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ELASTIC AND PLASTIC DEFORMATION
OF SOLIDS

262 Corr

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Cornell University
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October 22, 1973

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ABSTRACT

The 0°C freezing point of mercury determination based on the combined length and ultrasonic time pressure gauge developed by us was completed and published. The transformation pressure obtained in $P_T = 7571.2 \pm 1.6$ bars. The maximum deviation of our manganin gauge from linearity is -11.6 ± 0.1 bars at $P_T/2$. A method of machining meter long LiF single crystals was developed and combined length and ultrasonic measurements on such a crystal are now underway to determine second pressure derivatives of elastic moduli and to determine the pressure dependence of the Grüneisen parameter. An apparatus has been built to measure the pressure dependence of the yield stress of metals with small yield stress and experiments will commence shortly on potassium at liquid nitrogen temperatures. A pressure vessel has been equipped with a furnace for internal heating to high temperature and experiments are now underway to carry out hot isostatic compaction of very fine carbide particles under controlled conditions to obtain sintering to Theoretical density with little grain growth.

1. ABSOLUTE PRESSURE GAUGE

Three papers were published on this system, whose construction began in 1966. The first [Arthur L. Ruoff, R. C. Lincoln and Y. C. Chen, High Pressure Calibration with a New Absolute - pressure Gauge, Appl. Phys. Lett. 22, 310 (1973)] is a brief summary of the way pressure is obtained by simultaneously measuring ultrasonic transit times and length measurements at pressure. The second [Arthur L. Ruoff, R. C. Lincoln and Y. C. Chen, A New Method of Absolute High Pressure Determination, J. Phys. D: Appl. Phys. 6, 1295 (1973)] describes this method in detail except for the specific aspects of the length measurement system. The latter is described in the paper [R. C. Lincoln and Arthur L. Ruoff, Absolute Length Measurement at High Pressures, Rev. of Sci. Instrum. 44, 1239 (1973)].

The maraging pressure vessel and the two stainless steel end tubes, used in the original length measurements, has been replaced by a single straight cylinder of age hardened titanium alloy. A meter long LiF crystal has been grown and is in the pressure vessel; measurements are being carried out now on this system.

2. EQUATION OF STATE

The second pressure derivative of the bulk modulus evaluated at zero pressure (B''_0) has not been measured to significant accuracy to be quantitatively meaningful, except that its sign has been determined. The same applies to the second pressure derivatives of other elastic constants. We have currently underway combined measurements of length and ultrasonic transit times in LiF crystals, which we feel will give this information.

A paper on the pressure dependence of elastic constants in

LiBr and LiCl was published [L. S. Ching, J. Paul Day and Arthur L. Ruoff, Pressure and Temperature Dependence of the Elastic Constants of LiBr and LiCl, J. Appl. Phys. 44, 1017 (1973)].

3. GRÜNEISEN PARAMETER

Using the combined length-transit time system, we have two ways of evaluating the Grüneisen parameter γ at pressure and hence of evaluating its pressure dependence. The first utilizes the relation $\gamma = (B^S/B^T - 1) (\beta T)^{-1}$. Here β is the volume thermal expansion coefficient (directly measured in the experiment), T is the absolute temperature, B^S is the adiabatic bulk modulus (directly measured in the experiment by combining ultrasonic transit time measurements at pressure with length at pressure measurements and B^T directly from the length vs. pressure measurements. For the case where $\beta \gamma T$ is relatively large (say, 0.1), this method should give a reasonably accurate answer. Such is the case for the alkali metals and the alkali halides. The second method involves the use of $\gamma = \beta B^S / \rho C_p$. Here ρ is the density at pressure and C_p is the specific heat at pressure. We assume the values of ρ and C_p at zero pressure (or at atmospheric pressure are known). Then ρ at pressure is obtained from length measurements. Likewise C_p at pressure can be obtained

from

$$\left(\frac{\partial C_p}{\partial p} \right)_T = -T \left[\frac{\left(\frac{\partial \beta}{\partial T} \right) + \beta^2}{\rho} \right]_p,$$

since the latter quantities can be measured in our experiment.

The experiment presently underway on LiF will lead to the evaluation of $\gamma(P)$ and we are looking forward to obtaining good values of $d\gamma/dP$ and the nature of the $\gamma(P)$ relation. Were it not for the

fact that a considerable effort had to be made to "machine" the as grown LiF crystals so they would fit into the vessel, we would have such results at this time. This problem has been solved and measurements on LiF are now being made.

4. RELATIONSHIP OF ELASTIC CONSTANTS AND IN PARTICULAR HIGHER ORDER ELASTIC CONSTANTS TO PHASE INSTABILITIES.

The paper on V_3Si showing that the pressure derivative of the $[110] [1\bar{1}0]$ shear constant is strongly negative suggesting that a purely hydrostatic pressure of about 30 k bar might transform it has been published [R. E. Larsen and Arthur L. Ruoff, Pressure-Induced Elasticity Changes in V_3Si , J. Appl. Phys. 44, 1021 (1973)]. The V_3Si system was extensively discussed at the Gatlinburg meeting.

