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TECHNICAL REPORT ARLCB-TR-83038

ELASTIC PROPERTIES OF URANIUM - .78 TITANIUM AS A FUNCTION OF PRESSURE TO 1.6 GPa

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OCTOBER 1983

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4. TITLE (*and Subtitle*) ELASTIC PROPERTIES OF URANIUM - .78 TITANIUM AS A FUNCTION OF PRESSURE TO 1.6 GPa		5. TYPE OF REPORT & PERIOD COVERED Final 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(*s*) J. Frankel and D. Dandekar* *See Reverse		8. CONTRACT OR GRANT NUMBER(*s*)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Armament Research & Development Center Benet Weapons Laboratory, DRSMC-LCB-TL Watervliet, NY 12189		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS No. 611102H600011 PRON No. 1A1283121A1A
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research & Development Center Large Caliber Weapon Systems Laboratory Dover, NJ 07801		12. REPORT DATE October 1983 13. NUMBER OF PAGES 10
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)		15. SECURITY CLASS. (*of this report*) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

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17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

Presented at AIRAPT Conference, Uppsala, Sweden, 15-22 August 1981.
Published in proceedings of the conference.

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Uranium
Ultrasonic Velocities
Pressure
Elastic Properties

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The transit time for passage of longitudinal and shear ultrasonic waves through polycrystalline depleted uranium - .78 weight percent titanium (Ti) alloy was determined as a function of pressure in a hydrostatic medium. Specimens of two thicknesses were used in order to eliminate bond-transducer effects from transit time determinations. The longitudinal velocity v_L increases 3.5 percent from one atmosphere to a value of 3.48 km/sec at 1.6 GPa; the shear

(CONT'D ON REVERSE)

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20. ABSTRACT (CONT'D)

velocity v_s increases 5 percent to 2.08 km/sec; the adiabatic bulk modulus B^s increases 8.1 percent to a value of 120 GPa and the shear modulus μ, 9.4 percent to 81 GPa over the same pressure range.

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INTRODUCTION

Ultrasonic measurements to a pressure of 1.8 GPa in pure depleted uranium (DU) by a pulse overlap technique were previously reported by Abey and Bonner (ref 1). The present measurements with a different technique show that within experimental errors the present alloying does not markedly change the elastic properties of the material in the pressure range studied.

EXPERIMENTAL DETAILS

DU alloyed with .78 weight percent titanium was obtained from the Oak Ridge National Laboratory. An ingot cast of U - .78% Ti was first forged and rolled at 913°K in vacuum and water quenched, then aged at 643°K in an argon atmosphere, and water cooled. The quench brought the uranium from the γ(bcc) phase to the α (orthorhombic) phase and the aging treatment served to reduce voids and residual stresses. The microstructure of the material was acicular. Observation of the microstructure and shear velocity measurements with varying shear wave polarizations suggest that the acicular grains had a very mild anisotropy in one direction. Measurements were made in the specimen direction which showed no anisotropy.

The starting material was fabricated into two cubes whose opposing faces were parallel to .0003 cm over each face. Special care was taken for an even thin bond. The bonding material was a rapid room temperature curing cyanoacrylate MIL-A-460508 type 1 class 2 by Loctite. The resonance frequency of the Lithium Niobate transducers was 10 or 15 MHz. This was considerably

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[1] Abey, A. E. and Bonner, B. P., Jour. Appl. Phys., 1975, Vol. 46, No. 4, 1427-1428.

reduced by bonding and mildly increased by pressure. Pressure was applied in a Birch-Bridgman 30 Kbar system with a 50-50 Pentane-Isopentane mixture as a pressure medium.

The measurement method is based on the use of the double balanced mixer, and is described by Peterson et al (ref 2) (Fig. 1). When two coherent waves are combined in the mixer with proper amplitudes, the mixer output is zero volts (a null echo) if they have a 90 degree phase relationship. This is equivalent to saying that there is an integer n ± 1/4 number of rf periods in the continuous wave (CW) during the time interval in which it takes the ultrasonic wave to produce the m^{th} echo at the transducer.

