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CHARACTERISTIC OF DYNAMIC TENSILE FRACTURE IN AUGITE-PERIDOTITE

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Planar impact experiments were carried out to induce controlled dynamic tensile fracture in augite-peridotite. Samples, backed with PMMA buffer and windows, were impacted with PMMA impactor at velocities of 30 to 160 m/s. This resulted in maximum tensile stresses were in the range of ~ 50 to 290 MPa. Spall strength was determined to be ~ 58.1 MPa from a particle velocity profile measurement. The spall strength/HEL ratios for augite-peridotite and several other rocks were discussed based on the Griffith's yield criterion and the experimental measurements.

INTRODUCTION

Big impact and explosive cratering events in rock medium usually bring about several typical characteristic zones: vaporization, melting ,fragmentation, spallation and elastic deformation. A good understanding of the dynamic response of rocks is essential to the development of a predictive modeling for the cratering process. Spallation is a consequence of dynamic tensile failure. Melosh[1] has demonstrated that large ejected fragments are mainly produced by spall. Grady and Hollenbach[2], Cohn and Ahrens[3], and Ahrens and Rubin[4] have pursued this phenomenon for several kind of rocks.

In this paper, we report a basic study for the understanding of the dynamic tensile fracture characteristic in rock. Planar impact technique was employed to induce controlled dynamic tensile stress.

EXPERIMENTS

Sample Description

The augite-peridotite samples studied in the present work were collected from Baoxing county about 100km Southwest of Chengdu, P.R.China. It is an ultrabasic rock, consisting of 65% augite, 17% peridot, and 18% other minerals by volume. In order to eliminate the effect of pore water on dynamic fracture behavior, samples were heated at about 200 ℃ for 48 hours, and then kept in desiccator. Some basic parameters were measured as follows: mean grain size 1.5mm, bulk density 2.96Mg/m3, P-wave velocity 5.29km/s, S-wave velocity 3.46km/s, Poisson's ratio was measured to be 0.126. Travel-time method with 0.5MHz PZT transducers was used to measure the ultrasonic wave velocities.

Shock Impact

Planar impact experiments were performed on the one stage light gas gun (100mm diameter). Figure 1 is the schematic of the experimental set-up, which is similar to that designed by Grady and Hollenbach [2]. Upon impact, compressive waves propagate forward into the sample and back into the impactor. Tension is produced when these compressive waves, reflected as release waves from the rear surfaces of the sample and the impactor, later meet within the sample. Sample is square-shaped with 60mm side length, and 10mm thickness.

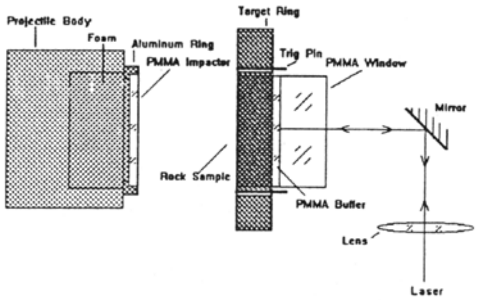

FIGURE 1. Schematic of the experimental set-up.

The thickness ratio of sample to impactor is 5:1, which ensures spall occuring in the middle of the sample, approximately.

A Michelson displacement laser interferometry was employed to measure the time-resolved motion at the interface between the buffer and window as shown in Fig.2. Displacement of the interface causes a fringe frequency, which is recorded by a photomultiplier and an oscilloscope. The particle velocity profile is then reduced from a differentiation of the time-resolved displacement data.

Four shots have been carried out, impact velocities varied from 30 to 160 m/s (see Table 1). In the first three shots, we did not get a good signal for analysis, because the fluctuation of interference field of the laser interferometer. Later, we added a polarizer and a 1/4 wave plate (see Fig.2) as a light isolater to improve the interference field. Also, we added another photomultiplier tube (No.2 in Fig.2) to monitor the laser output. Then, in the experiment, we waited and fired the gun during the time when the interference field was stable. Figure 3 is the particle velocity profile measured in the forth shot. A "pull-back" signal provides an indication of the fracture process, which is in agreement with the terminal observation that spall occured upon this impact. In all shots, a recovery positioned behind the target, which allowed the sample to be recovered and for post examination.

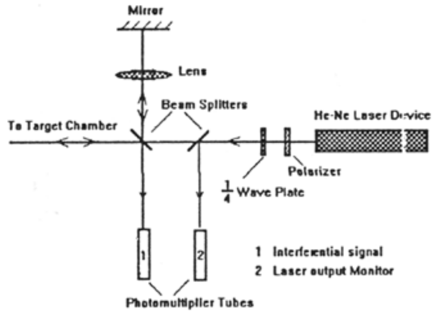

FIGURE 2. Schematic of the Michelson displacement laser interferometry.

