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# Formation and Migration of Dislocations Produced by Plastic Deformation in 1070 Al-alloy

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Positron Annihilation Lifetime (PAL) and X-ray are common nondestructive techniques used heavily in materials science to detect deformation and thermal effects in metals and alloys. In this work, the investigated wrought 1070 Al-alloy samples were plastically deformed at room temperature using a hydraulic press. X-ray diffraction patterns of the bulk and the deformed 1070 Al-alloy, at different degrees of deformation, have been studied and analyzed using MAUD program. The lattice parameter, the grain size and the intensity ratio of the maximum diffraction lines in addition to micro-strain as a function of the degree of deformation have been determined. The 20 % deformed sample was annealed and the behavior of the positron annihilation mean lifetime of the sample was studied as a function of the annealing temperature.

**Keywords:**

## 1. INTRODUCTION

Aluminum and its alloys have outstanding properties like, light weight, good electrical and mechanical properties, etc. which make them highly recommended for a lot of applications. The investigated 1070 Al-alloy samples have many applications such as general industrial parts, housing and construction, transportation, electrical materials, communication cables, fridges and freezer cabinets, and for joining two parts of aluminum. One method that is used to improve the mechanical properties of materials is the plastic deformation. Plastic deformation occurs when anadequate load is applied to a material causing a change in the shape of the material. This change produces deformation that is described as plastic deformation when involving the breaking the limited number of atomic bonds through the motion of dislocations. The importance of dislocations comes from the fact that they represent the basis for understanding the material's mechanical properties [1-5].

The characterization of materials can be performed using a diversity of techniques. In this work X-ray diffraction (XRD) and the positron annihilation lifetime spectroscopy (PALS) has been used. X-ray diffraction is a common non-destructive method which is used heavily by materials scientists due to its ability in materials phase identification and in determination of some of the most important physical properties such as lattice parameter, micro-strain and grain size. XRD was used heavily in studying the plastic deformation effect and the annealing process on metals and alloys [6-8]. On the other hand, PALS is known to be a powerful sensitive nondestructive nuclear method used in materials science. PALS has been used heavily in studying defects in metals and alloys [9-11]. This technique has many advantages such as the ability to detect and distinguish between different types of defects [12].

## 2. Experimental procedure

Samples of the the1070 Al-alloy, which have the chemical composition shown in the table (1), were homogenized at 673 K for 12 hours then slowly cooled to room temperature inside non-vacuum furnace.

| Elem ent | A l | F e | S i | Z n | V | C u | T i | M g | M n | O thers |
|---|---|---|---|---|---|---|---|---|---|---|
| Conte nt (%) | ≥ 99.7 | ≤ 0.25 | ≤ 0.20 | ≤ 0.04 | ≤ 0.05 | ≤ 0.04 | ≤ 0.03 | ≤ 0.03 | ≤ 0.03 | ≤ 0. 03 |

Table 1.The chemical composition of 1070 Al-Alloy [13].

Three samples were deformed, at room temperature (RM), to 8%, 13% and 20% thickness reduction using a hydraulic press. These three samples, in addition to the bulk sample were investigated using XRD technique. Continuous scanning was applied on the samples using a slow scanning rate (1°/min) and a small time constant (1sec) by means of a JEOL X-ray diffractometer (XRD) (Model JSDX-60PA) prepared with a Cu kα-radiation (λ= 0.145184 nm), X-ray source at 40 kV and 35 mA. A range of 2θ (from 30 to 100°) was covered, so that all the diffraction peaks could be detected. XRD profile peaks were analyzed using MAUD program.

A couple of 20% deformed 1070 Al-Alloy samples were annealed and the positron mean lifetime values were measured as a function of the annealing temperature every 25 °C. The construction of the positron lifetime experiment was shown elsewhere [5, 14, 15]. The positron ($e^+$) source, $^{22}$Na, was sandwiched between the 20% deformed couple. The sandwiched samples were then enfolded in a thin Al foil. The mean lifetime of the positron was recorded by a time spectrometer using a fast/fast coincidence method. Each spectrum was recorded a period of 3 hours during which about $5\times10^5$ coincidence counts were accumulated. The time resolution of the system using $^{60}$Co source was approximately 340.0 Ps.The lifetime spectra were analyzed with POSITRONFIT program [16].

