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Microhardness and Corrosion Resistance of AA1370 Aluminum Wire after Three ECAP-120° Passes

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Abstract: This study contributes to exploring the impact of grain refinement and intermetallic particle fragmentation resulting from the Equal Channel Angular Pressing (ECAP) processing of AA1370 aluminum alloy wire. The samples underwent progressive deformation to three passes in the ECAP, with an intersection angle of Φ=120° and a curvature radius of Ψ=0°, following route A, at room temperature. Microstructural analysis was carried out using optical microscopy and scanning electron microscopy (SEM) before and after ECAP deformation. X-ray diffraction (XRD) analysis was conducted to examine texture and morphology. Corrosion behavior was assessed using open circuit potential (OCP) and polarization techniques before and after ECAP. Penetration resistance was studied using a microhardness tester. The results of the study indicate that intermetallic particle fragmentation and reduction in crystallite size are observed as early as the first pass. However, microhardness only increased after the third pass. Additionally, deformation caused by the ECAP process results in an increase in OCP values and shifts the corrosion potential towards less negative values.

Keywords: ECAP deformation, Aluminum wire AA1370, Corrosion, Hardness, Intermetallic particles

Introduction

The effect of ECAP (Equal Channel Angular Pressing) deformation on structurally hardening aluminum alloys is influenced by various factors and can have contradictory consequences on sample hardness and corrosion resistance. Understanding these complex mechanisms is essential for optimizing the properties of aluminum alloys and their performance in various applications (Lowe & Valiev, 2000; Valiev & Langdon, 2006, 1993).

During ECAP processing, the induced shear stress can impact sample hardness through modifications in the microstructure. This includes the fragmentation of intermetallic particles, dissolution, and/or precipitation of precipitates. These microstructural changes depend on several factors, such as the deformation rate (Chegini et al., 2015; Damavandi et al., 2019; Youcef Hadj Ali et al., 2021), deformation temperature, number of passes, deformation angle, and alloy composition (Nurislamova et al., 2008).

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Regarding the effect of ECAP deformation on the corrosion resistance of aluminum alloys, research results are variable. Some studies have suggested that grain refinement and increased dislocation density, resulting in a more homogeneous microstructure with fewer impurities and defects, can improve the corrosion resistance of different alloys (Abd El Aal & Sadawy, 2015; Divya et al., 2018). However, other research has found that while grain refinement can enhance the mechanical properties of alloys, it does not necessarily contribute to increased corrosion resistance (Gravina et al., 2017). Additionally, it has been observed that grain refinement through severe plastic deformation can lead to the formation of shear bands, which become preferential sites for localized corrosion such as pitting. Similarly, segregation of intermetallic particles can also result in intergranular corrosion, reducing corrosion resistance (Gravina et al., 2017; Ly et al., 2018). The figure represents the microstructure of the sample that has undergone one pass of deformation. The microstructure obtained reveals that the size and density of the intermetallic particles have decreased because of deformation.

Experimental procedure

The extruded samples are obtained from an aluminum wire of AA1370 grade, which has a diameter of 2 mm and commercial purity. Its chemical composition is represented in Table 1.

Table 1. The chemical composition of AA 1370 aluminum wire

Al %	Fe %max	Si %max	Cu %max	Zn %max	Ti %max	V %max	Ga %max	Mg %max	Mn %max	Cr %max	B %max
99.70	0.25	0.10	0.020	0.040	0.020	0.020	0.030	0.020	0.010	0.010	0.020

A mild steel, which is harder than the aluminum samples, is used to manufacture the ECAP die and compression piston. The die consists of two cylindrical channels with a diameter of 3 mm, forming an intersection angle of Φ=120° and a curvature radius of Ψ=0°. The specific details of the ECAP die are provided in Figure 1. The samples, cut for the extrusion of the aluminum wire, have a length of 20 mm.

