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The Effect of Cross-Rolling Process on Nanostructure of Al 1050 Alloy

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Abstract

The cross-rolling is a new process that results in significant evolutions in microstructure of the metallic sheets. In this study, an aluminium 1050 sheet was rolled up to 95% reduction in cross directions for ten passes. The rolled samples were investigated by X-ray diffraction (XRD) and transmission electron microscopy (TEM). The rolled samples possess a high dislocation density and ultra-fine crystallite structure. In addition, an anisotropic texture was formed in the structure of material. In fact, the intensity of {220} planes of Al was extremely increased about 7500 counts per second (CPS) in cross-rolling process. In this research a new method called selected area electron diffraction (SAED) was used to determine the direction of planes. In cross-rolled samples, the rolling texture component {110} [001] was created that are known as brass texture (Bs). A regular geometric structure accompanied by ultrafine-grained observed in TEM micrographs. Ultra-fine crystalline structure is proved by rings which were obtained from SAEDs. The results show that the grain sizes are about 200 nm and 300 nm in cross-rolling and straight rolling, respectively.

Keywords: Cross-rolling; Al 1050; XRD; TEM; SAED; Microstructure evolution.

Nomenclature	
SAED	Selected area electron diffraction
UFG	Ultra fine grain
CR	Cross rolling
SR	Straight rolling
RD	Rolling direction
BS	Brass texture
SFE	Stacking fault energy

1. Introduction

Due to especial physical and mechanical properties of ultra fine grain (UFG) of aluminum (Al) a lot of interests have been demonstrated in the production of Al alloys with UFG in the recent years. Furthermore, various kinds of severe plastic deformation processes have been proposed and the authors

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try to overview the various rolling processes for ultragrain refinement [1]. The simple rolling process is one of the most important techniques for deforming of metals microstructural. This process is performed in two ways of straight rolling (SR) and cross rolling (CR) with different conditions such as i) cryorolling, ii) room temperature rolling, and iii) hot rolling. In fact, cross-rolling was introduced as a method in which the rolling direction (RD) was rotated 90° to the direction of pervious pass. The cross rolling process in different conditions was used to create special texture and microstructure. Evolution of crystallographic texture and nanostructure and its effect on mechanical properties of Al alloys have been studied extensively [2,3]. Evolution of nanostructure and texture in Al 7010 alloy during different modes of hot cross-rolling was performed by Mondal et al [4]. A randomization of the cube recrystallization texture of the Al alloy AA5182 was studied by applying an additional step of cross-rolling during the deformation. The results of this process were analyzed by X-ray diffraction (XRD) and transmission electron microscopy (TEM) [5]. Also, cross-rolling method was investigated in AlMn and Al-6Cu-0.4Zr alloys for studying the texture formation and nanostructure development [6]. Slip systems change with crystal lattice of the material, because the atomic density of planes and directions are difference [7]. In fcc crystals, slip often occurs in {111} planes and <110> directions [8-10]. Rolling texture specify with (hkl)[uvw], that (hkl) and [uvw], introduce the planes and directions, respectively. The rolling texture is very complicated and texture components have differences in planes and directions. So, (110)[112] and (110)[001] textures are often known as silver or Bs-texture and this texture belongs to the fcc crystal with low SFE. In Al with high SFE, important components of textures are (123)[412], (146)[211] and (112)[111]. These preferred directions are known as copper texture [11-18]. Different types of textures, which are characteristics of fcc metals, can create in Al alloys that depending on the composition of the alloy, rolling temperature and geometric conditions of rolling and samples [19-23].

In this paper, the changes of texture in Al 1050 during SR and CR process in room temperature were investigated by means of X-ray diffraction and SAED technique. Also, the samples were straight and cross-rolled, investigated by means of TEM and SAED techniques to obtain microstructure. Meanwhile, the microstructure evolutions under straight and cross rolling process were investigated.

2. Experimental procedure

In this study, sheets of commercial aluminium alloy (Al 1050) of dimensions 40mm (width)×80mm (length)× 4.2mm (thickness) were used. The chemical compositions of the Al 1050 are listed in table 1. First, the sample was rolled in rolling direction and after that, it was rolled in transverse direction as can be seen in figure 1, a schematically.