The measurement involves finding two frequencies. First a frequency is found for a null echo, then for another null, m (where m = echo number) extra periods are included in the time interval T_m by increasing the frequency to f'.

$$T_m = \frac{n \pm 1/4}{f} = \frac{n + m \pm 1/4}{f'} = mT_{rt} \tag{1}$$

The uncorrected round-trip time in the specimen is

$$T_{rt} = \frac{1}{f' - f} = \frac{1}{\Delta f_m} \tag{2}$$

The time T_m in reality is given by mT_{rt} less any delays. These are caused by the electronics and any phase changes at the transducer-specimen interface. One could make estimates of these corrections with available approximate theories by making measurements for two or more echoes. These require

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[2] Peterson, G. L., Chick, B., and Junker, W., 1975 Ultr. Symp Proc., 650-653, IEE Cat. No. CHO 994-4SU.

measurements at exactly the resonance frequency of the transducer, equal confidence in measurements on different echoes, and knowledge (not available for lithium niobate) of the transducer acoustic impedance for the pressures of the experiment.

We found the most useful approach was to avoid estimates of the above effects and to evaluate the transit times by a difference method: We measured the Δfm in a given specimen for two echoes $m = 2$ and $m = 3$. The specimen was then reduced in thickness and the Δfm was found with the same transducer and bond. The difference of the inverse Δfm for the two specimen thicknesses gave the travel time for the thickness of the residual specimen (.4683 cm at $P = 1$ atm.). Data on a second specimen of equal thickness with the first was also used and its values fell within the scatter of the first. Frequencies of measurement were reproduced at equivalent pressures for the thick and thin specimens (Figure 2).

DATA ANALYSIS

Data were separated according to echo number ($m = 2$ or 3) thick or thin specimen and longitudinal or shear wave. A straight line fit of the form $1/\Delta fm = a_0P+a_1$, was made through all data of each type by the method of least squares. Units of P are in GPa and $1/\Delta fm$ in μsec and r is the regression coefficient (Table I). The linear fit is justified by the high correlation coefficients and by the small changes in transit times obtained. The transit times in the residual portion of the specimen were obtained by subtraction (Table II). On the basis of the regression fit and averaging of the $m = 2$ and $m = 3$ data, the standard deviations for transit times of the longitudinal and shear waves are respectively $\sigma_L = .018$ and $\sigma_S = .031$.

An iteration process developed by Dandekar (ref 3) was used in determining the specimen length and ultimately the velocities from the transit times. Variations in $1+\Delta = B^S/B^T$ are included. Here

$$\Delta(P) = \beta^2(P)\ B^S(\rho)\ T/\rho(P)\ C_p(P) \qquad (3)$$

where β is the volume expansion coefficient and C_p is the specific heat. References 4 and 5 were used to obtain the thermodynamic data for estimating $\Delta(P)$. Because of the small changes involved, the iteration is only performed at 1.6 GPa; so we only report velocities and bulk moduli at that pressure (Table III). From the slopes of the bulk and shear moduli, we also get $dB^S/dP = 5.5$ and $d\mu/dP = 4.4$

Within the error of the experiment which is larger for the pressure derivatives, these values correlate with those reported by Abey and Bonner (ref 1).

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[1] Abey, A. E. and Bonner, B. P., Jour. Appl. Phys., 1975, Vol. 46, No. 4, 1427-1428.

[3] Dandekar, C., Jour. Appl. Phys., 1970, Vol. 41, No. 2, 667-672.

[4] AIP Handbook, Coord. Ed., D. E. Gray, Third Edition, 1972, McGraw-Hill, NY.

[5] Fisher, E. S., J. Nucl. Mat. 1966, 18, 39.

