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EVALUATING CRYSTAL ORIENTATION IN NI BASED ALLOY SAMPLES USING ULTRASONIC PHASED ARRAY

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ABSTRACT

In order to study the non-destructive evaluation method of crystal orientation in metal materials, the surface of ultrasonic velocity varying with propagation angle was obtained according to the Christoffel equation of anisotropic elastic wave. The delay curve of wave front received by the phased array transducer after interface refraction was then obtained. Ni-based single crystal material was selected and samples with different crystal orientation were cut. An immersion and penetrating phased array device was used to collect the ultrasonic signals. Experimental data were fitted with spherical harmonic(SH) function. The relationship between the coefficients of the SH function and the Euler angles of the crystal orientation was established by Wigner-D function. The complete Euler angles of the samples were obtained and compared with the results of the destructive EBSD. The deviation of the crystal orientation obtained by this method was less than 20° .

Keywords: crystal orientation, anisotropy, Ultrasonic Phased Array, spherical harmonic

NOMENCLATURE

(α, β, γ)	Euler angle
$\boldsymbol{r}(\theta, \phi)$	wave propagation vector defined with polar and azimuth angles in sample system
$\boldsymbol{R}(\Theta, \Phi)$	wave propagation vector defined with polar and azimuth angles in crystal system
$\boldsymbol{c}_{ij}$	elastic stiffness of single crystal
$\boldsymbol{\Gamma}_{\mathrm{ij}}$	Christoffel tensor
ρ	density
v	ultrasound velocity
T	time delay of wave front

1. INTRODUCTION

The anisotropy of crystals in metal materials can significantly affects the mechanical properties such as the strength. However the currently used methods for crystal orientation detection including X-ray diffraction, neutron diffraction and electron backscatter diffraction are all destructive to the sample, and only able to measure in a very small range or the surface of the sample, which is not suitable for engineering application. The experimental facilities required for these method are also expansive. Hence it's necessary to study a nondestructive and more efficient method for the detection of crystal orientation in metal materials.

2. MATERIALS AND METHODS

Ni-based single crystal material was selected and samples with different crystal orientation were prepared.

Ultrasound velocity of single crystal was acquired by Christoffel function :

$$v_i = \sqrt{\Lambda_i(\boldsymbol{\Gamma}(\boldsymbol{c}_{ij}, \boldsymbol{r}))/\rho} \quad (1)$$

The propagation vector in crystal system was transformed form the sample system by Euler Matrix with z-x-z order:

$$\boldsymbol{R} = \boldsymbol{M}(\alpha, \beta, \gamma)\boldsymbol{r} \quad (2)$$

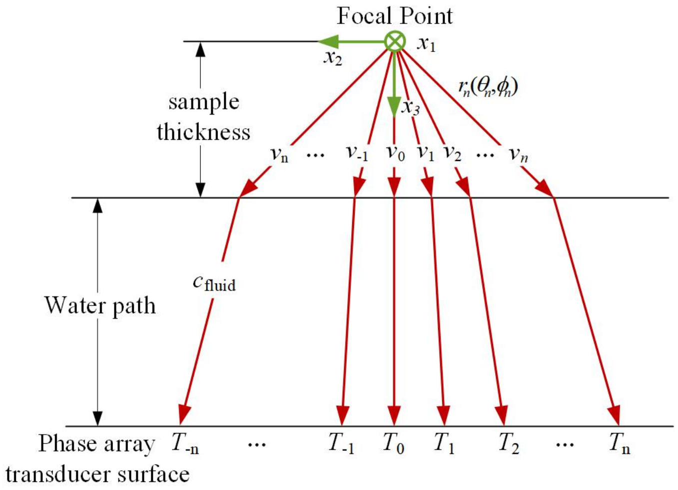

FIGURE 1: Wave front received by phased array transducer

3. RESULTS AND DISCUSSION

We built a data acquisition system includes M2M Multi2000 phased array ultrasonic pulse generator/receiver. The instrument provides hypertronics interface for phased array probe and single probe interface for conventional ultrasound. The water immersion point of Olympus V319 was used for the ultrasonic transmitter. The focal length of the transducer in water was F=39.2684 mm, transducer diameter D=12.7 mm, focal point diameter in water was 0.307 mm. The receiver was Olympus XAIM-0036 phased array probe, with element number n=64, pitch=0.5 mm. The precision of mechanical displacement table is 0.02mm. The sample is placed between the transmitting probe and the receiving probe.