Table 1. Chemical compositions of Al 1050

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
Wt%	0.25	0-0.4	0.05	0.05	0.05	0.05	0.03	-	Balance

The cross and straight rolling were performed for ten passes in room temperature. After deformation, thicknesses of the samples were reduced to 0.6, 0.4, 0.2 and 0.1 mm. Finally, an aluminium sheets were rolled up to 95% reduction after the rolling process. Figure 1, b schematically shows SR and CR processes of Al 1050 in ten passes.

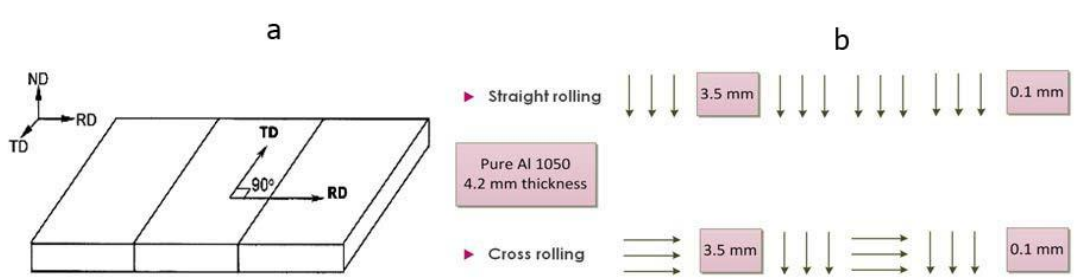


Figure 1. a) CR process, b) Schematic of SR and CR process for Al 1050 in ten passes

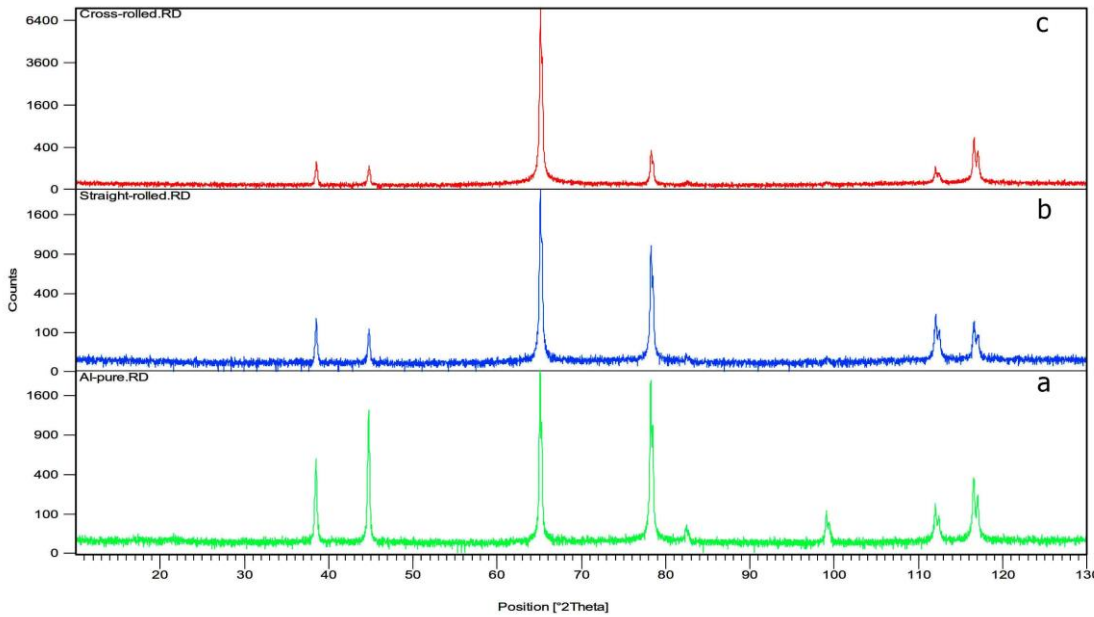


Figure 2. X-ray diffraction patterns of (a) pure, (b) straight rolled, and (c) cross-rolled samples.

