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SHOCK HUGONIOT AND RELEASE STATES IN CONCRETE MIXTURES WITH DIFFERENT AGGREGATE SIZES FROM 3 TO 23 GPA

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A series of controlled impact experiments has been performed to determine the shock loading and release behavior of two types of concrete, differentiated by aggregate size, but with average densities varying by less than 2 percent. Hugoniot stress and subsequent release data was collected over a range of approximately 3 to 25 GPa using a plate reverberation technique in combination with velocity interferometry. The results of the current data are compared to those obtained in previous studies on concrete with a different aggregate size but similar density. Results indicate that the average loading and release behavior are comparable for the three types of concrete discussed in this paper.

INTRODUCTION

Considerable interest in characterizing the dynamic response of concrete under impact loading exists because it is used extensively as a structural material. Concrete is a heterogeneous composite, typically consisting of quartz aggregate and cement grout. Local variations in the shock and particle velocities due to impedance differences within the material cause fluctuations in the measured particle velocity profiles. A deliberate attempt to average these local variations was made in this study by using "thick" copper and tantalum plates. Plate thickness was controlled, however, to also allow determination of isentropic decompression states. The plate reverberation technique has previously been used to determine the shock loading and release states for concrete (1) and quartz (2).

EXPERIMENTAL TECHNIQUE

The experiments were performed on an 89mm diameter, smooth bore powder gun which is capable of generating impacts in the 0.5 km/s - 2.4 km/s range. The tilt between impactor and target plate, exit velocity of the projectile, and particle velocity from the rear surface of the metallic target plate were measured during each experiment. The configuration used for this experimental series is shown in Figure 1. The projectile consisted

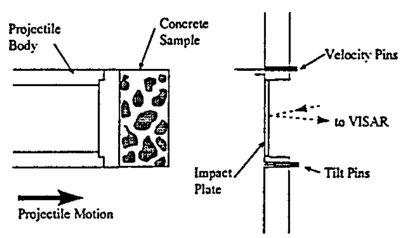

Figure 1: Experimental configuration

of a concrete sample attached to the aluminum projectile nose plate and phenolic body. The target

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Table 1: Experimental parameters and Hugoniot results

Shot Number	Concrete Density (kg/m^3)	Target Thickness/ Material (mm)	Impact Velocity (km/s)	σ_h (Gpa)	u_c (km/s)	U_c (km/s)	ε_c
LC-1	2353.9	3.51 / Cu	0.464	2.79	0.387	3.06	0.13
LC-2,b	2356.1	3.52 / Cu	0.797	5.97	0.637 / 0.647	3.98 / 3.66	0.16 / 0.18
LC-3,b	2356.1	3.52 / Cu	1.340	11.43	1.048 / 1.075	4.63 / 4.05	0.23 / 0.27
LC-4,b	2363.4	3.50 / Cu	1.740	15.86	1.368 / 1.360	4.98 / 4.76	0.27 / 0.29
LC-5,b	2356.7	3.50 / Cu	2.150	20.92	1.650 / 1.710	5.38 / 4.55	0.31 / 0.37
LC-7	2354.0	1.85 / Ta	2.140	22.17	1.833	5.12	0.36
SC-1	2340.2	3.50 / Cu	2.143	19.71	1.668	5.05	0.33
SC-2	2347.9	3.50 / Cu	1.748	15.52	1.363	4.85	0.28
SC-3	2321.6	3.50 / Cu	1.330	11.75	1.030	4.91	0.21
SC-4	2340.6	1.86 / Ta	2.175	22.70	1.820	5.33	0.34
SC-5	2327.7	3.52 / Cu	0.830	6.01	0.669	3.86	0.17
SC-6	2327.5	3.52 / Cu	0.451	2.07	0.394	2.26	0.17

was a thin metal plate inserted into an aluminum target holder. The resulting velocity profiles with copper target plates are shown in Figure 2. Release states for the concrete can be inferred by knowledge of the Hugoniot and release adiabat of the metallic plate material. In an isentropic release process approximation, an approach using stress and particle

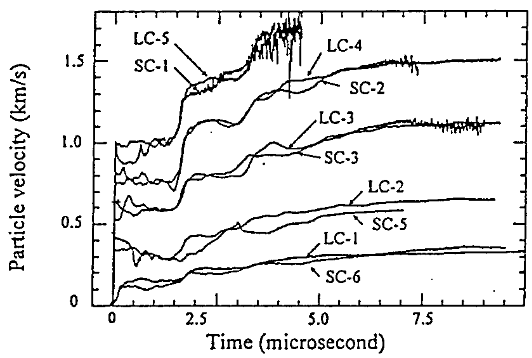

Figure 2. Velocity profiles for large and small aggregate concrete experiments which used copper target plates

velocity decrements can be employed to calculate the release path. This technique will satisfy the simple wave approximations until the first attenuating release wave from the concrete arrives at the impact surface.

