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Research Article

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Improved Ductility and Mechanical Properties of A5 Aluminum Alloy Thin Sheets Processed by Cold-Rolling and Annealing Treatment

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Abstract In this study we're particularly interested in the effect of heat treatment on mechanical properties and the microstructure evolution of A5 aluminum alloy, which has been plastically deformed by cold-rolling at room temperature. Morphological, microstructural, structural and thermal analysis (DSC) of the all samples was investigated by optical microscopy (OM), scanning electron microscopy (SEM), and X-ray diffraction (XRD). The mechanical properties were characterized by Vickers microhardness and tensile test. The results show clearly that after Cold-rolling and annealing treatment, the microstructure has a significant elegation, which depends on the rate of reduction. Significant increase in mechanical properties are observed such, yield strength (YS), ultimate tensile strength (UTS), elongation (E %), and Vickers microhardness. After the cold rolling and the annealing treatment, the amount of precipitates increases and the material provides good plasticity.

Keywords A5 alloy, cold rolling, thermal analysis DSC, mechanical behavior, plasticity

1. Introduction

Many researchers have focused on the development of new aluminum and its alloys due to their high technological value and its wide use in industrial applications, thanks to their various advantages such as lower density, good formability, high heat conductivity, high rigidity, excellent corrosion resistance and important tensile strength [1, 2]. Furthermore, aluminum alloys offers one of the best choices of metals for aircraft structural components because of their well known performance characteristics, manufacturing costs, implementation methods and manufacturing facilities, allowing their use in large amounts in the future [3]. However, it is important to improve the mechanical behavior of these engineering materials such as strength and ductility [4]. In particular, aluminum alloys of small thickness are desirable to reduce the weight and cost for structural applications. Forever, it's a challenge to produce an alloy with enhanced resistance and keeping a reasonable ductility. For not-heat-treated aluminum alloys, resistance can be obtained by forming heavy cold, which is related to the substructure refinement resulted in large plastic deformation. But, poor ductility is often accompanied by a heavy cold work. Recovery annealing at a lower temperature in the beginning of recrystallization may be applied to recover ductility without significant loss of strength, but frequently results in batch yield, followed by the location of the flow, and a low ductility [5–9]. In particular, the A5 aluminum alloy is generally characterized by low mechanical strength compared to other aluminum series, due to less solute atoms and particles which have precipitated a barrier against the mobility of dislocations. Nevertheless, the strength of A5 could is significantly improved by severe plastic deformation [10–12]. The A5 alloy in various metallurgical states is the subject of this study. It was homogenized at 500°C for 24 h in order to dissolve the excess quantity of impurities (Fe, Si). The main purpose of this contribution is to investigate the influence of cold rolling and annealing treatment on the behavior of A5 aluminum alloy.

2. Materials and Methods

The initial material used in this work is an A5-H14, 3 mm thick sheet. The chemical composition is given in Table 1. The material was annealed for 24 h at 500°C and finally quenched in iced water, in order to obtain a fully recrystallized homogeneous microstructure prior to cold-rolling respectively at 50% and 66% reduction. After that, it is annealed at 350°C for 1 hour. The metallographic analysis was conducted by exposing the specimens to grinding at up from 600 to 4000 abrasive papers, fine polishing to mirror finish with diamond paste respectively of 9µm, 6 µm, 3 µm and 1 µm and then the specimen surface were etched by an electrolytic etching Keller's solution reagent (2 % Hf + 3 % HCl + 5 % HNO_3 + 90 % H_2O). The microstructure evolution of the samples was studied using optical microscopy (OM) and scanning electron microscopy (SEM). The phase identification was examined by X-ray diffraction (XRD) using CuKα1 radiation in a Siemens D5000 X-ray diffractometer. The XRD patterns were achieved from the sheet of the 15 mm × 10 mm × 1 mm samples, cut along longitudinal direction**.** DSC experiments were performed using a "TA instruments Q100" apparatus under a low pressure of argon with a heating rate of 5°C.min-1 in the temperature range from 25 to 500°C.

Table 1: Chemical composition in weight % of the A5 aluminum alloy studied.