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1. Abey, A. E. and Bonner, B. P., Jour. Appl. Phys., 1975, Vol. 46, No. 4, 1427-1428.
2. Peterson, G. L., Chick, B., and Junker, W., 1975 Ultr. Symp Proc., 650-653, IEEE Cat No. CHO 994-4SU.
3. Dandekar, D., Jour. Appl. Phys., 1970, Vol. 41, No. 2, 667-672.
4. AIP Handbook, Coord. Ed., D. E. Gray, Third Edition, 1972, McGraw-Hill, NY.
5. Fisher, E. S., J. Nucl. Mat. 1966, 18, 39.

TABLE I. VALUE OF COEFFICIENTS FROM STRAIGHT LINE FIT
$1/\Delta f_m = a_o P + a_1$ TO DATA

Spec	Thick				Thin				Residual Length = 4.863 mm					
Echo	m = 3		m = 2		m = 3		m = 2		m = 3		m = 2		<Ave>	
Wave	Shear	Long	Shear	Long	Shear	Long	Shear	Long	Shear	Long	Shear	Long	Shear	Long
a_o	12.906	7.734	12.935	7.758	8.029	4.839	8.053	4.856	4.876	2.895	4.883	2.902	4.879	2.897
$-a_1$	.235	.168	.222	.175	.0865	.101	.0999	.102	.1485	.0688	.1217	.0727	.135	.07135
$-r$	.9423	.9730	.9807	.9813	.9510	.9718	.9715	.9726	.0535	.0258	.0324	.0324	-	-

TABLE II. ESTIMATE OF PRESSURE DEPENDENCE OF TRANSIT TIMES FOR LONGITUDINAL AND SHEAR WAVES IN DU - .78 Ti OF INITIAL THICKNESS 4.863 MM

Pressure (GPa)	Transit Time (μs)	
	Long.	Shear
0.0	1.449	2.439
0.4	1.434	2.413
0.8	1.419	2.386
1.2	1.406	2.358
1.6	1.342	2.331

TABLE III. ELASTIC PROPERTIES

	P = 0	P = 1.6 GPa
v_L	3.36 ± .04 km/sec	3.48
v_S	1.99 ± .03 km/sec	2.08
B^S	111 ± 5 GPa	120
μ	74 ± 2 GPa	81
B^T	108 ± 5 GPa	117

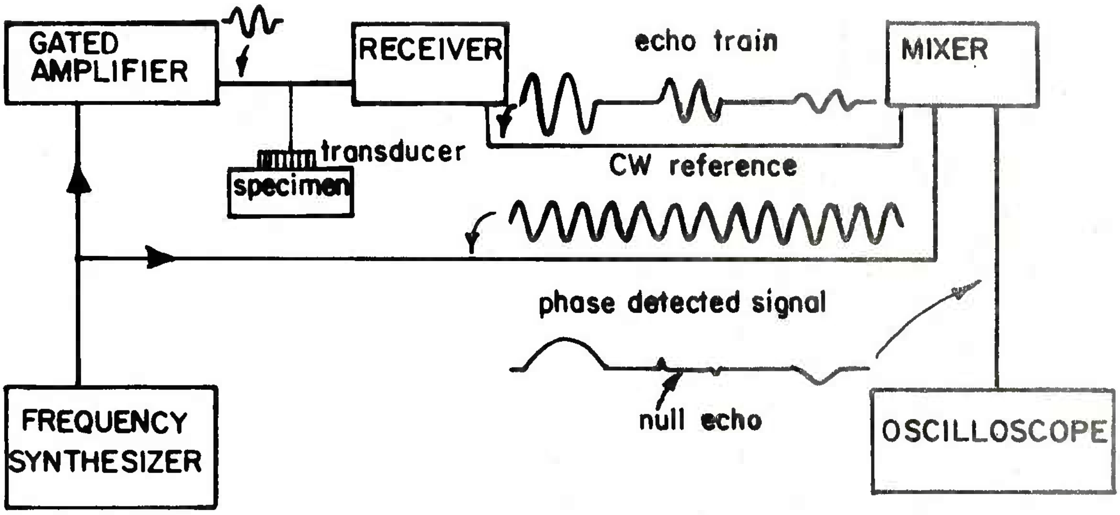

Figure 1. Schematic of Measurement.

