①

NORTHWESTERN UNIVERSITY

DEPARTMENT OF MATERIALS SCIENCE

TECHNICAL REPORT #19
JULY 1985

OFFICE OF NAVAL RESEARCH
CONTRACT # N00014-80-C-116 ①/C

X-RAY ELASTIC CONSTANTS AND THEIR MEANING FOR Aℓ AND Fe

by

Rui Mei Zhong, I. C. Noyan and J. B. Cohen

Distribution of this document is unlimited

Reproduction in whole or in part is permitted for any purpose of the United States Government

EVANSTON, ILLINOIS

X-RAY ELASTIC CONSTANTS AND THEIR MEANING FOR Aℓ AND Fe

Rui Mei Zhong*, I. C. Noyan and J. B. Cohen

Department of Materials Science and Engineering
The Technological Institute
Northwestern University
Evanston, IL 60201

S subscript 1 S subscript 2

INTRODUCTION

d subscript hkl

In the measurement of residual stresses via diffraction (using x-rays or neutrons) it is strains that are actually determined, by employing the interplanar spacing ($d_{hk\ell}$) of the {hkℓ} planes as an internal strain gauge. The change in this spacing is measured from the shift of diffraction peaks (and Bragg's law) at several orientations of the sample to the incident beam, and the resultant strains are converted to stresses with the "diffraction elastic constants", $S_1(hk\ell)$ and $S_2(hk\ell)/2$.[1] While these take on the values ($-\nu/E$) and ($1+\nu)/E$ respectively for an isotropic solid, in anisotropic materials their values depend on many factors: preferred orientation, shape and orientation of second phases, interaction between grains. In fact there are reports of variation these constants with plastic deformation[2] and theory predicts variations with morphology[3]. While it is possible to calculate approximate values for these constants from theory and the single crystal elastic constants[4], S_1 and $S_2/2$ are really not elastic constants in the strictest sense because of these other factors, and it is best to measure them. One of us (I. C. Noyan) has recently examined this problem in some detail[5], and we summarize his results here.

Cont'd DD147

In a measurement of diffraction elastic constants (on a piece of material as identical as possible to the piece whose stress is sought) a series of loads are applied in the elastic range. At each load, the inter-planar spacing is measured vs. $\sin^2\psi$ where ψ is the tilt of the specimen normal from the bisector of the incident and diffracted beams. The slope (β) is obtained at each applied stress, and plotted vs. this stress. The slope of this second plot is related to one of the desired constants:

$$\beta = \sigma^{\circ}_{11}\, S_1[S_{ijk\ell},\, K_i\,(\psi)] + C(\varepsilon^{r}_{ij}) \qquad (1)$$

Here σ°_{11} is the applied stress, $S_{ijk\ell}$ are elastic constants and the K_i are the stress interaction constants between grains, which depends on their orientation, and hence ψ. The term C is a complex function of any residual strain (ε^{r}_{ij}) present in the specimen. It is now well established that

---

* Currently at Beijing Research Institute of Mechanical and Electrical Technology, Beijing, China

there can be oscillations in d vs. $\sin^2\psi$, either due to fluctuations in residual stress[7] or due to preferred orientation and elastic anistropy[6-8]. Even if such fluctuations are present, β obtained by a least-squares fit is linear vs. the applied load[5]. In fact, Eq. 1 can be exploited to establish the cause of these oscillations. If plastic deformation changes only the residual stress distribution and not the texture or second phase morphology, S_1 is unchanged by the process. However, if texture or morphology are altered, S_1 changes. In this paper we discuss two examples of these effects.

EXPERIMENTAL PROCEDURES

Flat tensile specimens were prepared from 1100 Aℓ plate after annealing at 648°K for 2 hrs., followed by reduction in thickness by rolling on a two-high mill, 0.1mm per pass, to 65,82 and 90 pct reduction. Diffraction elastic constants were determined with V filtered CrK_α radiation in the apparatus described in Ref. 9, by applying loads up to 12,000 psi, in 2000 psi increments. The 311 reflection was employed.

RESULTS AND DISCUSSION

Some typical plots of d vs. $\sin^2\psi$ at various loads are shown in Fig. 1; oscillations are apparent. The slopes vs. applied load are given in Fig. 2, and linearly is reasonable. The evaluated elastic constants are summarized in Table I, where they are compared to calculated values. The agreement is quite good and there is no significant variation with deformation and its resultant texture. As Aℓ is nearly isotropic, Eq. 1, predicts that the elastic constants should be that calculated from theory ignoring the K_i because these are zero, and this is what is observed in Table I. The oscillations in 2θ vs. $\sin^2\psi$ are due to local fluctuations in residual stress.[7]

On the other hand for Fe it is known that oscillations occur (in d vs. $\sin^2\psi$), that the β vs. applied load is linear, but that the diffraction elastic constant varies with deformation and do not agree with theory which neglects K_i.[2] Again, this is expected; the variation in preferred orientation with deformation causes changes in the K_i in this case.