Al	Fe	Si	Mg	Mn	Ni	Cu	Cr	Zn	Pb
balanced	0.21	0.0693	≤0.05	0.0170	≤0.1	0.0823	≤0.03	≤0.15	≤0.03

Tensile test were carried out to evaluate the mechanical properties of the A5 alloy. It was performed on testing machine at a transverse speed of 5mm / min. The train was measured using an extensometer (50mm gauge length).Three samples per condition were prepared and tested; each test is repeated to obtain representative values and to ensure a good reproducibility of the results. The test is performed on INSTRON 4500 Tensile Testing Machine following the standard ISO 6892. The extensometer attached to the sample gauge was used to determine strain and total elongation. Hence, specimens were prepared from homogeneous sheet samples and cold-rolling at 50 % and 66 % respectively and finally annealed at 350°C by cutting along rolling direction namely, 0° to the rolling direction of the sheet. Although, A5 alloy at a received condition and homogeneous were tested. Vickers microhardness was measured on different region by applying a load of 300g for 15s.

3. Results and their discussion

The data of the mechanical properties of the A5 alloy obtained from the stress-strain curves, the yield strength (YS) and ultimate tensile strength (UTS) ,elongation (E %) and microhardness HV at break are shown in Table 2. Firstly, the material at the received state A5 was analyzed. It has acceptable properties which are in good agreement with other studies on the same material [13]. After homogenization and quench in ice-water, it is noticed that the tensile properties are considerably reduced in terms of microhardness with a drop of 37 ± 1 HV to 22.5 ±1 HV. Moreover the tensile strength of a value of 103 MPa to 71MPa ±1 and the yield strength of 85MPa to 27MPa while increasing elongation with values from 6 ± 3% to 42% ± 3. Although a cold -rolling was operated, the mechanical behavior of the material increases. A significant increase in mechanical properties of the A5 alloy was obtained after deformation and annealing. Note that the values of the yield strength and the tensile stress increase with increasing strain rate. There is an increase in the microhardness that goes from 22.5 ± 1 HV in the homogenized state to 43 ± 1 HV in the case of cold-rolling at 50% and annealing at 350°C for one hour. A more intense deformation with cold-rolling about at 66% and annealing at 350°C for one hour led to an increase in microhardness to a value 48.83 ± HV. Vickers microhardness values found in this study are comparable with those of X .G. Qiao and al for the same material plastically deformed by ECAP material [14]. This improvement in mechanical properties can be explained by accumulation of dislocations in the grain boundaries caused by the cold-rolling and which are not completely canceled by the annealing effect. This increase of the dislocation density has given the A5 alloy suitable metallurgical condition. In fact, it presents a good compromise between a good tensile strength on the one hand and on the other hand desirable ductility, so that it is suitable for cold forming applications.

Table 2: Tensile properties and hardness of A5 in various conditions

Condition	YS(MPa)	UTS(MPa)	Elongation (%)	HV (0.3)	Reference
A5 alloy a received state	85±1	105±1	3±2	35±2	Present
A5 alloy homogenized at 500°C for 24 hours	27±1	71±1	41±2	22 ±2	Work
A5 alloy cold-rolled at 50% without annealing	90±1	120±1	2.5±2	48±2	
A5 alloy cold-rolled at 66 % without annealing	100±1	140±1	1.75±2	53±2	
A5 alloy cold-rolled at 50% and annealed at 350°C for 1 hour	31±1	81 ±1	28±2	43±2	
A5 alloy cold-rolled at 66% and annealed at 350°C for 1 hour	38±1	86 ±1	36±2	49 ±2	
A5- H14	103	-	-	20.9	[13]
A5-O	28	-	-	31.8	[13]
Hot extruded A5	20	72	12	24	[19]

Fig. 1 shows the optical micrograph of the A5 alloy samples with various treatments. The optical micrographs of A5 alloy in the received state (Fig.1-a) has a heterogeneous microstructure with grains dispersed in various directions. After homogenization, (Fig.1-b) the grains are well separated and the grains are clear along with homogeneous repair grains. Under the effect of the deformation caused by cold-rolling the grains are more or less elongated following the rolling direction. The cold-rolling and annealed samples at 350°C for one hour have a partially fragmented structure which proves that the annealing did not completely cancel the effect of the deformation. However it gave the material a more stable metallurgical state that in the case of cold-rolling only. The complete recrystallization took place after annealing at 350°C, resulting in a fine and equiaxed grain structure as shown in (Fig. 1c) and (Fig.1d). As with other thermo-mechanical treatments, the cold-rolling followed by subsequent heat treatment resulted in a significant reduction in grain size. The same result confirmed by Jun-Hyun, Han and al [15].

Fig. 2 shows the morphology of the A5 alloy analyzed by SEM. It is shown the homogenizing effect on the microstructure of the A5 (Fig.2c-d). Firstly the A5 alloy in its present state of reception (Fig .2a-b) demonstrated considerable mechanical behavior. It shows the existence of some precipitates. This explains students values of yield strength and tensile stress and microhardness accompanied by a low elongation [16, 17].After cold-rolling, the SEM micrograph of A5 (Fig.3a-b) and (Fig.3c-d) shows that the precipitates are very fine [18]. Also, the particle morphology and the particle size distribution become nearly homogeneous. In fact the deformation by cold-rolling generating the fragmentation of the microstructure has not been canceled even by annealing at 350°C.