MATERIAL DESCRIPTION

The concrete used in the present study had two distinct aggregate size distributions. The concrete referred to as large aggregate had an ASTM aggregate size number of 57. This implies that 5% of the material by weight is between 25 mm and 37.5 mm, 40% to 75% is between 19 mm and 25 mm and the balance is 4.75 mm or smaller (3). The concrete referred to as small aggregate had an ASTM aggregate size number of 7, which means 10% of the material by weight is 12.5 mm, 30% to 60% is 9.5 mm and the balance is 4.75 mm or smaller (3). Cores were taken from large castings in both cases to ensure representative responses. Samples were obtained from each core and measurements made to determine densities. Results are listed in Table 1.

HUGONIOT RESULTS

The experimental parameters and Hugoniot results from this investigation are given in Table 1. In typical experiments, measurements of shock velocity and particle velocity are made directly on the sample of interest. For a highly heterogeneous material such as concrete, however, the measurements of these parameters are best made through an averaging medium such as a homogeneous metallic plate. The stress in the concrete is given by $\sigma_c = \rho_{0c} U_c (V_i - u_2/2)$. The corresponding strain can be obtained using $\varepsilon_c = u_c/U_c$.

The results, including some lower pressure data on SAC-5 (12, 13), are plotted as stress vs. particle velocity with quadratic curve fits in Figure 3. As can be seen, the curves are tightly grouped. This indicates that the loading response of concrete is somewhat independent of aggregate size at these stresses. Scatter bars representing stress deviations due to local variations in the measured particle velocity at the Hugoniot state for each experiment are included. Greater dispersion of the data can be seen in a stress-strain plot. This is expected since strain varies as the square of the particle velocity. The shock velocity, U_s, versus particle velocity, u_p, Hugoniot data for the concrete has been plotted in Figure 4. Also shown in the figure are the results of previous studies on other concrete both above (1) and within (4) the elastic regime. There appears to be a definite slope change in the concrete behavior above the initial elastic regime. A linear least squares fit to the large aggregate, small aggregate, and corresponding SAC-5 data yields $U_c = 2235 + 1.75u_c$. For comparison, the fit for the lower stress data is given by $U_c = 551 + 4.52u_c$. This behavior can be attributed to both the porosity and heterogeneous nature ot the material. The large slope, S, indicated for the elastic behavior suggests relatively large compressions are occurring in this pressure regime. As the stress increases beyond this point, considerably stiffer compaction behavior is indicated by the lower slope value.

RELEASE STATE RESULTS

Once the Hugoniot point is established in the P-u_p plane, subsequent release stress states can be determined within concrete using Δu_c as the change in particle velocity between states of interest. The average wave velocity within the concrete, C_c, can be estimated from $Cc = \Delta\sigma_c/\rho_{0c}(\Delta u_c)$ where $\Delta\sigma_C$ represents the difference in stress. The quadratic curve fits to the release data in the concrete are tightly grouped in the P-u_p plot, as shown in Figure 5. As with the Hugoniot curves, this would indicate that the release response of the concrete does not exhibit a great dependence upon aggregate size at these stress levels. Larger deviations can be seen in a stress-strain plot. This can be partly attributed to the difficulty in determining an average particle velocity and two way transit time within the metallic plate as the particle velocity steps become less discernible late in time. Also,

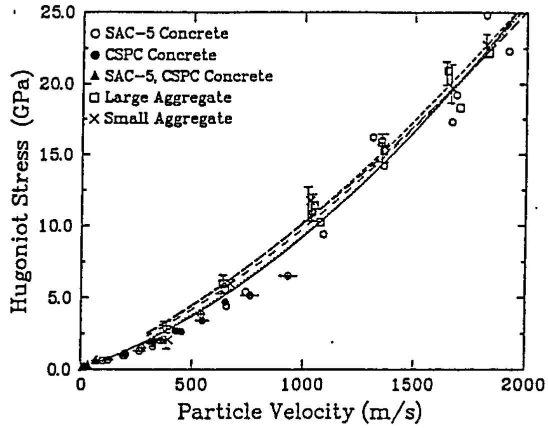

Figure 3. Stress vs. particle velocity for large aggregate, small aggregate, SAC-5 and low stress conventional concrete Hugoniot data