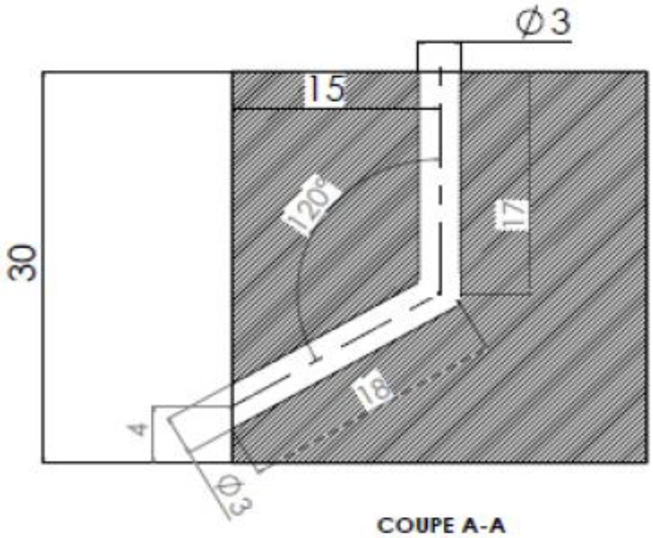

Figure 1. Parameters of the ECAP extrusion die

The studied surface is the cross-section of the AA1370 aluminum wire (sample P0) and the extruded samples, 1P120, 2P120, and 3P120, corresponding to the first, second, and third pass, respectively. The samples were cold-mounted, mechanically polished with abrasive paper of 2400 and 4000 grit, and then polished with OP-S (colloidal silica suspension) with a maximum particle size of 3 µm.

For the microstructural analysis, an optical microscope (OM) was used with a magnification of up to 5000X. A microhardness tester was employed to monitor the evolution of microhardness as a function of the number of passes. X-ray diffraction (XRD) was used to detect the diffraction peaks of aluminum, structural changes, and different phases after deformation. The study concluded with an analysis of corrosion behavior and morphology.

The potential was monitored for 48 hours of immersion in a 3% NaCl sodium chloride solution (by weight), using an Ag/AgCl reference electrode at room temperature. The polarization test was carried out under the same conditions after 24 hours of immersion, using two graphite auxiliary electrodes.

Results and Discussions

The microstructure in Figure 2. (P0) shows an aluminum matrix with the presence of two types of intermetallic particles, distributed heterogeneously and varying in size. SEM observations and EDS analyses confirm the microscopic observations and the presence of intermetallic particles in gray and light colors, with globular and/or irregular shapes and a heterogeneous distribution. The light-colored particles are rich in iron, whereas the dark-colored particles are rich in silicon.

