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Mechanical properties and electrical conductivity performance of ECAP processed AA2024 alloy

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This paper presents an experimental examination of AA2024 aluminium alloy through Equal Channel Angular Pressing (ECAP), annealing, and ECAPed plus aging applications. The aim of this study is to compare and observe the effects of the a forecited processes in terms of hardness and electrical conductivity. ECAP is one of the frequently used methods for Severe Plastic Deformation (SPD). SPD give rises to obtain stronger mechanical properties of materials as an improvement technique in material science. Four AA2024 specimens are prepared. One is as received sample, second is annealed AA2024, third one is ECAP processed and the last one is ECAP and then aging processed form. Hardness measurement is done as mechanical properties investigation. In addition, microstructure behaviour with SEM is studied. Once again, electrical conductivity of all four specimens are examined. All parameters are compared with each other. After annealing process the hardness of AA2024 is reduced according to as received form. ECAP increased the hardness, despite this, the highest hardness value is observed on ECAPed plus aging processed sample. The electrical conductivity of AA2024 is increased after annealing process according to as received form. However, it reduced after ECAPed plus aging process. Nevertheless, ECAPed sample gained more conductivity and has the least resistivity.

Keywords: ECAP, AA2024, Electrical Conductivity, SEM

Copper added aluminium alloys, called 2xxx Series for aluminium, are highly preferred. Mostly used 2xxx series aluminium is AA2024. Because of its strong and good machinability properties, it is used especially in areas such as the aircraft industry where unit weight resistance should be high. In contrast to these advantages and widely using areas, it has poor formability[1-4].

Conventional materials do not satisfy the needs in industry adequately. Hence, new techniques have been studied especially in the last two decades. Severe Plastic Deformation (SPD) is a technique, which results stronger materials by obtaining ultrafine grains[5]. Moreover, Equal Channel Angular Pressing (ECAP) is one of the most known methods as an SPD technique. ECAP leads to strength and ductility improvement through the grain refining, and development of a suitable texture[6]. The most striking advantage of ECAP is while increasing the mechanical properties (especially in terms of hardness) of a material the brittleness of material does not diminish. During ECAP, the direction and number of billet passes through the channels are very important for microstructure refinement[7]. As the number of passes increase, the ultimate strength goes up accordingly[8]. Lately, mechanical properties of this technique is often researched[9-14], but there are limited studies on effects of electrical conductivity.

Experimental Section

Commercial aluminium 2024-T6 alloy which was produced from extrusion, was used for experiments with a chemical composition of 4.28Cu-1.53Mg-0.58Mn-0.38Fe-0.25Si-0.04Zn-0.03Ti-0.01Cr-0.01 other-balanced Al in weight percentage. Four samples were prepared from this alloy. Firstly, cylindrical as received commercial alloys were machined with saw and lathe. The length and diameter of the sample were respectively, 55 mm and 20 mm. The first sample was received as AA2024 alloy. The second sample was made with the same geometry after annealing process of another as received form at 460°C for 2 h. The third specimen was prepared by ECAP. The specimen was heated to 200°C with die and pressed at 2 mm/sec. Only one pass was done because the main objective of this study was to examine and compare the effects of processes. Following this ECAP process the ejected specimen was cut with precision cutting machine. One slice was used as the third sample that was ECAPed sample. The other slice of ECAPed sample was heated to130°C at 24 h for aging process. By this way, the fourth sample was set which is one pass ECAPed plus aging processed.

For hardness testing, Future-Tech Microhardness Tester FM-700 machine was used. Applied load was selected to be 1000 gf and dwell time is 9 sec. For each specimen, the Vickers hardness measurement was repeated for five times and average value is obtained and compared.

For microstructure investigation, the specimens were firstly grint from 600 to 4000 Si cemery papers and subsequently polished in diamond paste up to 3 μ and 1 μ particle sizes. After that, the specimens were etched by Keller's reagent (90%H_2O+5% HNO_3+3%HCl+2%Hf). Finally, optic images and SEM images were observed by Zeiss Axotech 100 Olimpos AX41M-LED optical microscope with Nicon Eclipse L-50 and, Hitachi Scanning Electron Microscope SU3500 machines. In order to observe orientations, phase diffractions and, deformation patterns SEM images were captured from as received and ECAPed specimens. In addition, optic microscope images were examined and compared from all specimens.

In order to examine conductivity of specimens, resistivity values of materials were measured by four-probe method. Lucas LAB 302 device was used in order to perform four probe method tests. In this method as shown in Fig. 1, at outer probes, current was passed through to the specimen and then from the inner probes voltages were measured. The spacing between the probe points was kept constant. Resistance was measured by using Ohms law. Results were collected by a Pro4 software and interface.