It has been suggested that when oscillations occur in 2θ or "d" vs. $\sin^2\psi$, that hoo or hhh reflections will not show this, if anisotropic elasticity is the cause.[6,10] This is only the case in the Reuss limit and without grain interaction which is generally not the case in deformed materials. In fact, there are reported cases where the oscillations do not vanish for hoo or hhh peaks.[7] Also Aℓ is nearly isotropic and yet, as we report here, there are oscillations. The source of these oscillations is local fluctuations in residual stress. In such a case (because the depth of penetration varies with ψ) an average value of stress is of little use,[11] and attempts to eliminate the oscillations by increasing the depth of penetration[12] (changing the wavelength) simply averages over the (important) fluctuations. The tests described here provide a means to decide on the source of the oscillations.

ACKNOWLEDGEMENTS

This research was supported by ONR under Grant No. N00014-80-C116. We thank Paul Rudnik for assistance with the diffraction measurements.

REFERENCES

1. M. E. Hilley, J. A. Larson, C. F. Jactzak and R. E. Rickefs (eds),

"Residual Stress Measurement by X-ray Diffraction", SAE Information Report, J. 784a, (2nd edition), SAE, Inc, New York (1971).

2. R. H. Marion and J. B. Cohen, The Need for Experimentally Determined X-ray Elastic Constants, *Adv. in X-ray Analysis*, 20:355(1977).
3. T. T. Wu, The Effect of Inclusion Shape on the Elastic Moduli of a Two-Phase Material, *Int. J. Solids and Structures*, 2:1(1966).
4. H. Dölle, Influence of Multiaxial Stress States, Stress Gradients and Elastic Anisotropy on the Evaluation of (Residual) Stresses by X-rays, *J. Appl. Cryst.*, 12:489(1979).
5. I. C. Noyan, Determination of the Elastic Constants of Inhomogeneous Materials with X-ray Diffraction, *Mat. Sci & Eng.*, in press.
6. H. Dölle and V. Hauk, Einfluss der Mechanischen Anisotropie des Vielkristalls (Textur)auf die Rontgenographische Spannungser Mittlung, *Z. Metallk.*, 69:410(1978).
7. I. C. Noyan and J. B. Cohen, Determining Stress in the Presence of Nonlinearities in Interplanar Spacing vs. Sin$^2\psi$, *Adv. in X-ray Analysis*, 27:129(1984).
8. R. H. Marion and J. B. Cohen, Anomalies in Measurement of Residual Stress by X-ray Diffraction, *Adv. in X-ray Analysis*, 18:446(1975).
9. K. Perry, I. C. Noyan, P. J. Rudnik and J. B. Cohen, The Measurement of Elastic Constants for the Determination of Stresses by X-rays, *Adv. in X-ray Analysis*, 27:159(1984).
10. H. Dölle and J. B. Cohen, Evaluation of (Residual) Stresses in Textured Cubic Metals, *Met. Trans.*, 11A:831(1980).
11. I. C. Noyan and J. B. Cohen, The Use of Neutrons to Measure Stresses, *Scripta Metall.*, 18:627(1984).
12. V. M. Hauk and G. J. H. Vaessen, Residual Stress Evaluation with X-rays, *Met. Trans.*, 15A:1407(1984).

TABLE I.

DIFFRACTION ELASTIC CONSTANTS FOR 1100 Aℓ .

REDUCTION IN THICKNESS	S2/2 x 10^{-8}	ERROR DUE TO COUNTING STATISTICS x10^{-9} [a]
65 pct	12.76	2.8
81.7 pct	12.60	1.3
90 pct	13.08	1.4
Calculated Value[b]	13.24	———

a. See Ref. 8 for equations to calculate errors due to counting statistics.

b. Average of Reuss and Voight limits.