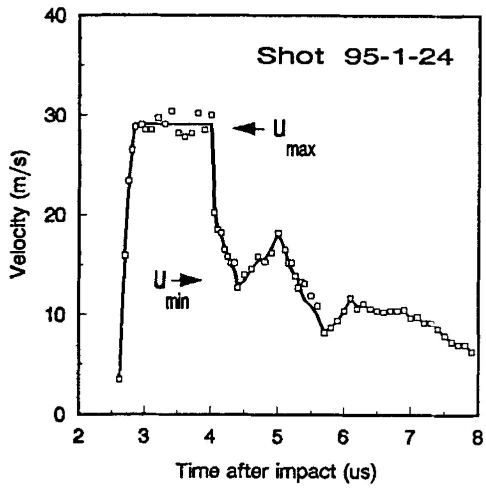

FIGURE 3. Particle velocity profile measured in shot 95-1-24, points are experimental data, solid line is eyeball fit.

RESULTS AND DISCUSSION

Spall Strength

Table 1 is a list of the loading conditions and preliminary results.

Define shock impedance,

$$Z_i = \rho_i c_i \qquad Z_t = \rho_t c_t \qquad Z_w = \rho_w c_w \qquad (1)$$

where ρ and c are initial density and P-wave velocity; subscripts *i, t, w* refer to the impactor, target,

TABLE 1. Results of Dynamic Tensile Fracture in Augite-Peridotite

Shot	Impact velocity (m/s)	Calculated maximum tensile stress (MPa)	Measured spall strength (MPa)	Terminal observation
94-7-29	94.2	168.5	-----	spall
94-8-18	27.5	49.2	-----	no spall
94-8-24	159.1	284.6	-----	spall
95-1-24	111.8	200.4	58.1	spall

Note: 1. Impactor material is PMMA, 2mm thickness, 85mm diameter;
2. Sample is square-shaped, 10mm thickness, 60mm side length.

and window (and buffer), respectively. In this study, impactor, window and buffer are the same material PMMA. Its initial density is 1.18Mg/m3, its shock wave speed in the low-stress regime is 2.8km/s.[5]

Maximum tensile stress in the target (rock sample) is calculated as follow:

$$\Delta\sigma = \frac{Z_i Z_t}{Z_i + Z_t}\left(1 - \frac{2Z_w}{Z_t + Z_w}\right)U_i. \qquad (2)$$

Here U_i is the impact velocity.

Spall strength is determined by [6]:

$$\sigma_{spall} = \frac{1}{2}(Z_t - Z_w)u_{max} - \frac{1}{2}(Z_t + Z_w)u_{min} \qquad (3)$$

Here u_{max} is the peak amplitude of the velocity, u_{min} is the lowest amplitude of the velocity (see Fig.3). No attention is payed to the effect of attenuation of the wave when it propagates from the spall plane to the recording interface. In shot 95-1-24, the average u_{max} is 28.9 m/s, u_{min} is 12.7 m/s(see Fig.3), this yields a spall strength about 58.1 MPa for augite-peridotite.

Ahrens and Rubin [4] observed substantial sound velocity reduction in the post-shock rock samples, indicating the dynamic tensile damage in those samples. In shot 94-8-18, the calculated maximum tensile stress was slightly less than the spall strength. This sample was recovered in a whole block, and no apparent damage or cracks was found on the outside surface. Therefore, it is interesting to measure the sound velocity to see if there is any velocity reduction. Results show that P-wave velocity is 5.44 km/s, S-wave velocity is 3.33 km/s. They are almost the same as the pre-shock sample's, no sound velocity reduction is observed. Therefore, we infer that the threshhold stress of cracks growing is between 49.2 and 58.1 MPa for augite-peridotite.

Spall Strength/HEL Ratio

Recently, Rosenberg[7] suggested the applicability of the Griffith failure criterion[8] for ceramics and demonstrated the ability of this criterion to capture several of the unique shock effects in these brittle materials. Griffith's biaxial-stress criterion gives the following equation for the yield surface:

$$(\sigma_1 - \sigma_2)^2 = 8\sigma_0(\sigma_1 + \sigma_2) \qquad (4)$$

where σ_1, σ_2 are principal stresses and σ_0 is the tensile strength under uniaxial stress conditions.