Results and discussion

Hardness

According to the results of Vickers test, micro-hardness of AA2024 is decreased by 5.43% after annealing process, but by one pass of ECAP process it is increased by 7.25% when compared to as received form. However, the most hardness increase is measured from one pass of ECAPed plus aging processed specimen with a value of 17.15%. Figure 2 illustrates the measured Vickers hardness values of specimens. According to study of Goodarzy *et al*.[9] hardness is also increased with ECAP process and it is

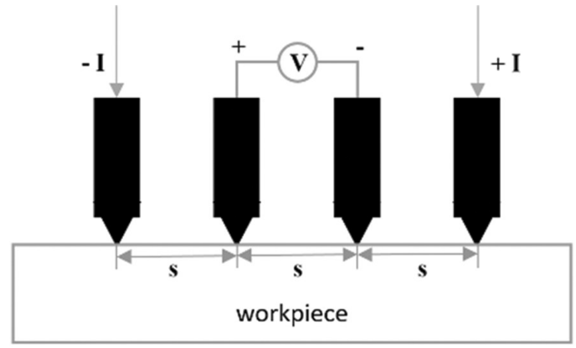


Fig. 1 — Method of 4 probe

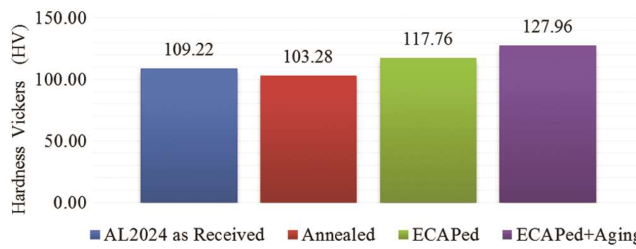


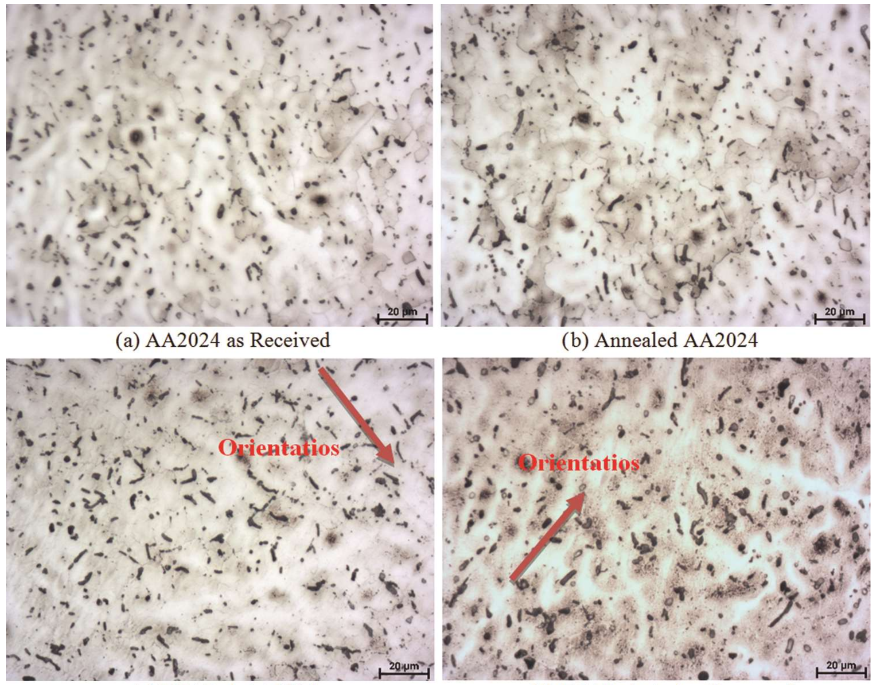
Fig. 2 — Vickers hardness results

more increased and obtained highest hardness values with ECAP plus aging process. Also Kim *et al*[10] obtained similar results. This increase is due to the increase in the amount of particles in secondary phase besides grain thinning in the microstructure as shown in Fig. 3