## 3. Results and discussion

The XRD spectrums of the investigated samples are shown in Figure 1. X-ray charts show that only peaks (111, 200, 220, 311, and 222) of Al-based FCC crystal structure are present for the 1070 Al-alloy. There is a variation in the intensity of the diffraction lines with increasing the degree of deformation; meanwhile there is no change in the phase was observed. The analysis of the X-ray diffraction charts was performed using MAUD program [17, 18] to get more information about some physical properties of the alloy under investigation. The miller indices (hkl) of the different peaks and the d-spacing for the non-deformed and the 20% deformed samples are indicated in Table 2. The measured d-spacing values of all diffraction lines for the non-deformed sample is higher than that of the 20% deformed sample.

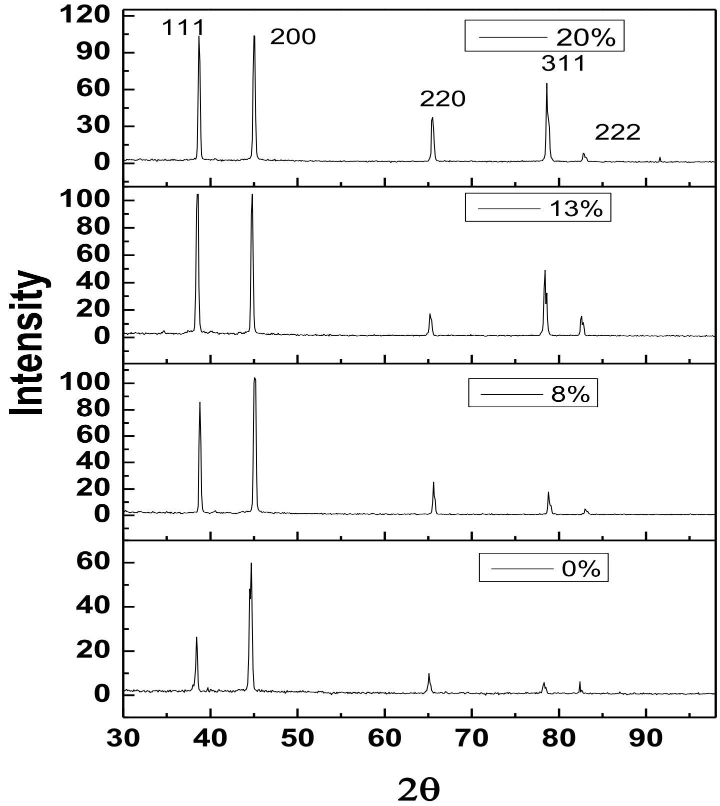


**Figure 1**. XRD charts of 1070 Al-alloy samples at different degree of deformation.

The lattice parameter, grain size and the intensity ratio $I_{(200)}/I_{(111)}$ are shown in Figures 2, 3 and 4 respectively as a function of the degree of deformation. The lattice parameter seems to have a very slight decrease with thickness reduction from around 4.05 Å at zero deformation to approximately 4.03 Å at 20 % deformation. The grain size has value of about 0.31 $\mu m$ below 10% thickness reduction above which an abrupt decrease in the measured grain size is observed until 14% thickness reduction is reached. Grain size value of about 0.15 $\mu m$ was obtained at higher degree of deformation.Figure 4 shows that the relation between both the intensity ration $I_{(200)}/I_{(111)}$and the macro-strain as function of thickness reduction seems to have the same behavior at which slow decrease is observed until 14% thickness reduction is reached then both values of the intensity ratio and micro-strain are kept constant.

Table 2.d-spacing of non-deformed and 20% deformed samples at the corresponding hkl of 1070 Al-alloy

| **d for non-deformed sample** | **d for 20% deformed sample** |
|---|---|
| 2.343 Å | 2.326 Å |
| 2.029 Å | 2.014 Å |
| 1.435 Å | 1.424 Å |
| 1.223 Å | 1.214 Å |
| 1.171 Å | 1.163 Å |

