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Ultrasonic pole figure for the texture of aluminum alloy

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An approximate method is proposed to calculate the pole figure diagrams based on the elastic anisotropy measured by ultrasonic velocity experiments. An example is taken from the surface texture of rolled plates of aluminum alloy 7075-T651, for which the angular dependence of the Rayleigh wave is measured in the rolling plane and analyzed to obtain the expansion coefficients of orientation distribution function. The ultrasonic pole figures are favorably compared with the conventional x-ray pole figures, both demonstrating a single texture centered over (001)[110] orientation.

When a polycrystalline metal plastically deforms, the crystallites are rotated with the crystal slip and their certain crystallographic orientation tends to be partially aligned depending on the flow geometry and magnitude. This partial alignment is called preferred orientation or texture. Most polycrystalline materials as a whole exhibit weak elastic anisotropy due to the texture. The relationship between the texture and the elastic anisotropy has been established by introducing the orientation distribution function (ODF) which gives the probability of crystallite orientation with respect to the sample axes.[1] The texture slightly modifies the second-order elastic constants through three independent ODF coefficients, w_{4m0} ($m = 0, 2, 4$), in the case of cubic metals. Therefore, it is now possible to infer the texture from the measurements of anisotropy in the ultrasonic velocities.[2,3] The ultrasonic method is basically incapable of such detailed texture characterization as the x-ray and neutron diffraction methods can do, but it makes a nondestructive and easy inspection possible.

This letter focuses on the surface texture of rolled plates of aluminum alloy 7075-T651. The surface texture can be most conveniently examined using the Rayleigh wave, which penetrates into the depth about a wavelength from the surface. Sayers[4] and Delsanto et al.[5,6] derived the formula relating the propagation velocity V_r and the ODF coefficients in the first-order approximation. When the Rayleigh wave propagates at an angle θ to the rolling direction in the plate surface, V_r varies as

$$V_r(\theta) - V_{ro} = \frac{c}{\rho V_{ro}} (r_0 w_{400} + r_2 w_{420} \cos 2\theta$$
$$+ r_4 w_{440} \cos 4\theta), \qquad (1)$$

where V_{ro} is the velocity in the isotropic case ($w_{4m0} = 0$), ρ the density, and c the anisotropy factor of the crystal. The coefficients r_i depend only on the Poisson ratio: for aluminum, $r_0 = -1.29$, $r_2 = 2.45$, and $r_4 = 0.39$. It is seen then that the cos 2θ term has the largest influence on the variation of V_r. This is the case for most solids.

A sing-around experiment was conducted for V_r's angular variation. Both ends of an acrylic bar were cut to the critical angle for the Rayleigh wave generation and detection, where two piezoelectric transducers (PZT's) were mounted. The center frequency was 5 MHz and the gauge distance was 131 mm. The bar was rotated around its center at every 5° by a stepping motor operated with a personal computer, which was also used for data acquisition and calculation. Four test plates are sized 200×300 mm^2 and of thickness ranging from 25.5 to 12.7 mm (TP 71 to 74).

Typical results of the measurements are shown in Fig. 1 for a quadrant of each plate. All the data were analyzed to obtain the coefficients of constant, cos 2θ, and cos 4θ components. The curve, which is reconstructed using these three components, is drawn in the figure together with the experimental results. The good agreement with the plots indicates that the measured angular variation of V_r can be well interpreted with formula (1). The ODF's coefficients are then determined from the Fourier coefficients as $w_{420} = -0.0010$ and $w_{440} = -0.0051$ for TP 71. These values were reproducible within 0.00011 for w_{420} and 0.00055 for w_{440}.

We need w_{400} and the higher order coefficients of ODF to calculate the pole figures, but they cannot be determined from the ultrasonic experiments.[1-3] We here propose a procedure for approximating w_{400} and the higher order coefficients, which is applicable for a single texture. The previous work[2] revealed that the surface texture of 7075-T651 aluminum rolled plates is best described by an ideal orientation, (001)[110]. The delta-function representation of ODF[7] for (001)[110] texture gives

$$w_{400} = 0.0313, \quad w_{420} = 0, \quad w_{440} = -0.0184, \quad \text{and}$$
$$w_{600} = 0.0081, \quad w_{620} = 0, \quad w_{640} = 0.0151, \quad w_{660} = 0 . (2)$$
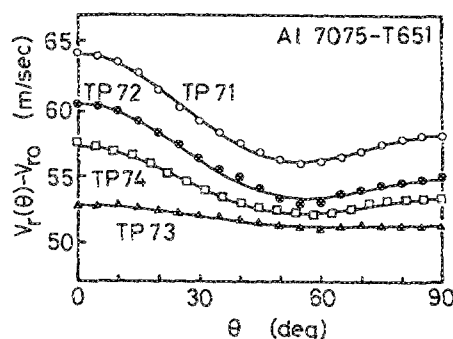