Microstructural Observations

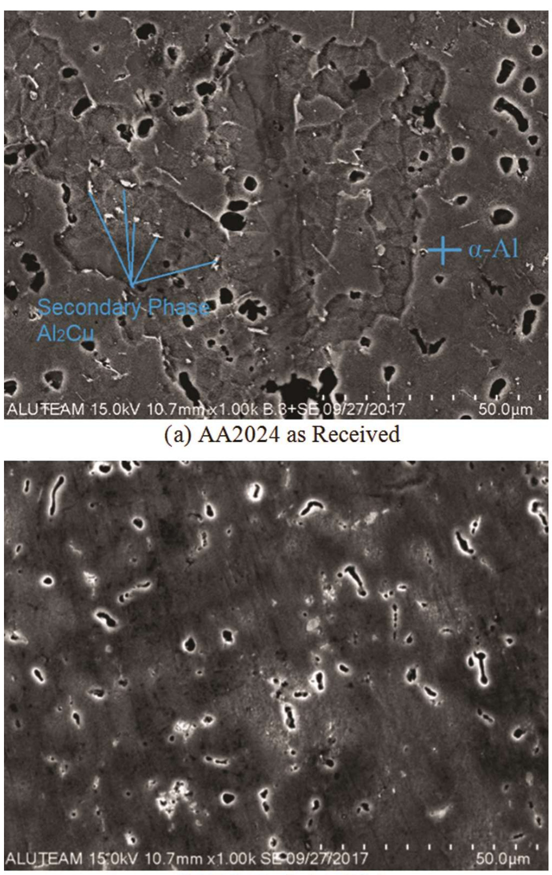
Optic microscope images from all materials are shown in Fig. 3. After annealing process, intermetallic compound distributions in secondary phases are observed more apparently. This caused the material to reshape and grow in its grains as shown in Fig. 3b. In addition, the material became more homogeneous. Figure 3c and 3d illustrates optic images of ECAPed and ECAP plus aging processed samples. These processes leads to orientations of microstructures. Also, after these processes precipitations in grain boundaries are increased and the rounded appearance of the secondary phase materials has diminished and shrunk. By this way, hardness of material is increased.

SEM images are given in Fig. 4. For as received form of AA2024 grains are spread out randomly and dimensions of grains became bigger as shown in Fig. 4a. A general view of matrix is generated. The matrix consists of several secondary phases embedded in α-Al. In addition, the base material has large grain structures. Randomly distributed secondary phases (Al_2Cu) are dissolved because of



(a) AA2024 as Received (b) Annealed AA2024
(c) ECAPed AA2024 (d) ECAPed+Aging Processed

Fig. 3 — Optic microscope images



(a) AA2024 as Received
(b) ECAPed AA2024

Fig. 4 — SEM images of materials

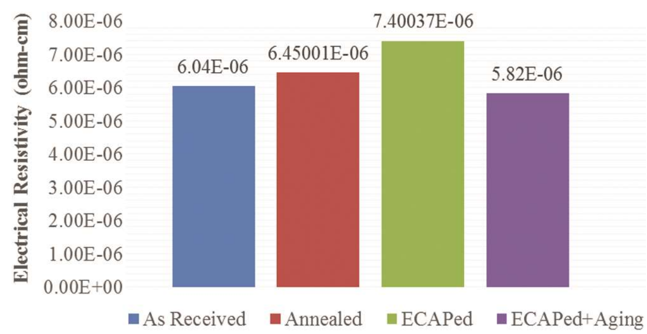


Fig. 5 — Electrical resistivity of specimens

over etching. Same observations are obtained from literature[4,9-10,13-14].

In Fig. 4b, despite the over etching, the matrix has very fine grain structures. Moreover, more homogeneously distributed secondary phases are observed due to severe plastic deformation application[4,9,10,13,14].

Electrical Conductivity

Instead of measuring electrical conductivity, resistivity is evaluated. Since resistivity and conductivity are inversely proportional, conductivities can be compared. As can be seen from Fig. 5, ECAPed plus aging process results highest conductivity because of precipitations of secondary phases as shown in Fig. 3. On the other hand, ECAP process decreases the conductivity more than the other processes and gives the lowest conductivity. Annealing process also decreases the conductivity but not as much as one pass of ECAP process. Results of resistivity are shown in Fig. 5. Same conductivity order is obtained in similar studies as well[19-21].

Conclusion

In this study, four types of specimens are examined in terms of electrical conductivity and hardness parameters. As a result, hardness is decreased by annealing but increased by ECAP process and much more increased by ECAPed plus aging process. Grain boundaries and sizes are the most effective parameter for hardness behaviour of materials. As illustrated from SEM and optic microscope images, ECAP results smaller grain sizes. The results are consistent with microstructure analysis ones. On the other hand, conductivity is ordered from lower to higher as ECAPed plus aging processed, then as received form, after that annealed form and at last ECAPed. The results are consistent with microstructure observations.

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