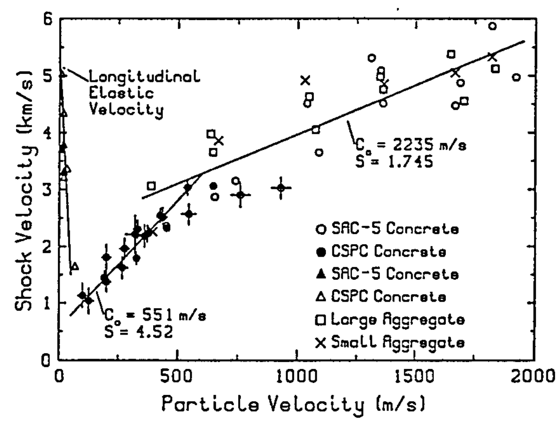

Figure 4. U_s-u_p for Large aggregate, Small aggregate, SAC-5 and low stress conventional concrete Hugoniot data

the change in strain between release states is dependent upon the square of the corresponding change in particle velocity.

COMPARISON WITH PREVIOUS STUDIES

In order to obtain a measure of the variations in particle velocity that can be expected within a particular type of concrete due to its heterogeneous nature, two VISAR signals were recorded at separate locations on the same experiment where possible. Results indicated the largest deviation in local particle velocity was seen in shot number LC-3, where as much as 29% deviation was seen between the maximum and minimum values during initial loading, while an approximate 5%

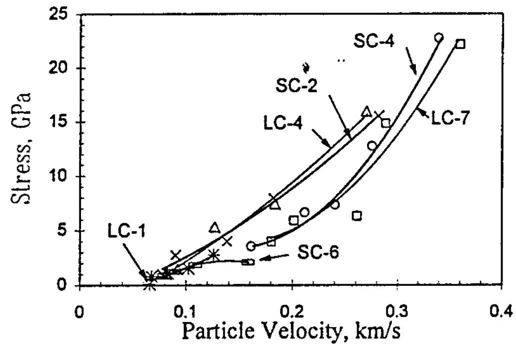

Figure 5. Stress versus particle velocity release curves for high, medium and low stress data sets on Large and Small aggregate concrete which used copper target plates.

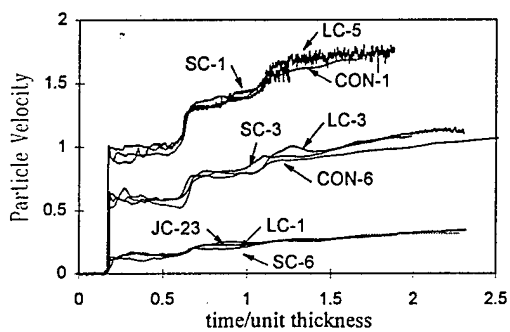

Figure6: Normalized particle velocity traces for Large aggregate, Small aggregate and SAC-5 concrete for high, medium and low stress tests using copper target plates.

deviation between average values was observed.

Figure 6 shows normalized velocity profiles for large aggregate, small aggregate, and the SAC-5 (1) concrete. The time axis was divided by the corresponding plate thickness in millimeters to obtain transit time per unit thickness for each experiment. The velocity axis was not normalized since variations in impact velocity were small. The average value for particle velocity at the Hugoniot state, in both the high and medium velocity experimental sets varies by no more than 5%. The average value for the lower velocity set varies by as much as 25%. This indicates that material characteristics such as aggregate size are more significant at lower stress levels.

SUMMARY

In summary, Hugoniot and release state data was collected for two types of concrete, differentiated by aggregate size, but with average densities varying by less than 2 percent over a stress range of approximately 3 to 25 GPa using a plate reverberation technique in combination with velocity interferometry. This data set was compared in several ways to data obtained in previous studies on SAC-5 concrete (1), which has a different aggregate size but similar density. Stress versus particle velocity data for both the Hugoniot and subsequent release states were plotted and compared, and particle velocity profiles were normalized with respect to plate thickness and overlayed on the same graph. Results indicate that the average loading and release behavior of the three types of concrete discussed in this paper are loosely grouped within scatter bars derived from particle velocity variations due to the heterogeneous nature of the material. Therefore, it appears that concrete does not exhibit a strong dependence upon aggregate size in the 3 to 25 GPa stress range.

REFERENCES

(1) Grady D.E., "Dynamic Decompression Properties of Concrete From Hugoniot States 3 to 25 Gpa", Sandia National Laboratories Technical Memorandum - TMDG0396, February 1996

(2) Chhabildas and D.E. Grady, "Dynamic Material Response of Quartz at High Strain Rates", Material Response Symposium Proceedings, Elsevier 22, pp 147-150 (1984)

(3) American Society for Testing and Materials, C33-93 Standard Specifications for Concrete Aggregates, pp 3, 1993.

(4) Kipp, M.E., Chhabildas, L.C., Reinhart, W.D., "Elastic Shock Response and Spall Strength of Concrete", Proceedings of the American Physical Society Topical Conference, 1997

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