At the present time no good CsCl crystals have been grown by us at high pressures, although it is expected that this will soon be accomplished. The elastic constants and their pressure derivatives will then be measured at temperatures near to the phase transformation temperature.

A paper is in preparation on lithium which showed no unusual behavior in the vicinity of the phase transformation.

Two papers on experimental techniques were published [J. Paul Day, Paul S. Ho and Arthur L. Ruoff, A cw Interferometer for Elastic Constant Measurements, Rev. Sci. Instrum., 44, 478 (1973) and Y. C. Chen, R. H. Martinson and Arthur L. Ruoff, A Multiple Crystal Holder for Ultrasonic Measurements, Rev. of Sci. Instrum., 43, 1712 (1972)]

5. PLASTIC DEFORMATION AT PRESSURE

A pressure system capable of accurately measuring the stress-strain curves of materials with low flow stresses such as potassium (or harder materials) at liquid nitrogen temperatures or above to pressures of 10 k bars has been designed and completion of construction is near. Considerable developmental work was carried out in dynamic seals for use at this temperature and an excellent system is now available.

This device will be used to measure the pressure dependence of the flow stress in metals. From theoretical considerations a linear variation of the form

$$\alpha_o = \sigma_{oo} \left(1 + \frac{E'_o}{E_o} P \right)$$

is expected. The effect should be appreciable in potassium.

6. FINE PARTICLES.

An internal heating system for a pressure vessel was built so that isostatic compaction could be carried on at high pressures and high temperatures. In initial runs, TaC powder of 1μ diameter has been isostatically compressed. In experiments now under way $300 \text{ \AA}$ powders are being compressed. We are attempting to adjust the temperatures and pressure and other factors so that a highly dense solid with final grain sizes 0.03 to 0.1μ is obtained. We expect such a material to have higher strength and greater ductility than present existing sintered carbides.

A master Thesis was written on the fine lamellar structure superconductors [R. Rickenback "Multilayered Thin Film Superconductor", Cornell University, Ithaca, New York (1973)].

7. ULTRAPRESSURES

Attempts to make metallic ammonia (NH_4) have (probably) been unsuccessful to this point although it appears that in the process other new compounds may have been prepared. This is being investigated further.

PUBLICATIONS SINCE LAST ANNUAL REPORT

- C00-3153-102 Y. C. Chen, R. H. Martinson and Arthur L. Ruoff
"A Multiple Crystal Holder for Ultrasonic Measurements"
Rev. Sci. Instrum. 43, 1712 (1972)
- C00-3153-103 Arthur L. Ruoff, R. C. Lincoln and Y. C. Chen
"High Pressure Calibration with a New Absolute
Pressure Gauge"
- C00-3153-104 R. C. Lincoln and Arthur L. Ruoff
"Absolute Length Measurements at High Pressures"
- C00-3153-105 Arthur L. Ruoff, R. C. Lincoln and Y. C. Chen
"A New Method of Absolute High Pressure Determination"
- C00-3153-106 L. S. Ching, J. Paul Day and Arthur L. Ruoff
"Pressure and Temperature Dependence of The Elastic
Constants of LiBr and LiCl"
J. Appl. Phys. 44, 1017 (1973).
- C00-3153-107 R. E. Larsen and Arthur L. Ruoff
"Pressure-Induced Elasticity Changes in V_3Si "
J. Appl. Phys. 44, 1021 (1973).
- C00-3153-108 Arthur L. Ruoff, R. C. Lincoln and Y. C. Chen
"High Pressure Calibration with a New Absolute-
Pressure Gauge"
Appl. Phys. Lett. 22, 310 (1973).
- C00-3153-109 J. Paul Day, Paul S. Ho and Arthur L. Ruoff
"A cw Interferometer for Elastic Constant Measurements"
Rev. Sci. Instrum., 44, 478 (1973).
- C00-3153-110 R. Rickenback
"Multilayered Thin-film Superconductors"
M.S. Thesis, Cornell University, Ithaca, New York (1973).
- C00-3153-111 Arthur L. Ruoff, R. C. Lincon and Y. C. Chen
"A New Method of Absolute High Pressure Determination"
J. Phys D: Appl. Phys. 6, 1295 (1973).
- C00-3153-112 Arthur L. Ruoff; "Penultimate Static Pressure Containment
Considerations and Possible Applications to Metallic
Hydrogen Preparation" in Advances in Cryogenic Engineering,
Ed. K-D. Timmerhaus, 18, 435 (1973).
- C00-3153-113 R. C. Lincoln and Arthur L. Ruoff, "Absolute Length
Measurement at High Pressure", Rev. Sci. Instrum, 44,
1239 (1973).

IN PREPARATION

Arthur L. Ruoff

"On Grain Size Shape Changes During Diffusional Creep"

J. Chua

"Dynamic High Pressure Seals at Cryogenic Temperatures"

J. Paul Day

"Dependence of Elastic Constants of bcc Lithium on Temperature and Pressure near the Phase Transformation"

K. Y. Kim

"Machining of LiF crystals"

R. C. Lincoln

"Effects of Errors in Pressure Measurement on Quantities which are Pressure Derivatives"