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Dynamic Compression of Quartz

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Measurements of the stress-density states achieved during shock compression of *X*-, *Y*-, and *Z*-cut crystalline quartz are presented. For the elastic shocks comparison is made with predictions based on acoustic measurements of the second- and third-order elastic coefficients, and observed differences, which are substantial, are used to calculate two of the fourth-order coefficients. The values of c_{1111} and c_{3333} are found to be $159.3 \pm 20\% \times 10^{12}$ and $184.9 \pm 20\% \times 10^{12}$ dynes/cm^2, respectively. This procedure, employing the difference between acoustic measurements and shock wave measurements to evaluate higher-order elastic coefficients, should be generally applicable to solids that sustain large-amplitude elastic waves.

INTRODUCTION

The shock compression of quartz is of particular interest because of its importance to geophysics, its widespread use in shock wave studies as a pressure transducer, and its representation of a different class of materials than the more thoroughly studied metals. In this paper we describe measurements similar to those reported by *Wackerle* [1962]. The data are in substantial agreement; however, the recording techniques were somewhat different, so that the present results provide independent corroboration, in most respects, of Wackerle's data. (The present data were reported originally in *Fowles* [1961*a*].)

As in Wackerle's experiments double shock fronts were observed. The first is identified as the elastic shock; the second is the 'plastic' shock in which permanent deformation occurs. The separation into a fast and slow front is thus attributed to instability of the initial shock caused by yielding at the elastic limit [*Duvall and Fowles*, 1963]. For *X*- and *Y*-cut crystals the elastic amplitudes are in the range 55–85 kb; for *Z*-cut crystals elastic amplitudes are observed in the range 100–150 kb. The maximum pressure in these experiments (230 kb) was not high enough to show clearly the phase transition to stishovite.

In addition to describing the experiments and the results, we examine the agreement between the uniaxial stress-strain data derived from shock experiments and predictions based on finite strain theory and the second- and third-order elastic constants measured by *McSkimin et al.* [1965] and *Thurston et al.* [1966]. From this comparison it is clear that shock wave measurements and low-pressure acoustic measurements are complementary methods for evaluating higher-order elastic coefficients.

EXPERIMENTS

Experimental method. In the experiments shock propagation velocities and associated free surface velocities were measured in α quartz crystals oriented as *X*, *Y*, or *Z* cuts. (Synthetic crystals were supplied by Valpey Corporation.) Shock waves of varying intensity were generated by plane-wave explosive lenses with or without additional explosive pads.

The experimental arrangement is shown schematically in Figure 1. A 4-inch-diameter explosive lens (and in some cases an explosive pad) was cemented to one surface of a ½-inch-thick, 5-inch-diameter Dural plate. The quartz specimens (usually two) were cemented to the opposite lapped surface of the plate. The specimens were accurately flat and polished; the tolerance on crystallographic orientation was ±1°. The faces of the specimens in contact with the plate were vapor-plated with aluminum to yield a reflecting surface. Lucite mirrors, also aluminized on their inside faces, were cemented to the outer surfaces of the specimens at angles of 3° to 8°. The edge of the lucite mirror in contact with the specimen was, in each case, set back from the edge

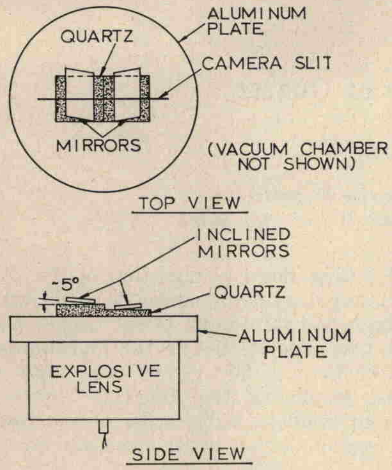

Fig. 1. Diagram of experimental assembly.

of the specimen at least one specimen thickness to avoid interference from edge effects. The *X*, *Y*, or *Z* orientation refers to the smallest linear dimension and also designates the direction of shock propagation. The *X*-cut crystals were measured in both the plus and minus orientations because of the large differences observed in electrical experiments [*Neilson et al.*, 1961].

In some of the experiments an inclined lucite mirror was cemented directly to the aluminum plate. Its function was to measure the free-surface velocity of the aluminum to permit impedance-match solution to the final shocked states [*Duvall and Fowles*, 1963].

The angles of the inclined mirrors with respect to the quartz surfaces were measured after assembly by mounting the assembly on a mill table and observing with a telescope the superposition of a cross-hair and its image reflected alternately in the quartz and lucite surfaces. The angles could thus be measured to a precision of 0.1%. Some difficulty was encountered in keeping the lucite mirrors extremely flat. It was necessary to allow angular deviations of up to ±1 min of arc. In each case this amounted to less than ½% of the total angle.

To obtain the desired accuracy in shock velocity, ±1%, good contact (0.0002 inch) between the inside edge of the inclined mirror and the outer quartz surface was required. A contact in which no transmitted light was visible was considered satisfactory.

To avoid complications due to air shocks the assembly was evacuated before firing to a pressure of less than 0.05 torr. A hemicylindrical section of lucite tubing cemented to the aluminum plate served as a vacuum chamber. (A photograph of an assembly, without explosive, before firing is shown in Figure 2.)

The assembly was viewed through a slit of a rotating-mirror streak camera aligned along the centers of the inclined mirrors in the direction of maximum inclination (i.e., the direction in which the mirror angles were previously measured). The camera was focused on the reflecting surfaces. The slit width was 0.05 mm; the time resolution, determined from the slit width and the camera writing speed (3.81 mm/μsec), was approximately 0.01 μsec.

Illumination was provided by an explosive argon light source consisting of a 4-inch-diameter, 18-inch-long cardboard tube with a 1-inch pad of composition C-3 explosive at one end. A ground glass diffusing screen was placed over the other end, and argon flowed continuously through the tube. The light source explosive was initiated simultaneously with the plane-wave lens of the experimental assembly. The resulting strongly luminous shock in the argon produced a bright reflection from the aluminized surfaces a few microseconds before the first arrival to be recorded in the quartz.

A drawing of the complete arrangement as it appeared before firing is shown as Figure 3.

An abrupt change in intensity of the light reflected from the aluminized surfaces of the assembly showed arrival times of the shock fronts and free surfaces on impact with the mirrors.

A streak camera photograph taken in this

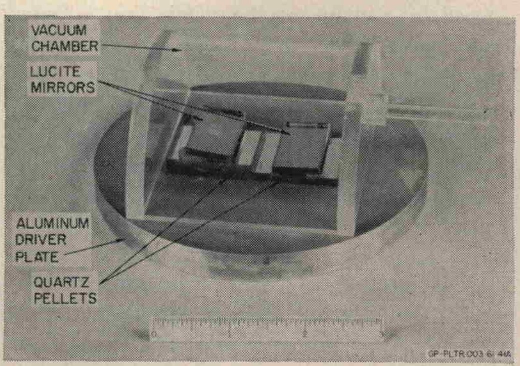

Fig. 2. Photograph of experimental assembly.