Figure 4 depicts the XRD patterns of the analyzed specimens before and after cold rolling process.

The sample at a received state presents a final texture on the plane (220). After homogenization, a new privilege texture is generated following a new plan (200). Further, It is noticed the presence of all peaks on the face-centered cubic structure of the aluminum. Besides the fundamental reflexions of the aluminum matrix, very fine XRD reflexions with law intensity are observed (fig.4a-b-c-d).These XRD reflexions correspond to the presence of a second phase and an intermetallic compound. Then, it's could be attributed to the precipitates Al_8Fe_2Si and Al_3Fe .The crystallographic structure of Al_8Fe_2Si can be judged as hexagonal structure, and Al_3Fe as a monoclinic structure. Our results are in good agreement with other work done on the same alloy [18]. Even after cold-rolling and annealing at 350°C no changes in texture was observed.

The thermal behavior of all samples has been investigated by DSC measurements as a function of metallurgical state; the results are shown in (Figure. 5). The DSC curve reveals the presence of two exothermic peaks A and B with a maximum situated at respectively 110 and 385°C. The presence of those peaks can be explained by the precipitation which is due to impurities dissolution Al_8Fe_2Si and Al_3Fe. Then, and phases followed by endothermic peaks due to the dissolution process: a first endothermic peak (a) in the temperature interval [50–85 ◦C], an endothermic peak (b), with a minimum situated at 365 ◦C.

The cold rolling pressed material is thermally stabilized that can be justified by the presence of the precipitates Al_8Fe_2Si and Al_3Fe which retard the phenomenon of recrystallization. Our results are in good agreement with other work done on an alloy of the same family [20].

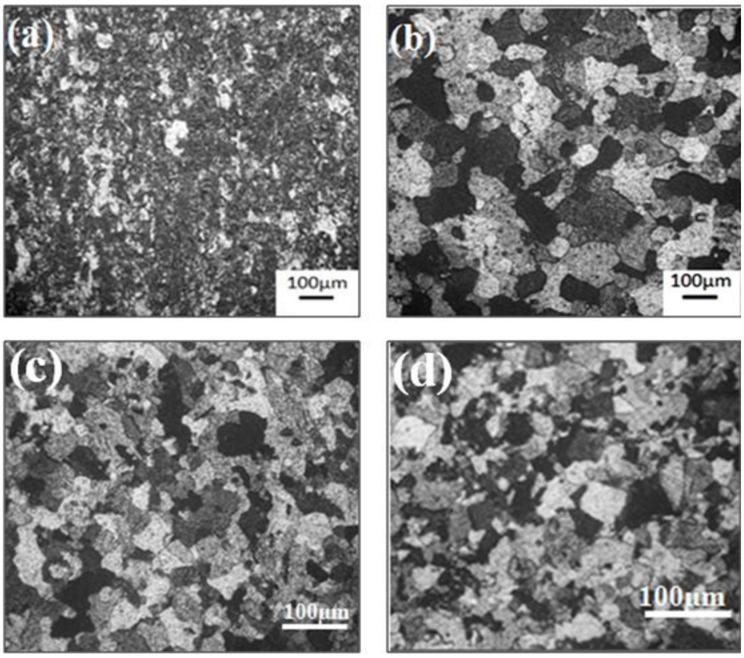

Figure 1: Optical micrograph (OM) of the received state A5 (a) A5 recrystallized (b), A5 (c) rolled at 50% and annealing at 350°C for one hour(c), A5 at rolled at 66% and annealing at 350°C for one hour(d).