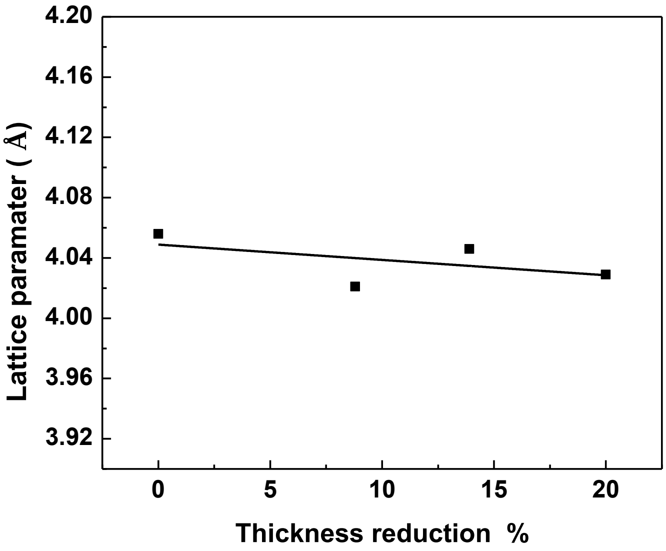


**Figure 2**.Lattice parameter as a function of thickness reduction of 1070 al Alloy.

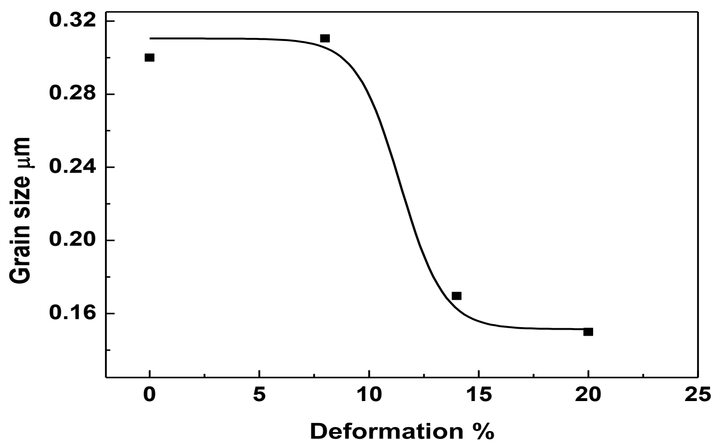


**Figure 3**. Grain size as a function of deformation of 1070 Al alloy

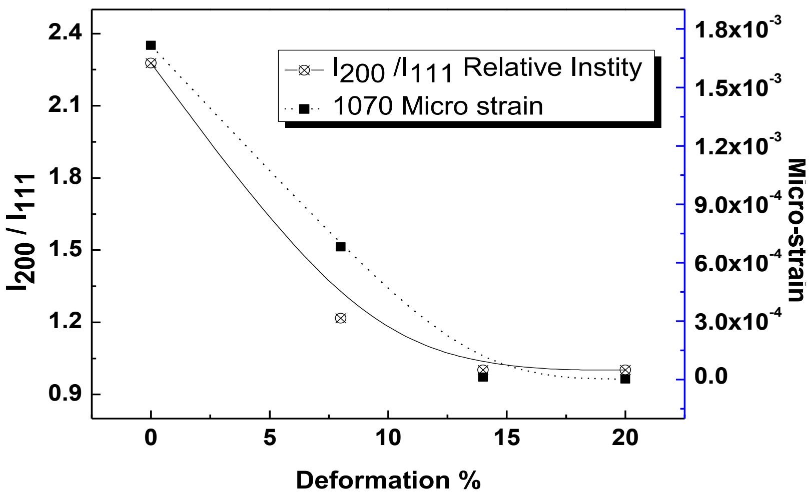


**Figure 4**.$I_{(200)}/I_{(111)}$ and Micro strain as a function of Thickness reduction of 1070 Al alloy.

Then, a 20% deformed couple was subjected to annealing and the positron mean lifetime values were measured as a function of the annealing temperature. The mean positron lifetime values, as obtained experimentally, are plotted in Figure 5 as a function of annealing temperature. The value of the positron mean lifetime in the trapped state ($\tau_t$) (deformation 20%) was found to be 202.9 ps and it was gradually decreased to reach 165.6 ps at 300 °C which is the same value of the mean lifetime ofpositron in the defect free state ($\tau_f$).