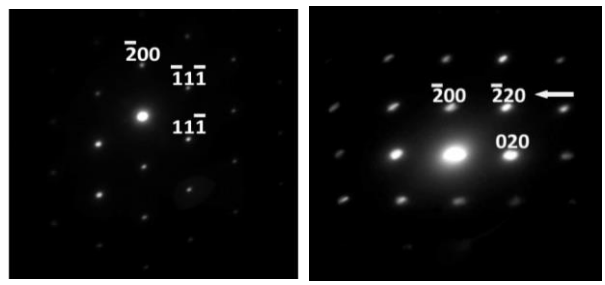
The results of the CR and SR techniques in different reduction were compared with each other. Subsequently, X-ray diffraction and SAED techniques were used to characterize the preferred orientation of samples. Also, microstructure evolution of Al pure, SR and CR samples were observed by using of the optical microscope (Leitz-wetzlan) and XRD (Philips-PW1800). Chemical polishing and micro etching were employed for metallographic preparation. In order to reveal the grain boundaries, the samples were etched in a solution of 10 ml HF and 90 ml distilled water at room temperature. For a detailed understanding of the microstructural evolution, TEM (Philips-EM208S) operating at 100 kV was used. Specimens for TEM were prepared by utilizing a conventional jet electro-polishing technique (Struers, Tenupol3, DK-2610) in a %5 perchloric acid in %95 ethyl alcohol (V/V) solution at -20 ˚C.

3. Results and discussions

3.1. Texture analysis by XRD and SAED

The present study focuses on the influence of various rolling processes (SR and CR) on texture of Al 1050 alloy. The intensity of {220} planes of Al was extremely increased about 7500 counts per second (CPS) in cross-rolling process. It was expected that copper texture created in Al, but Bs-texture created by CR process. The study of the texture indicates that increasing the number of rolling passes increase the severity of a texture's component. The main component of texture was Bs- (110)[112] + (110)[001] and the intensity of that was increased by number of rolling passes. The formation of high intensity texture in CR process was created the fine grain structure. Figure 2 shows the X-ray diffraction patterns of different samples. In SR sample, there was not any typical rolling texture component but in CR sample, Bs-texture was observed. As can be seen, the intensity of the {220} planes was extremely increased that shows the formation of rolling texture component. According to the results of this paper, Bs-texture was created by CR process at room temperature. In this research a new method was used to determine the direction of planes called SAED. Normal direction of planes easily achieved by analysis of this diffraction patterns. Diffraction patterns of different parts of sample were studied by XRD to find the preferential directions and dominant planes.

In this study SAED was taken from different areas of samples. By use of this method, orientations and directions were achieved. Electron diffraction patterns of SR and CR samples are shown in figure 3. The preferred orientation was {110} [001] which showed Bs-texture in cross-rolled sample.



(a) (b)

Figure 3. Electron diffraction patterns of (a) straight rolled with z=[011]; (b) cross-rolled with z=[001] samples

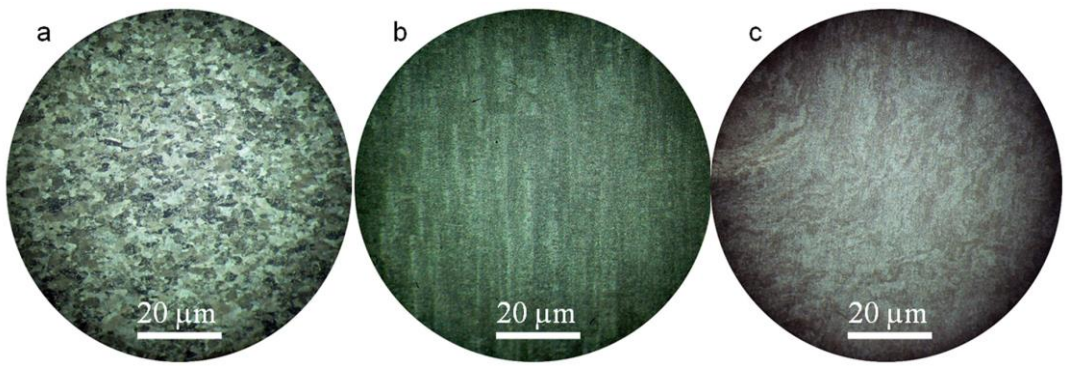


Figure 4. Microstructure of (a) pure; (b) straight rolled; (c) cross rolled samples prepared by optical microscope