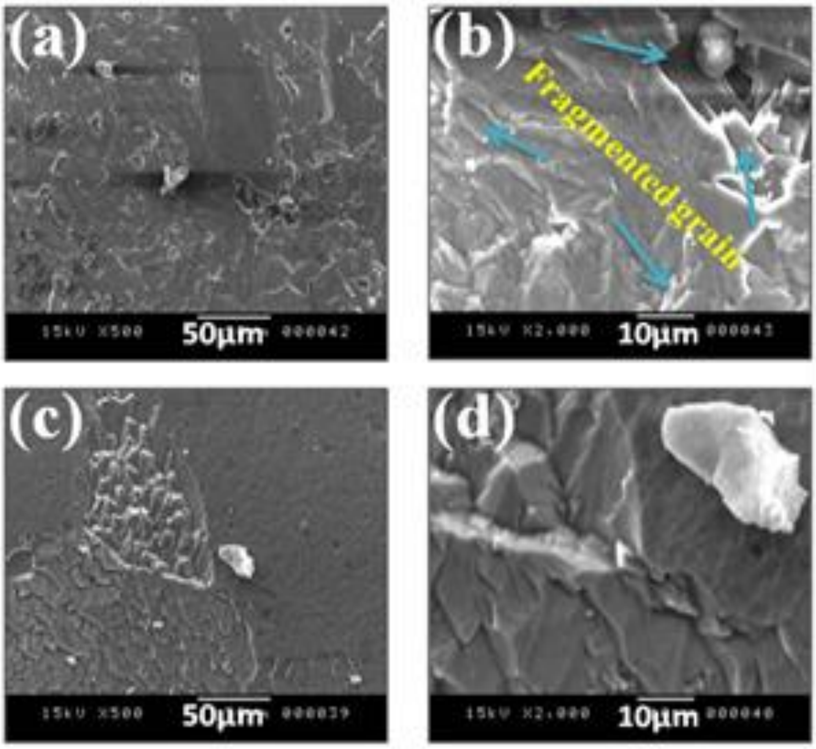

Figure 2: SEM observation of the received state of A5 alloy (a,b) and SEM observation of the homogenized state at 500°C for 24 hours and quenched with ice water of alloy A5 (c, d).

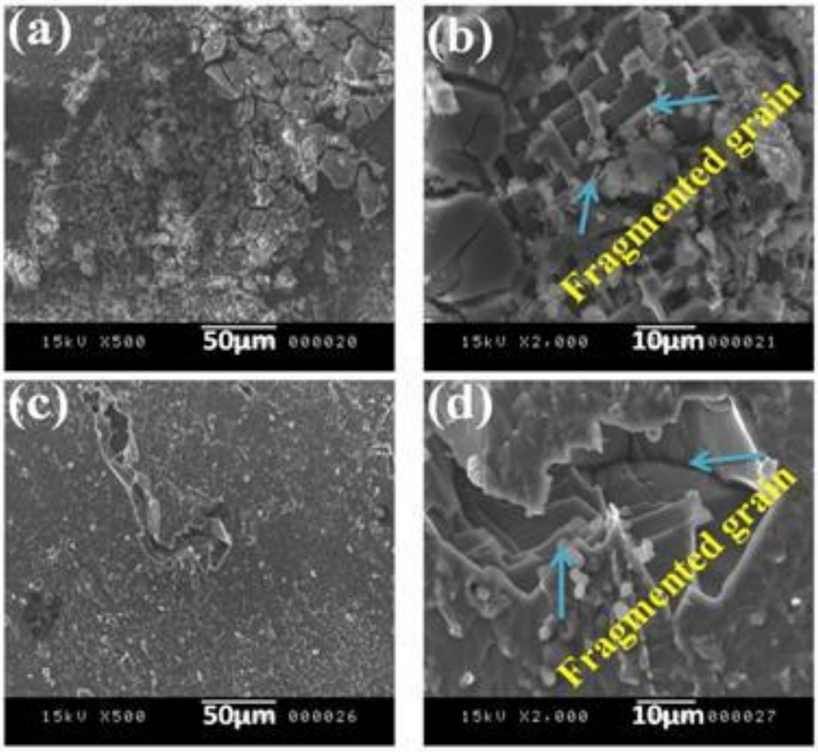

Figure 3: SEM observation of the homogenized alloy A5 and then rolled at 50 % and annealed at 350°C for one hour (a, b) and SEM observation of the homogenized alloy A5 and then rolled at 66 % and annealed at 350°C for one hour (c, d).

