IMPEDANCE TOMOGRAPHY AND CONDUCTIVITY STRATIFICATION OF COLD ROLLED RECRYSTALLICED ALUMINUM ALLOY

C. Gonzalez, F. Fraudita, Audry Gallipoli.
Facultad de Ingeniería, Universidad Central de Venezuela, Caracas, Venezuela
E-MAIL: dejgonzalez@cantv.net; frauditafa@gmail.com; audryevelingn@yahoo.com

Abstract

Cold rolled Al-3003 H14 aluminum alloy is recrystallized from 0% to 100% in order to establish the conductivity profile developed by means of an impedance tomography procedure. Numerical solution for direct and inverse problem for axial symmetry is implemented with appropriate boundary conditions, in order to simulate possible situations and judge sensitivity to conductivity contrast as depth increases. Conductivity obtained varies from 1 to 10% relative to initial conductivity (0% recrystallization). A bilateral symmetry profile is expected, with variations of the conductivity from half plane to surface of laminated samples. Macroscopic (average or bulk) conductivity increases with recrystallization, but the conductivity profile indicates that near surface conductivity, contributes more than internal conductivity, to macroscopic conductivity. Results are found consistent with conventional macroscopic conductivity measurements, obtained by means of the four wires method.

Key words: Layered electrical conductivity; stratified electrical conductivity.

Introduction

Impedance tomography [1] is based in the solution of the inverse problem related to equation (1)

$$\vec{\nabla}\cdot\left(\sigma\vec{\nabla}\varphi\right) = -\frac{\partial\rho}{\partial t} \qquad (1)$$

Where σ is the electric conductivity, φ is the electric potential and ρ the charge density.

For flat rolled products, bilateral and translational symmetry should be expected. Current pin electrodes are placed one in front of the other, at both sides of a plate and far from edges. Let us suppose that electric fields in the material have axial symmetry, around the normal to surface axis where electrodes are located. In this case, equation 1 takes the form

$$\frac{\partial\sigma}{\partial z}\frac{\partial\varphi}{\partial z} + \sigma\left(\frac{1}{r}\frac{\partial\varphi}{\partial r} + \frac{\partial^2\varphi}{\partial r^2}\right) + \sigma\frac{\partial^2\varphi}{\partial z^2} = -\frac{\partial\rho}{\partial t} \qquad (2)$$

Equation 2 for finite differences is

$$\left(\sigma_{i+1} - \sigma_{i-1}\right)\left(\varphi_{i+1,j} - \varphi_{i-1,j}\right) + 4\sigma_i\left(\frac{\varphi_{i+1,j} - \varphi_{i-1,j}}{2j} + \varphi_{i,j+1} - 2\varphi_{i,j} + \varphi_{i,j-1}\right) +$$
$$4\sigma_i\left(\varphi_{i+1,j} - 2\varphi_{i,j} + \varphi_{i-1,j}\right) = -\frac{4I}{h}\sum_{i_0,j_0}\delta\left(i - i_0, j - j_0\right) \qquad (3)$$

Where I is the source current intensity applied to current electrodes, h is the cell parameter, i_0, j_0 are current electrodes position indexes and δ is the delta Dirac function.
The inverse problem to be solved is the recovery of i^{th} layer conductivity from electrodes current and surface potential measurements.

Experiment

Current source up to 1.0 A was applied to current electrodes in a plate 3mm thick. Sample material used was Al-3003 H14 subjected to cold rolling followed by progressive recrystallization, with known electrical and mechanical macroscopic properties [2]. Potential electrodes were located in the radial direction with spacing of the order of one tenth of plate thickness. Figure 1 shows the experimental outline.

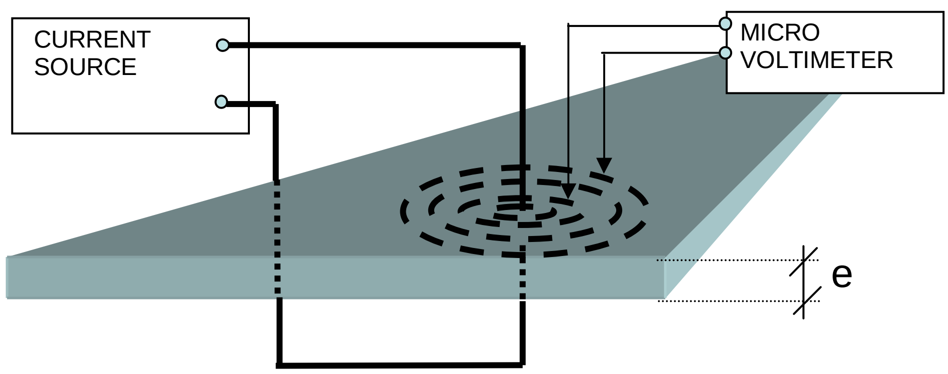

Fig. 1 Experimental array for measurement of surface potentials from 0.1 mm to 2.0 mm with stepping of 0.1 mm. Specimen thickness e=2.15 mm.