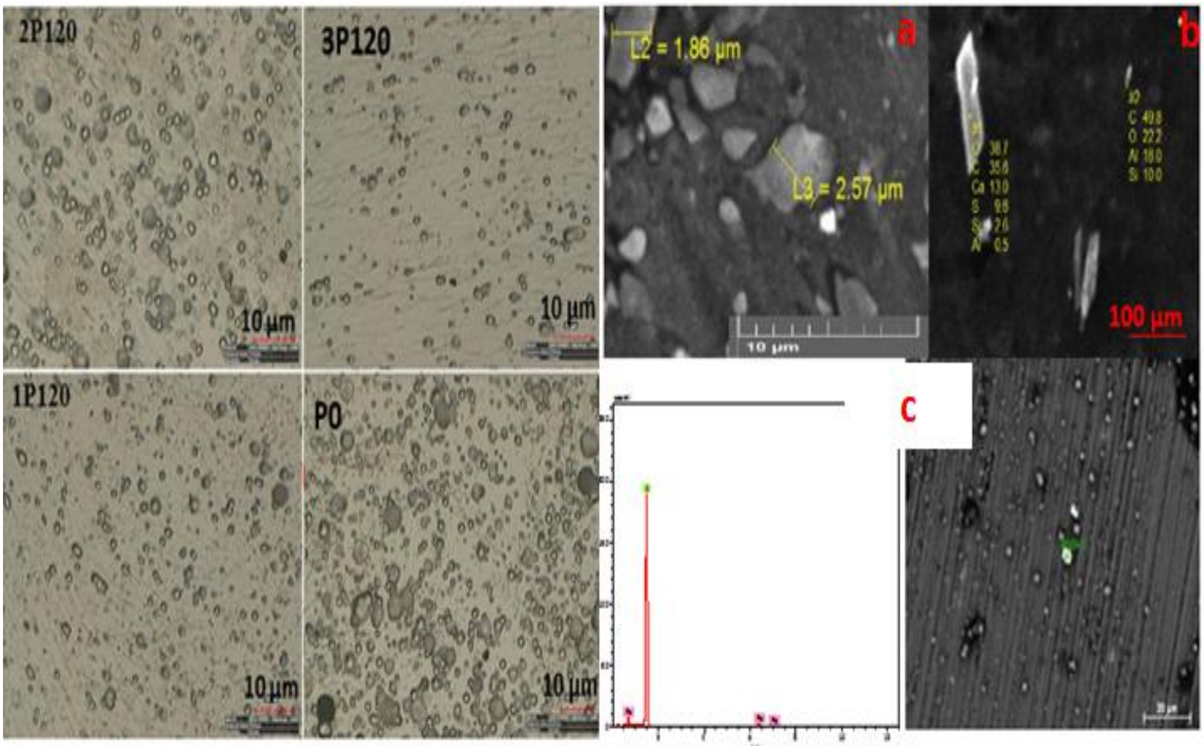

Figure 2. The microstructure before and after ECAP deformation

The figure shows that after the first pass, the intermetallic particles underwent fragmentation, resulting in reduced size and density. This fragmentation and shearing of the particles was further observed during the second pass. The third pass led to a decrease in the density of intermetallic particles. The results are in good agreement with the work of Gravina et al. (2017, 2018).

Figure 2. (1P120), represents the microstructure of the sample that has undergone one pass of deformation. The obtained microstructure reveals that the size and density of the intermetallic particles have decreased due to the effect of deformation. After the second and third passes of deformation, the intermetallic particles undergo further fragmentation, a reduction in density, and a preferential alignment in the direction of deformation figure 2. (2P120) and (3P120).

X-ray diffraction (XRD) analyses reveal the emergence of a new texture after the first deformation pass. A comparison of the diffraction spectra between the deformed and undeformed samples, using the ICDD for pure aluminum, shows the absence of peaks and a decrease in the intensity of existing peaks. X-ray diffraction (XRD) analyses reveal a structure with binary and ternary phases, rich in iron, aluminum, and silicon for the undeformed sample. After the first pass, a new iron phase appears under the crystallographic planes (111) and (200) (Figure 3).

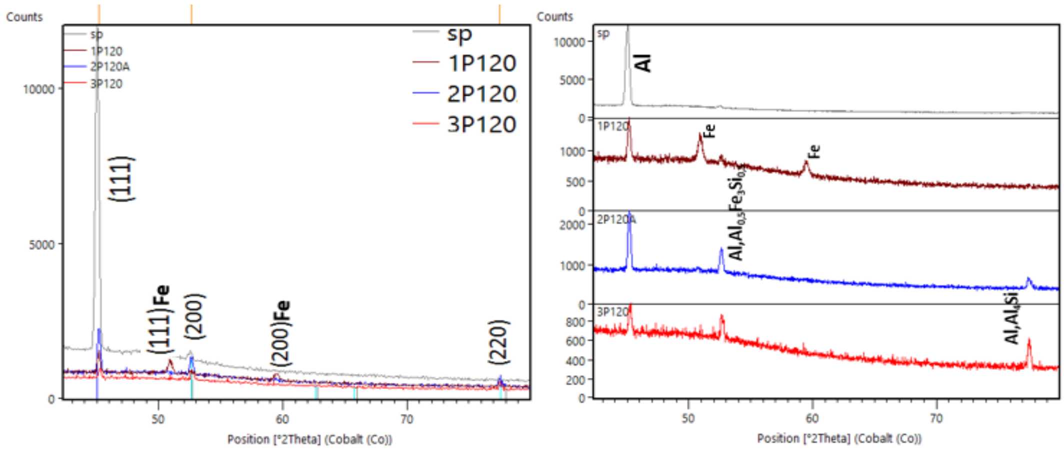

Figure 3. Comparison between the X-ray diffraction patterns of the AA1370 aluminum wire before and after deformation and phase identifications

The evolution of microhardness shows a non-linear trend throughout the different deformation stages. It decreases slightly after the first and second passes, followed by an increase after a third additional deformation. This initial decrease in microhardness could be related to a temporary softening due to local grain restructuring and partial annihilation of dislocations. The subsequent increase in hardness coincides with the reappearance of certain aluminum peaks in the diffractogram, particularly the (220) peak, suggesting a reorganization of the crystals and a new accumulation of defects in the crystal lattice. This microstructuring promotes hardening through dislocation density increase (Figure 4).