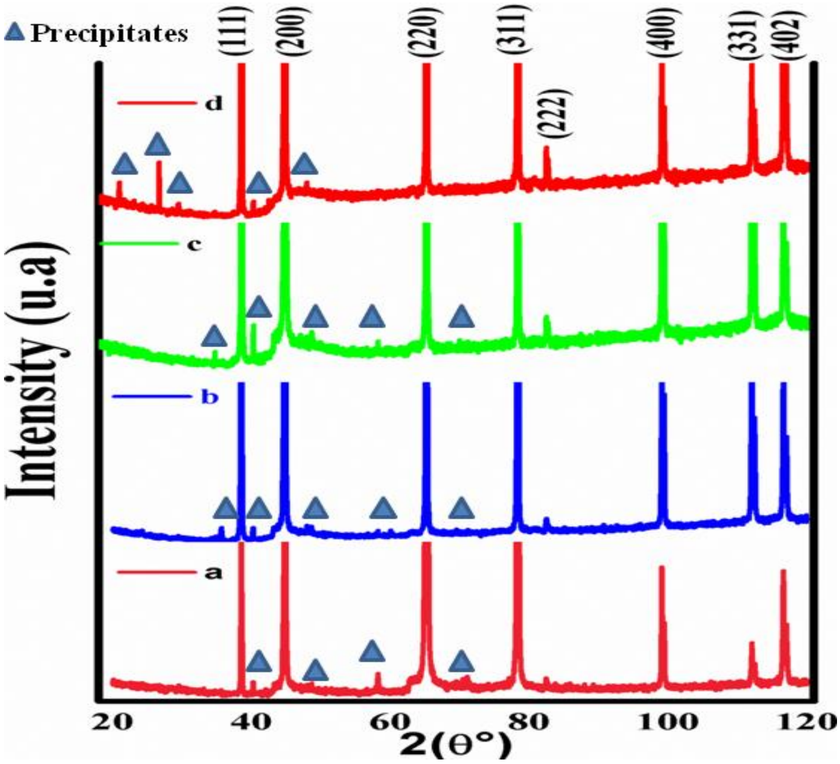

Figure 4: (a) diffraction pattern of X-ray of the A5 alloy in the different metallurgical states

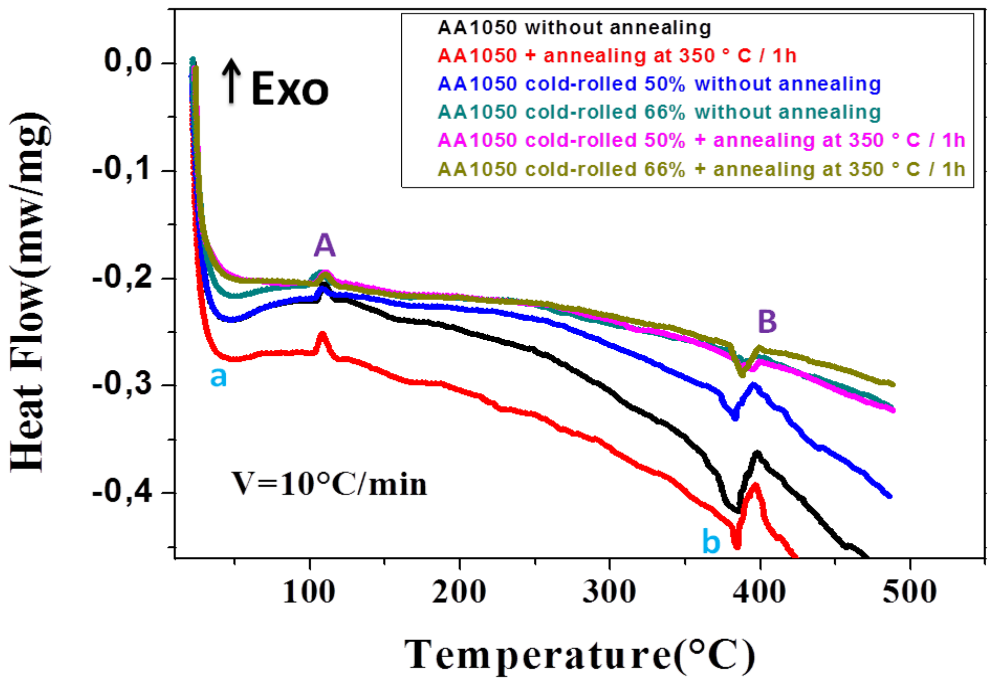

Figure 5: DSC curves of the A5 alloy as a function of metallurgical states

4. Conclusion

After annealing treatment, the material has a more uniform distribution than at the unreformed state. Micrographs SEM show that the annealing did not completely offset the effects of cold-rolling and the structure is again fragmented and the precipitates are fine. XRD shows that the material has a well defined texture on the plane (220) after homogenization it becomes the plane (200) and the same cold-rolling and annealing at 350°C did not change this texture. Furthermore, it was noticed the presence of all the fundamental peaks on the face-centered cubic structure of the aluminum of the matrix with the existence of some secondary peaks of low intensity which could be attributed to the precipitates Al_8Fe_2Si and Al_3Fe.The tensile properties were much improved as a function of cold-rolling rate and the material shows good plasticity. The microhardness Vickers shows a good improvement after the cold-rolling and annealing treatment. The calorimetric analysis reveals the presence of exothermic and endothermic peaks due to the precipitation reactions; the suggested precipitation process corresponds to the process already accepted for A5 alloys.

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