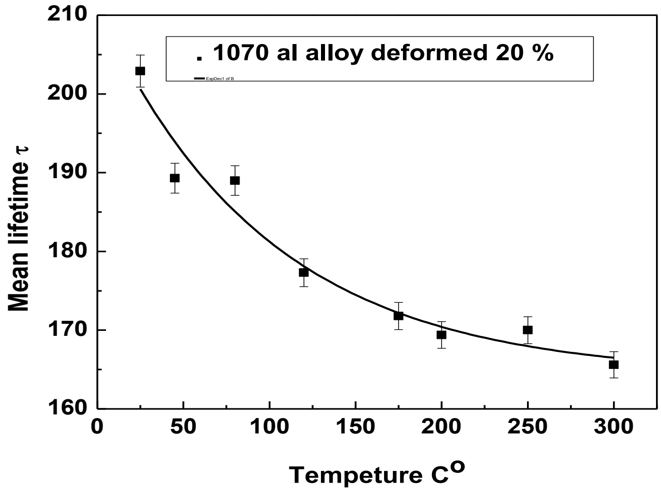


**Figure 5**.The mean lifetime as a function of annealing Temperature.

The accuracy of the positron mean lifetime measurements has been verified by measuring the variance of the mean lifetime versus annealing temperature. The variance of goodness of fit using PATFIT program analyses is close to unity as shown in Figure 6.

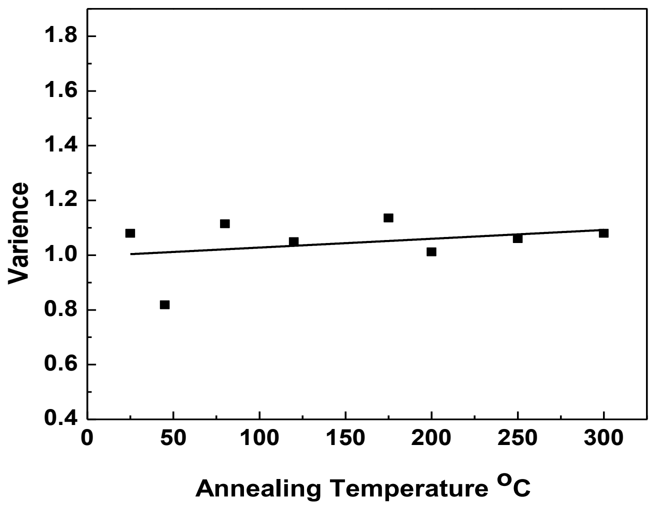


**Figure 6**.The variance of goodness of fit as a function of the annealing Temperature.

Table 3. The lattice parameter and grain size of 20% deformed 1070 Al-Alloy.

| **1070 al alloys** | **Lattice parameter** | **Grain size by (XRD)** | **Grain size by (PALT)** |
|---|---|---|---|
| Deformed 20% | 4.02945 Å | 0.13285 µm | 0.1318 µm |

The mean crystal size (*l*) can be obtained from the positron results according to the equation reported by Hidalgo and de Diego [19]:

$$\tau = \tau_f + \left[ \left( \tau_t - \tau_f \right) \frac{L_d}{\ell} \right] \qquad (1)$$

Where $L_d$ is the mean diffusion length of positron in metal (Al) :$L_d$ =1500 A. This equation was used to calculate the grain size for the 20% deformed couple as indicated in Table 3, and it was found to be 0.1318 µm that is in a very good agreement with the grain size calculated from the XRD charts for the same deformed sample, 0.13285 µm.

## 4. Conclusions

From our measurements concerning the influence of plastic deformation and the annealing of the 1070 Al-alloy using X-ray diffraction and positron annihilation lifetime technique, we found that:

- The XRD spectrums show that only diffraction peaks of Al-based FCC crystal structure are present for the 1070 Al-alloy.
- There is no change in the phase was observed and the lattice parameters seems to have a very slight decrease with increasing the degree of deformation.
- The grain size decreased from about 0.31 µm at 0% deformation to approximately 0.14 µm at 20% deformation.
- The relation between both the ratio of the intensity $I_{(200)}/I_{(111)}$and the macro-strain as function of thickness reduction was found to be similar.
- Positron mean lifetime values of about 202.9 ps and 165.6 ps was obtained for the trapped state and the defect free state respectively.
- The grain size values determined by XRD (0.1318 µm) and PAL (0.13285 µm) techniques are in a very good agreement with each other.

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