In the shock wave environment, Rosenberg suggests that the value σ_0 in Eq.(4) is substituted by the spall strength, then the following relation of HEL and spall strength can be written:

$$\sigma_{HEL} = 8\frac{1-\nu}{(1-2\nu)^2}\sigma_{spall} \qquad (5)$$

where ν is the Poisson's ratio

Based on Eq.(5), a comparison of $\sigma_{spall}/\sigma_{HEL}$ ratio between the theory and experiment is shown in Fig.4 for augite-peridotite and selected rocks,corresponding experimental data and references are listed in Table 2.

TABLE 2. Spall strength / HEL Ratio for Selected Rocks

Rock	Cp (km/s)	Cs (km/s)	ν^*	σ_{spall} (MPa)	σ_{HEL} (GPa)	$\sigma_{spall}/\sigma_{HEL}$ ($\times 10^{-2}$)
Arkansas Novaculite	5.99	4.06	0.075	94.7	8[9]	1.18
Westerly Granite	5.04	3.09	0.199	45	2.7-3.7[10]	1.22-1.67
San Marcos Gabbro			0.32[11]	147[12]	3-6[13]	2.45-4.9
Blair Dolomite	6.26	3.51	0.271	47	2.5[14]	1.88
Baoxing Augite-peridotite	5.29	3.46	0.126	58.1	5-6**	0.97-1.16

Note: 1). * $\nu = \frac{1}{2}[1 - \frac{1}{(Cp/Cs)^2 - 1}]$; ** Measured by us in another experiment.

2). All the other data are from Ref.[2].

Except for San Marcos Gabbro, the other rocks are much below the Griffith's prediction, which indicates that these rocks can not be treated as pure Griffith type brittle material in shock wave environment.

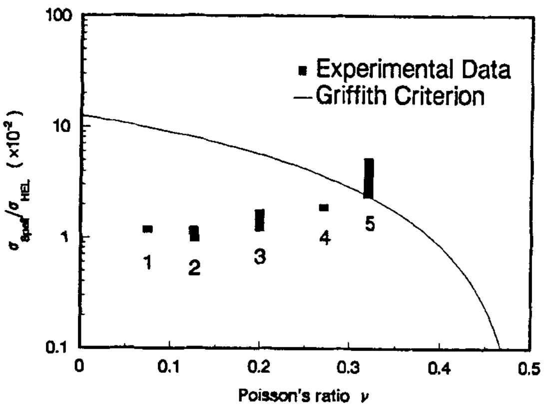

FIGURE 4. A comparison of $\sigma_{spall}/\sigma_{HEL}$ ratio between the theory and experiment for selected rocks. 1--Arkansas Novaculite; 2--Baoxing Augite-peridote; 3--Westerly Granite; 4--Blair Dolomite; 5--San Marcos Gabbro.

ACKNOWLEDGMENTS

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REFERENCES

1. Melosh, H.J., *Icarus* **59**, 234-260 (1984).
2. Grady, D.E., and Hollenbach, R.E., *Dynamic tensile fracture in rock*, Rep. SAND-78-0531, Sandia Lab., Albuquerque, NM, 1978.
3. Chon, S.N., and Ahrens, T.J., *J.Geophys.Res.* **86**, 1794-1802 (1981).
4. Ahrens, T.J., and Rubin, A.M., *J.Geophys.Res.* **98**, 1185-12-3 (1993).
5. Barker, L.M., and Hollenbach, R.E., *J. Appl Phys.* **41**, 4208-4226 (1970).
6. Grady, D.E., and Kipp, M.K., "Dynamic fracture and fragmentation", in *Hing-pressure Shock Compression of Solids* (J.R.Asay and M.Shahinpoor, Ed.), Springer-Verlag, 1992, pp.265-322.
7. Rosenberg, Z., *J.Appl.Phys.* **74**, 752-753 (1993).
8. Griffith, A.A., "Theory of Rupture", in *Proceedings Frist International Congress Applied Mechanics*, Delfe,1924, pp.55-63.
9. Grady, D.E., Murri, W.J., and Fowles, G.R., *J.Geophys. Res.* **79**, 332-338 (1974).
10. Rosenberg, T.J., *Dynamic shear strength in shock-loaded granite and ploycrystalline quartz*, Final Report, Stanford Research Institute, DASA 2718, 1971.
11. Birch, F., "Compressibility: Elastic constants". in *Handbook of Physical Contants* (S.Clark, Jr.,Ed.), Geol. Soc. Amer. Mem. 97, 97-173 (1966).
12. Lange, M.A., Ahrens,T.J., and Boslough, M.B., *Icarus* **58**, 383-395 (1984).
13. Polanskey, C.A., and Ahrens, T.J., *Icarus* **87**, 140-155 (1990).
14. Grady, D.E., Murri, W.J., and Mahrer, K.D., *J. Geophys. Res.* **81**, 889-893 (1976).