3.2. Nanostructure analysis by microscopic methods;

3.2.1. Optical microscope

Figure 4 shows the microstructure of three different samples with three different grain structures. There is a noteworthy decrease in the grain size and significant change in grain morphology as can be seen in figure 4. The grains were elongated in the SR process along the rolling direction (figure 4.b.). Also, shape of the grains were twisted and extremely deformed in the CR process (figure 4.c.).

3.2.2. TEM

The TEM micrographs of pure samples without any cold rolling and working were shown in figure 5 (a) and (b). The size of individual grain of this sample is about 800 nm. For studying of the nanostructure evolution, the Al pure sample was compared to the SR and CR samples. Figure (5, c) shows single crystal spot electron diffraction pattern for the fcc crystal structure of Al pure sample with axis zone of z=[111]. In addition, the planes of the sample was indexed by measuring of the angles and distances between spots. Figure 6 illustrates the shape of the grains with dislocations. The bright field TEM image of SR samples clearly reveals the presence of dislocations in grain boundaries and formation of ultrafine grains structure. The SAED of the SR sample in figure (6, c) exhibits the diffraction rings, which indicates a polycrystalline structure and nanostructure grains. Sequentially, the habit planes and interplanar spacing of SR sample was determined. The average grain size of SR samples was about 300nm that measured by image tools software and SAED technique confirms this nanograins size.

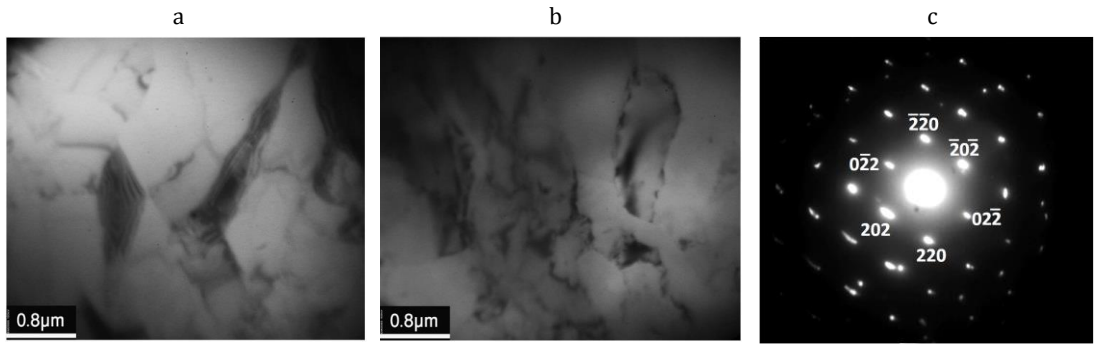


Figure 5. TEM micrographs of Al pure 1050 alloy (a) and (b), and electron diffraction patterns of Al pure 1050 alloy with the zone axis z= [111] (c).

