

pression curve for the sample material. In the present paper two characteristically different wave profiles are observed in the various stress ranges. These are (1) a single elastic compressive wave of stress less than the HEL and (2) a two-shock front profile consisting of an elastic wave, whose amplitude is the HEL, and a slower moving higher pressure wave. Since different assumptions are employed in the data reduction in each of the two cases the method of data reduction for each experiment will be described.

The stress vs. compression states for each experiment are calculated assuming steady wave conditions and applying the conservation of mass and momentum conditions across each shock front. Thus, from the conservation of mass

$$\frac{\Delta V}{V_0} \equiv \eta = \frac{\Delta u}{U - u_i}, \quad (9)$$

and from the conservation of momentum

$$\Delta \sigma = \rho_0 (U - u_i) \Delta u, \quad (10)$$

where V_0 is the specific volume ahead of a shock front, ΔV is the magnitude of the change in specific volume imparted by the shock front, η is the strain or compression, Δu is the change in particle velocity, u_i is the particle velocity ahead of the shock front, $\Delta \sigma$ is the change in stress imparted by the shock front in a direction normal to the shock front. All velocities are in laboratory coordinates.

(a) *Elastic range experiments*

Experiments conducted within the elastic range were accomplished with the symmetrical impact configuration. Under these conditions a single shock front propagates with amplitude equal to the input particle velocity and travels with a fixed shock propagation velocity. In the experiment the particle velocity is measured with an accuracy of ± 0.3 per cent while the shock velocity is measured with an accuracy of ± 1 to $1-\frac{1}{2}$ per cent. These values should be

contrasted to the explosively driven experiments which produce multiple shock fronts whose free-surface velocities are measured with an accuracy of ± 3 per cent while the shock propagation velocities are measured with an accuracy of 1 to 2 per cent.

The shock velocity and particle velocity values observed are shown in Table 2 along with the computed stress and compression data. The experiments in the elastic range are conducted over a range of stress from 15 to 100 kbar with measurements in three crystallographic orientations. Typical records from which these data are obtained have been previously shown [32]. Increased shock velocity is observed with increasing particle velocity in all crystallographic orientations. This behavior will be compared to ultrasonic determinations of higher order elastic constants in the discussion section.

One special experiment was conducted on a 60° orientation sample. This crystallographic orientation is the natural growth direction of the artificially grown sapphire boules. For this reason, the availability, low cost and high quality of the material in the large diameters required for this work, make the 60° orientation more desirable than other orientations. On the other hand, this crystallographic orientation is apparently not a 'specific direction,' that is, a longitudinal motion applied along the disk axis may produce both a quasi-longitudinal and a quasi-shear wave [35]. However, even though sapphire has trigonal symmetry the elastic stiffnesses do not vary significantly with orientation. For example, the longitudinal wave speeds in the 0° and 90° orientations differ by only $\frac{1}{2}$ per cent. Hence, the nonsymmetric response would be expected to be small if not insignificant.

To determine the extent of the effect, a 60° orientation sample was impacted at 28 kbar with a quartz gauge which precisely measures the input stress to the sample. This same experiment also included a quartz gauge measurement of the resulting shock wave profile after propagation through a distance of

Table 2. Shock compression data for sapphire

$\rho_0 = 3.986 \text{ g cm}^{-3}$

Configuration	Sample thickness	U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8	U_9	U_{10}	U_{11}	U_{12}	U_{13}	U_{14}	U_{15}	U_{16}	U_{17}	U_{18}	U_{19}	U_{20}	U_{21}	U_{22}	U_{23}	U_{24}	U_{25}	U_{26}	U_{27}	U_{28}	U_{29}	U_{30}	U_{31}	U_{32}	U_{33}	U_{34}	U_{35}	U_{36}	U_{37}	U_{38}	U_{39}	U_{40}	U_{41}	U_{42}	U_{43}	U_{44}	U_{45}	U_{46}	U_{47}	U_{48}	U_{49}	U_{50}	U_{51}	U_{52}	U_{53}	U_{54}	U_{55}	U_{56}	U_{57}	U_{58}	U_{59}	U_{60}	U_{61}	U_{62}	U_{63}	U_{64}	U_{65}	U_{66}	U_{67}	U_{68}	U_{69}	U_{70}	U_{71}	U_{72}	U_{73}	U_{74}	U_{75}	U_{76}	U_{77}	U_{78}	U_{79}	U_{80}	U_{81}	U_{82}	U_{83}	U_{84}	U_{85}	U_{86}	U_{87}	U_{88}	U_{89}	U_{90}	U_{91}	U_{92}	U_{93}	U_{94}	U_{95}	U_{96}	U_{97}	U_{98}	U_{99}	U_{100}																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
H	2.54	0.0333	11.29	15.2	0.9970	17.9	0.9964	21.3	0.9958	36.7	0.9929	42.1	0.9916	50.4	0.9901	175	0.9674	157	0.9707	142	0.9730	0.49	8.05	7.56	196	12.70	0.30	11.55	138	0.9740	0.69	8.88	8.61	271	8.49	0.71	8.76	8.91	337	10.86	0.33	11.55	148	0.9722	0.86	9.12	8.91	370	12.68	0.41	11.77	195	0.9652	1.08	8.82	8.52	419	10.86	0.37	11.55	170	0.9677	0.83	8.55	8.24	499	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	586	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	619	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	652	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	685	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	718	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	751	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	784	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	817	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	850	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	883	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	916	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	949	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	982	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1015	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1048	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1081	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1114	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1147	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1180	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1213	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1246	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1279	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1312	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1345	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1378	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1411	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1444	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1477	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1510	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1543	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1576	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1609	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1642	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1675	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1708	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1741	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1774	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1807	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1840	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1873	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1906	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1939	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	1972	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2005	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2038	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2071	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2104	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2137	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2170	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2203	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2236	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2269	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2302	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2335	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2368	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2401	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2434	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2467	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2500	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2533	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2566	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2599	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2632	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2665	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2698	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2731	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2764	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2797	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2830	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2863	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2896	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2929	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2962	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	2995	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3028	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3061	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3094	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3127	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3160	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3193	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3226	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3259	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3292	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3325	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3358	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3391	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3424	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3457	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3490	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3523	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3556	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3589	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3622	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3655	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3688	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3721	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3754	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3787	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3820	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3853	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3886	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3919	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3952	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	3985	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4018	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4051	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4084	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4117	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4150	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4183	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4216	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4249	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4282	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4315	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4348	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4381	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4414	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4447	10.86	0.342	11.39	155	0.9700	0.474	6.90	5.97	4480