Results and discussion

Figure 2 indicate bulk conductivity as a function of recrystallization for the test samples. Inversion algorithm results are show in figure 3 where surface and internal conductivity is plotted as a function of recrystallization. Direct solution simulations indicate that DC measurements are not sensitive enough to develop conductivity contrast toward the half thickness of the plate. A sharp difference between surface and bulk conductivity is recovered in the inversion procedure. Integration of the resistivity profile is in good agreement with bulk resistivity measured with the DC four points method [3]. Solving the direct problem for prescribed conductivity profiles indicates that for a two-layer model of arbitrary thickness, surface potential are representative of average conductivity for each layer.

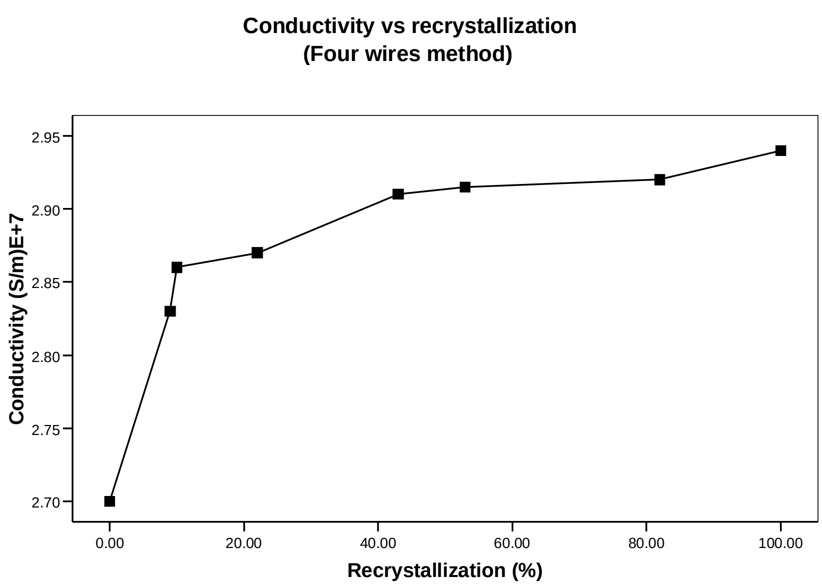

Fig. 2 Macroscopic or bulk DC conductivity as a function of recrystallization. Material AA3003 H14 cold worked and recrystallized.