It's worth mentioning that the relative parallelism between the emitter probe, the measured single crystal sample surface and the receiving phased array probe surface was critical for obtaining the precise experimental data. An Angle fine-tuning sample clamp was designed. In addition, in order to avoid the effect of stress on ultrasound velocity measurement, the sample was adhered to one end of the stick rather than clamped.

The Experimental data were fitted with Legendre polynomials in a special case ϕ=0 in this paper:

$$V(\theta)=\sum_{l=0}^{\infty}\left(\frac{2l+1}{2}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} v(\alpha,\beta,\gamma,\theta)P_l(\sin\theta)\cos\theta\mathrm{d}\theta\right)P_l(\sin\theta), \tag{3}$$

$$(\theta\in[-\frac{\pi}{2},\frac{\pi}{2}], l\in \boldsymbol{N})$$

Due to beam deflection, The error of measuring ultrasound velocity with a single probe can be as high as 30%. However the wave velocity in anisotropic material is a curves continuously varying with incident angle. With the help of PA, the rate of change over θ can be measured.

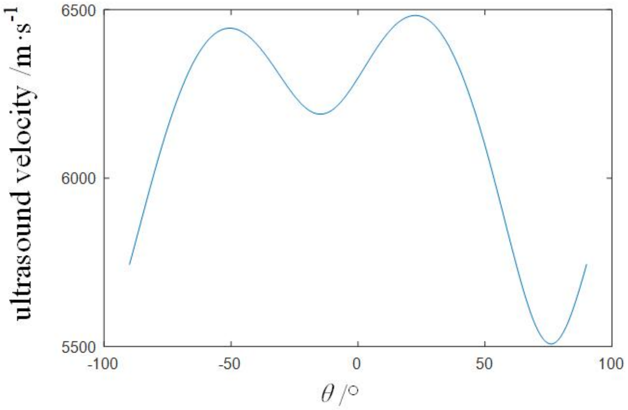

FIGURE 2: the P wave velocity-incident angle curve with α=67, β=38, γ=203 (degree)

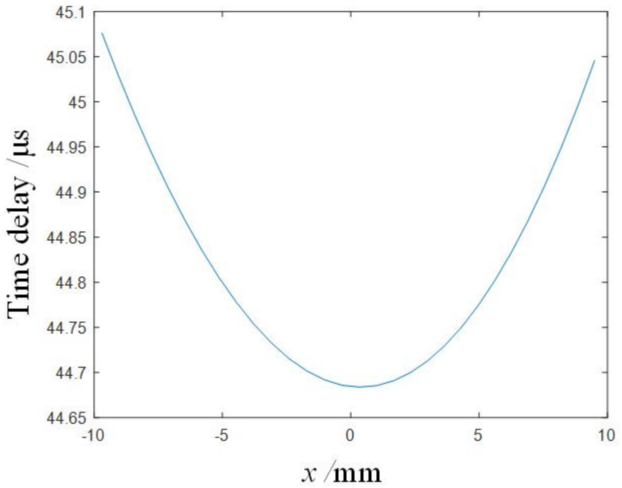

FIGURE 3: the Time delay-PA element position curve with α=67, β=38, γ=203 (degree)

4. CONCLUSION

In this paper, phased array technology was used to collect ultrasonic scattering signals in a wide range, which directly reflects the beam deflection and realized the evaluation of 3 Euler angles. It's a constructive attempt to use non-destructive method as a substitution destructive method to detect crystal orientation.

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