11th International Conference on Advanced Materials

ICAM 2009

Rio de Janeiro Brazil
September 20 - 25

Ultrasound as a Probe of Plasticity? Resonant Acoustic Spectroscopy Measurements with Aluminum

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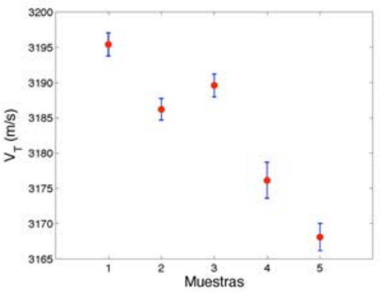
Dislocations in a material will, when present in enough numbers, change the speed of propagation of elastic waves. Consequently, two material samples, differing only in dislocation density, will have different elastic constants, a quantity that can be measured using Resonant Ultrasound Spectroscopy (RUS). Measurements of this effect on aluminum samples are reported. They compare well with the predictions of the theory.

Resonant Ultrasound Spectroscopy allows precise measurements of the elastic constants of a sample independent of its symmetries. An homogeneous and isotropic material is characterized by two independent elastic constants, λ and μ, or equivalently $C_{11} = \rho v_L^2$ and $C_{44} = \rho v_T^2$ RUS is known to give more precise measurements of C_{44} than for C_{11}, and therefore a comparison with the theoretical prediction for v_T is possible. We have used commercially 1100 pure aluminum. From the same bar, five samples were taken to prepare the studied conditions classified as original, annealed and laminated material: two samples were annealed at 400 °C, one for 5 hours and another for 10 hours. Other two were cold-rolled, one at 33% and another at 43%. Longer annealing means lower dislocation density, and stronger cold-rolling means higher dislocation density. The five samples were shaped as rectangular parallelepipeds. Opposite sides are parallel within 0.06° and adjacent sides are orthogonal within 0.3°, thus our samples can be safely modeled as perfect rectangular parallelepipeds.



A RUS apparatus was built in-house [2, 3], and used to measure the two elastic constants of the five samples. The sample-apparatus contact force is small, of the order of 0.1 N, which corresponds to about the half of the sample weight Mg ≈ 0:22 N. Each resonant frequency is measured for several ultrasonic driving amplitudes (typically five) in order to verify that the resonances are well in the linear acoustic regime. Additionally, each sample is placed five times in the apparatus in order to reduce errors due to slight dependence of the resonant frequencies on the contact load and positioning with respect to the ultrasonic receiver.

The figure shows the measured v_T for the five samples, plotted in order of increasing dislocation density. The trend is as predicted by theory, and consistent with a difference in dislocation density of about 10^8 mm^{-2}, a conclusion that it should be possible to verify by direct measurement with HRTEM.

References

[1] F. Barra et al., “Measuring Dislocation Density in Aluminum with Resonant Ultrasound Spectroscopy”, to appear.
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[3] A. Jara, “Caracterización Acústica de Diferentes Muestras de Aluminio" (2007, unpublished).