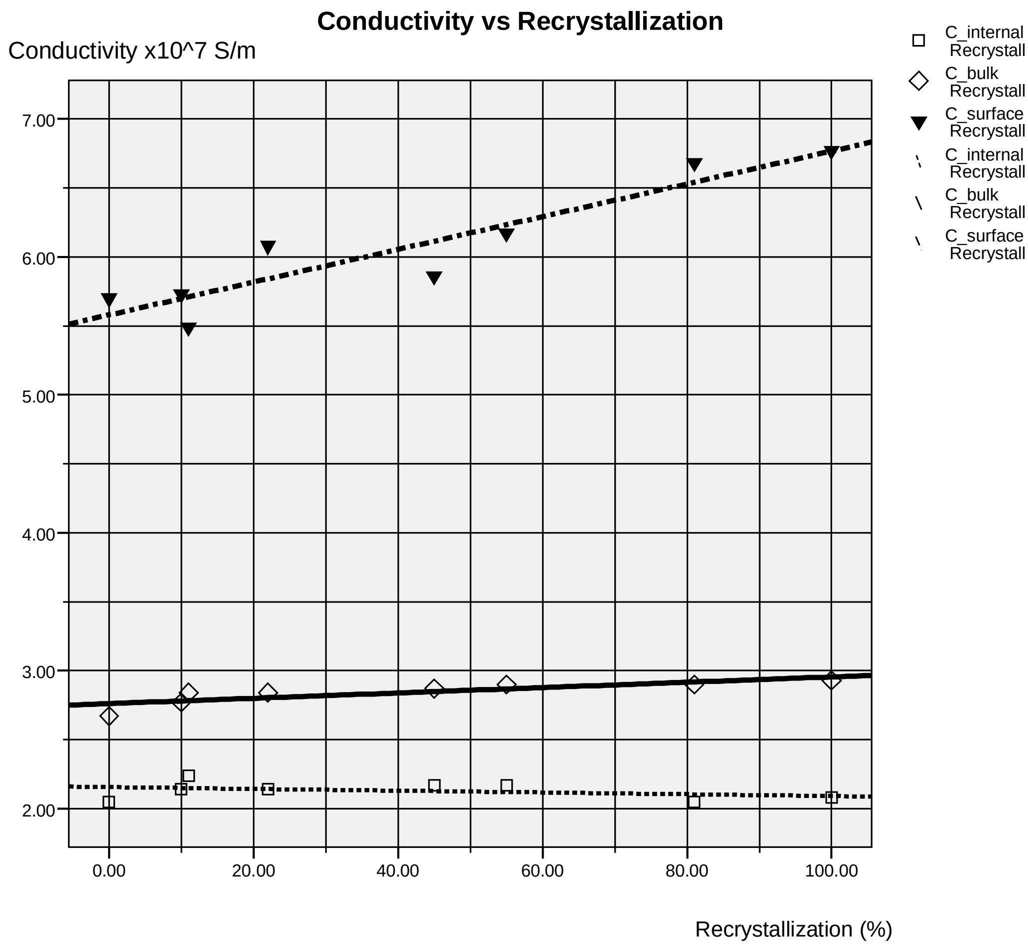

Fig. 3 Conductivity vs. recrystallization for bulk (macroscopic), surface and internal conductivity. Bulk resistivity is in good agreement with the weighted average of resistivity, obtained by integration of resistivity in the cross section of the sample. Surface layer is t/11 where t is the plate thickness.

Contact AC methods as well as inductive method have been proposed for the recovery of shape and conductivity profile in multilayered materials [4]. The result of this work indicates that a DC method allows discrimination between surface and subsurface conductivity.

Conclusions

- A simple procedure for recovering conductivity contrast between bulk and surface conductivity have been developed and applied to cold rolled plates subjected to progressive recrystallization.
- Conductivity changes obtained for the material and processing used, are due mainly to surface conductivity contribution.
- Inversion procedure is very sensitive to near surface layers and decreases rapidly towards the center of the plate.

References

[1] Borcea, L., *Electrical Impedance Tomography*, Inverse Problems, 18, No. 6, 2002, pp. R99-R136.

[2] Gallipoli Audry. *Cambio de Resistividad en la Aleación comercial de Aluminio 3003 H14 Durante la Recristalización,* Thesis, Facultad de Ingeniería Universidad Central de Venezuela, March 2004.

[3] ASTM International: *Standard test methods for resistivity of electrical conductor materials*. Designation: B 193-02.

[4] Zorgati R. , Duchne B., Lesselier D. y Ponds F. *Eddy Current testing of anomalies in conductive materials, Part I: quantitative imaging via diffraction tomography*; en: IEEE Transactions on Magnetics, Vol 27, No 6. 1991.

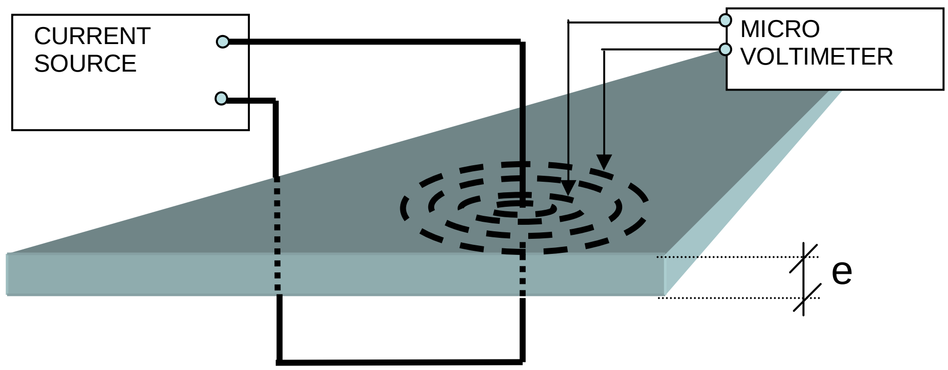

Fig. 1 Experimental array for measurement of surface potentials from 0.1 mm to 2.0 mm with stepping of 0.1 mm. Specimen thickness e=2.15 mm.