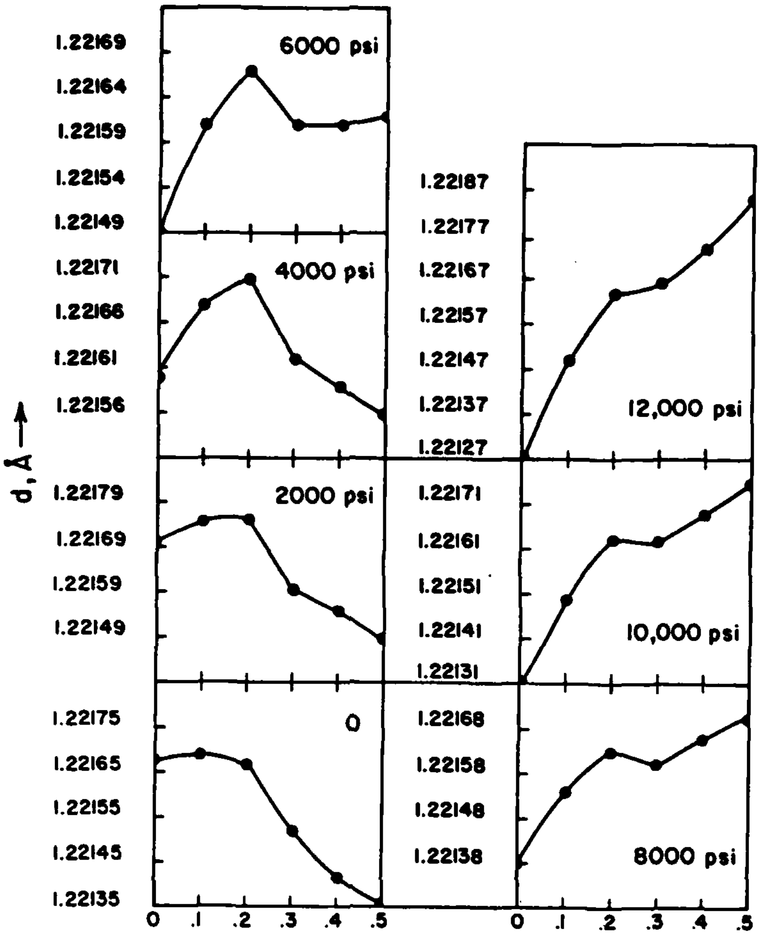

Fig. 1 Interplanar spacing, "d" vs. $\sin^2 \psi$ for 1100 Aℓ reduced in thickness 65pct by cold rolling. Each figure is for the indicated applied load.

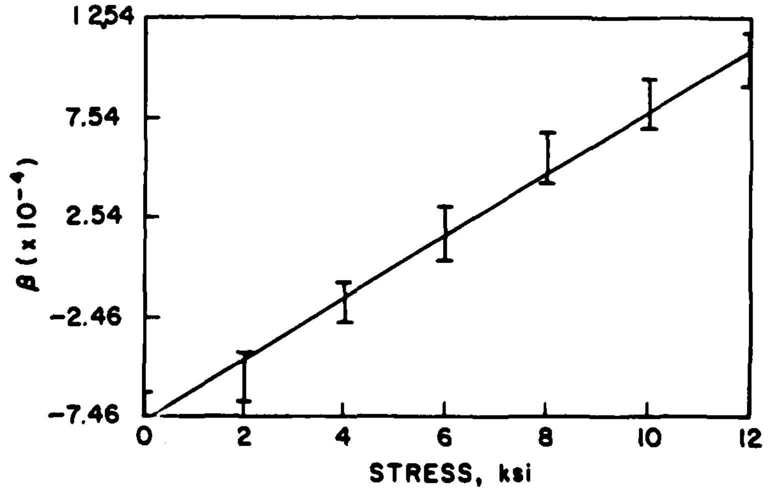

Fig. 2 The constant β in Eq. 1 vs. applied stress. 1100 Aℓ reduced in thickness 81.7 pct by cold rolling.

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* J. B. Cohen Northwestern University Evanston, IL 60201	2a. REPORT SECURITY CLASSIFICATION 2b. GROUP

3. REPORT TITLE

X-RAY ELASTIC CONSTANTS AND THEIR MEANING FOR Al AND Fe

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

TECHNICAL REPORT #19

5. AUTHOR(S) *(First name, middle initial, last name)*

Rui Mei Zhong, I. C. Noyan and J. B. Cohen

6. REPORT DATE July 1985	7a. TOTAL NO. OF PAGES 4	7b. NO. OF REFS

8a. CONTRACT OR GRANT NO. N00014-80-C-116	9a. ORIGINATOR'S REPORT NUMBER(S) 19
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. DISTRIBUTION STATEMENT

Distribution of document is unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Metallurgy Branch Office of Naval Research

13. ABSTRACT

Contd

Sin Squared Psi

It is demonstrated that the diffraction elastic constants for residual stress measurements can be determined even in the presence of oscillations in interplanar spacing vs $\sin^2\phi$. Furthermore, these values can be employed to ascertain whether the oscillations are due to local fluctuations in plastic deformation, or elastic anisotropy.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Residual stresses X-ray measurements of residual stresses Diffraction elastic constants						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

Security Classification