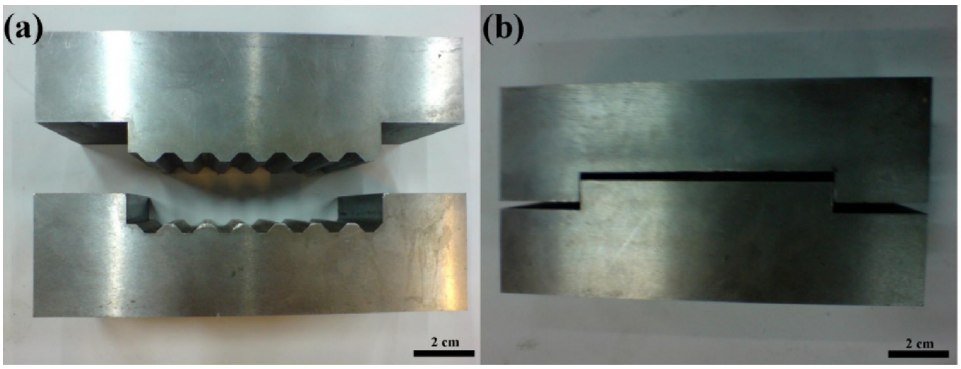

Fig. 1 – Illustration of (a) corrugated and (b) flattened dies applied in CGP process.