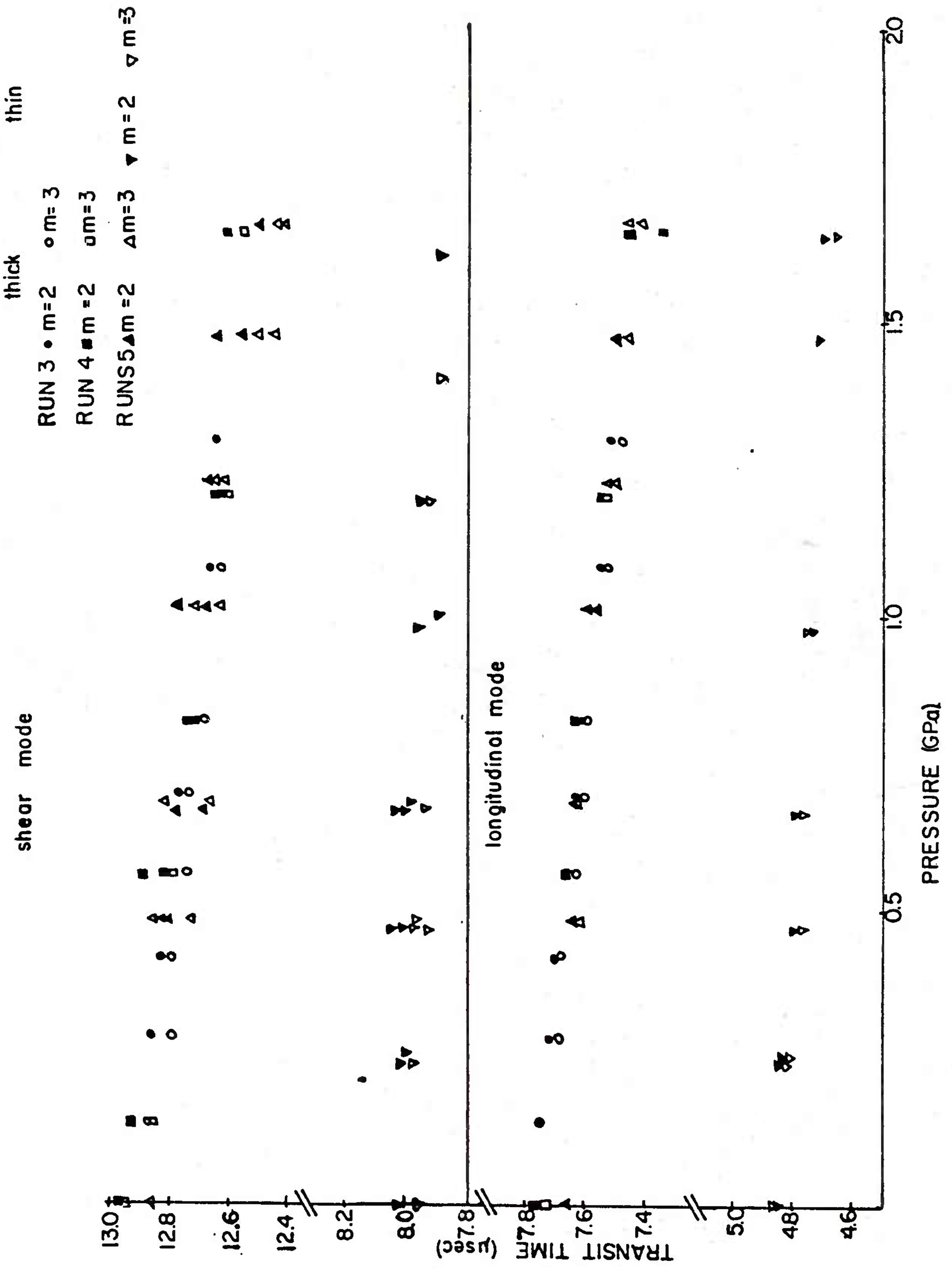

Figure 2. 1/Δfm Against Pressure.

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