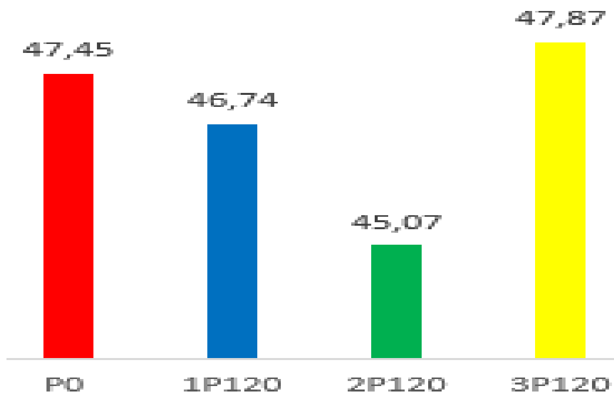

Figure 4. Comparison of microhardness between the undeformed sample and samples deformed with one, two, and three passes

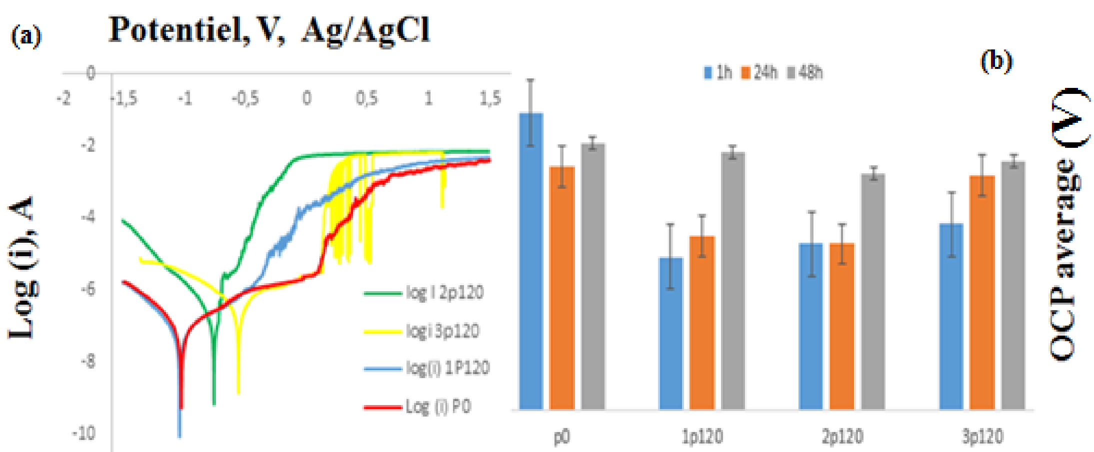

Figure 5. Electrochemical results. (a) Polarization curves and (b) OCP average, for the undeformed sample and samples deformed with one, two, and three passes

The evolution of electrochemical properties as a function of the number of deformation passes is presented in the attached figure. The polarization curves (a) and the open circuit potential (OCP) diagrams (b) reveal a general trend of improved corrosion resistance with increasing deformation. The corrosion potential (Ecorr) becomes less negative, evolving with the increasing number of deformation passes. This evolution indicates a decrease in electrochemical activity, possibly linked to the progressive passivation of the surface. The average OCP follows the same trend, with less negative potentials as the number of passes increases. However, the increase in current density indicates an acceleration of corrosion processes, which limits the overall improvement in corrosion resistance despite the apparently more effective passivation. This improvement can be attributed to microstructural modifications such as grain size reduction, redistribution of intergranular phases, fragmentation of secondary particles, or a reduction in surface roughness.

Conclusion

The ECAP process induces significant microstructural and property changes in aluminum alloys. Fragmentation and alignment of intermetallic particles occur progressively with each deformation pass, contributing to a refined microstructure. XRD analysis confirms texture evolution and the emergence of new iron-rich phases after the first pass. Microhardness follows a nonlinear trend, with an initial decrease likely due to local softening, followed by an increase after the third pass, associated with dislocation accumulation and crystal reorganization.

Electrochemical measurements show improved corrosion resistance through enhanced passivation, reflected by less negative OCP and Ecorr values. However, increased corrosion current density suggests a trade-off between passivation and corrosion kinetics. Overall, optimizing the number of ECAP passes is key to achieving a balance between mechanical strengthening and corrosion resistance.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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