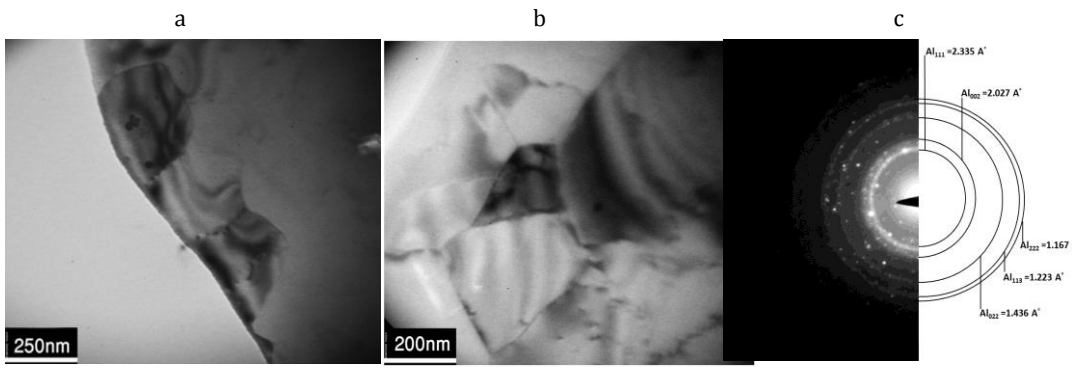


Figure 6. TEM micrographs of straight-rolled specimen after 95% thickness reduction (a)and (b), and electron diffraction patterns of straight-rolled specimen (c).

TEM study of the CR and SR samples was performed to observe the evolution of nanostructure such as changes in dislocation content, subgrain, morphology, formation of texture and other parameters. A regular geometric structure was created in CR (figure 7) that this paper is offered a reasonable explanation for this result. Specifically, a heavily deformed nanostructure was observed in the CR samples, that dislocations in grains were evidence in this sample. The nanostructure evolution of both samples indicates an increasing of dislocation density and relaxation of cell boundaries in to subgrain walls special CR sample. Base on the TEM micrographs, it is concluded that the minimum crystallite size was created in CR sample. The size of the grains changed considerable to 200 nm. Individual subgrains with a size of 100 nm were also observed. CR process to 95% reduction created considerable nanostructure and increased the dislocation density.

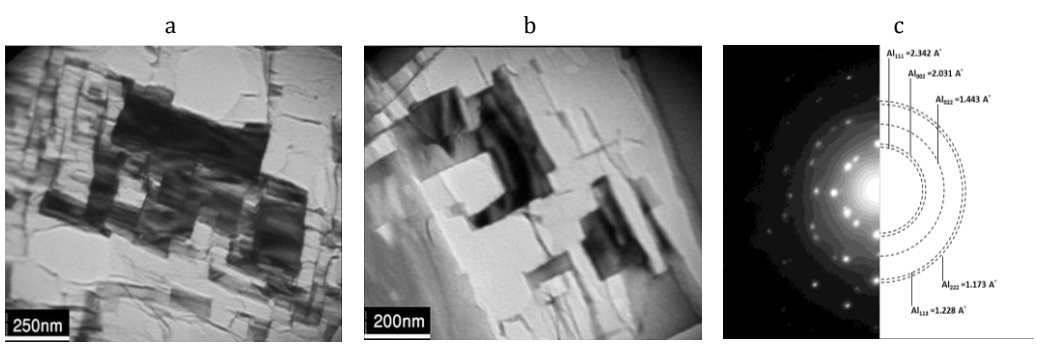


Figure 7. TEM micrographs of cross-rolled specimen after 95% thickness reduction (a) and (b), electron diffraction patterns of cross-rolled specimen (c).

The dislocation density at the subgrain walls was more than that inside of the grains. CR process was increased the dislocation density, subsequently, subgrain was created by increasing the dislocation lines. The matrix orientation was determined by SAED technique that was {110} [001] texture orientation component and the orientation were uniform throughout the matrix of the sample. SAED patterns of the CR sample characterize planes, interplanar spacing, nanostructure and zone axis as explained previous part of this paper, as can be seen in figure 7 (c).

4. Conclusion

The rolled samples possess a high dislocation density and ultra-fine crystallite. In addition, an anisotropic texture produced in structure of the material. In fact, intensity of {220} planes of Al was extremely increased in CR process. In cross-rolled specimen, the rolling texture component {110} [001] was created that are known as Bs-texture.

This study showed that the CR process was an effective method to create Bs-texture in Al 1050 alloy compared to the SR process. This investigation also shows that the CR process is an effective technique to create UFG structure. The dislocation density at the subgrain walls was more than that inside of the grains. CR process increased the dislocation density, subsequently, subgrain boundaries was created by increasing the dislocation lines. Also, CR process to 95% reduction created considerable nanostructure and increased the dislocation density and as a consequence, the results of TEM micrographs were validated by SAED technique in both CR and SR methods for creating nanostructure.

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