FIG. 1. Raw data and fitted curves for angular dependence of Rayleigh wave velocity for rolled aluminum alloy 7075-T651. Angle θ is measured from the rolling direction.
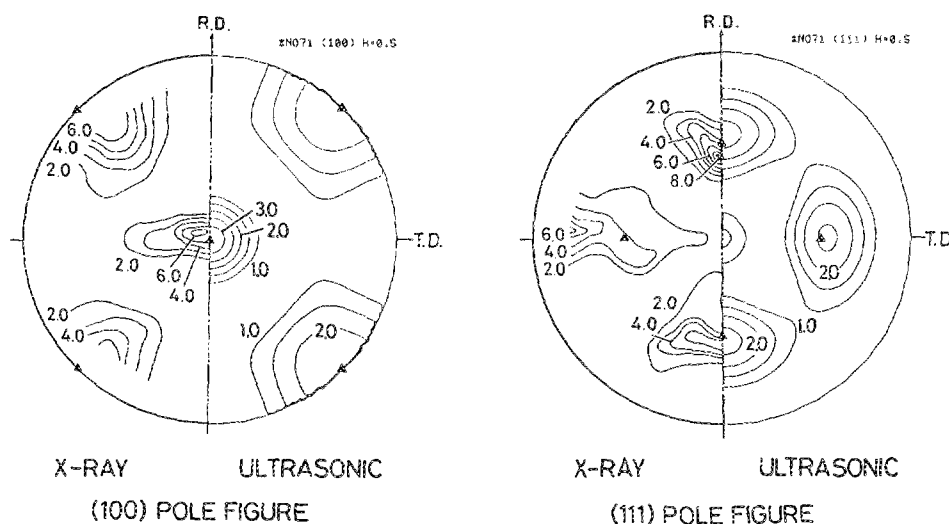
FIG. 2. Comparison of ultrasonic pole figures to x-ray pole figures (TP 71). ▲, (001)[110]. The ultrasonic pole figures [$4\pi q(\zeta,\eta)$ of Eq. (3)] involve terms with the fourth- and sixth-order ODF coefficients.

X-RAY   ULTRASONIC

(100) POLE FIGURE

X-RAY   ULTRASONIC

(111) POLE FIGURE

These ODF coefficients apply exactly to the polycrystalline metals with all the crystallites aligned in (001)[110] orientation. We assume that the ratio of measured w_{440} to thus determined w_{440} indicates the "intensity" of that texture. By multiplying the w's in Eq. (2) with this intensity, we may obtain the approximation for the ODF coefficients that cannot be measured using ultrasonics. They are $w_{400} = 0.0094$, $w_{600} = 0.0024$, $w_{640} = 0.0045$, and $w_{620} = w_{660} = 0$ for TP 71, for example. The ultrasonic pole figure is calculated by substituting them in addition to measured w_{420} and w_{440} into

$$q(\zeta,\eta) = 1/4\pi + S_4[P_4^0(\zeta)w_{400} + P_4^2(\zeta)w_{420}\cos 2\eta + P_4^4(\zeta)w_{440}\cos 4\eta]$$

$$+ S_6[P_6^0(\zeta)w_{600} + P_6^2(\zeta)w_{620}\cos 2\eta + P_6^4(\zeta)w_{640}\cos 4\eta + P_6^6(\zeta)w_{660}\cos 6\eta].$$ (3)

where $P_l^m(\zeta)$ denotes the normalized associated Legendre function of $\zeta = \cos\chi$, χ and η being, respectively, the polar and azimuthal angles with respect to the samples axes. w_{420} is zero in Eq. (2) but we use the measured w_{420} in Eq. (3). The factors S_4 and S_6 take the following values:

$S_4 = S_6 = 2\pi$ for (100) pole figure

$S_4 = -\pi/2$ and $S_6 = -13\pi/4$ for (110) pole figure

$S_4 = -4\pi/3$ and $S_6 = 32\pi/9$ for (111) pole figure.

In Fig. 2 the (100) and (111) ultrasonic pole figures are compared with those measured by the x-ray diffractometer (Schulz reflection method). Favorable correspondence suggests that the ultrasonic pole figure would be a useful texture indicator.

The angular variation of the surface skimming SH wave has been separately measured with the same test plates for evaluating w_{440}.[2] The experiments were made using 2 MHz PZT elements. The difference of w_{440} measured by Rayleigh wave and by SH wave is not negligible, but as small as that observed by Clark et al.[8] or less. We also found that this difference tends to increase as the plate thickness decreases so far as the four plates used are concerned. This observation suggests that the texture inhomogeneity through thickness would be the major cause of the difference in the values of w_{440}.

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