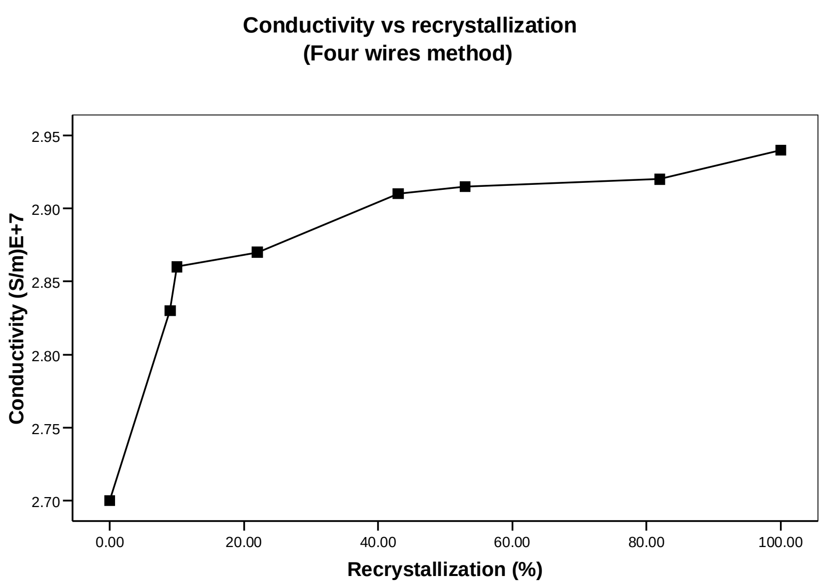

Fig. 2 Macroscopic or bulk DC conductivity as a function of recrystallization. Material AA3003 H14 cold worked and recrystallized.

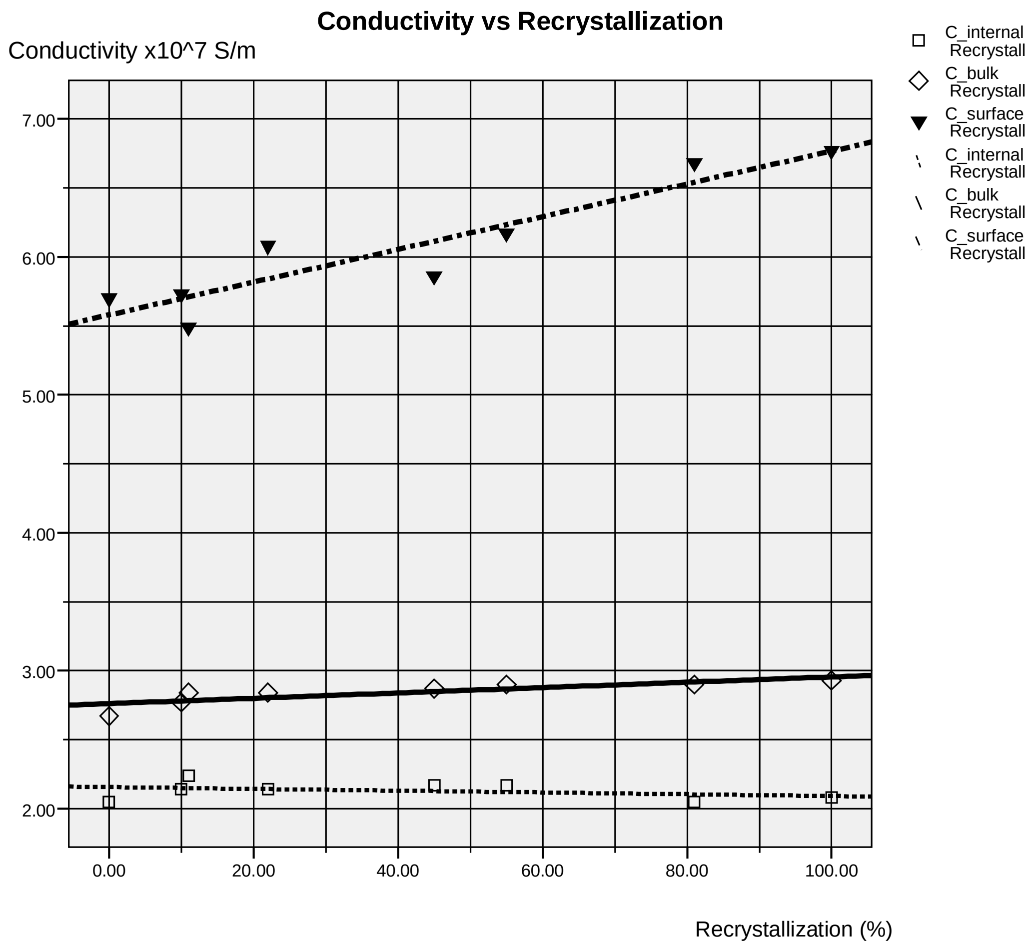

Fig. 3 Conductivity vs. recrystallization for bulk (macroscopic), surface and internal conductivity. Bulk resistivity is in good agreement with the weighted average of resistivity, obtained by integration of resistivity in the cross section of the sample. Surface layer is t/11 where t is the plate thickness.