THE RATE OF GROWTH OF CRACKS IN ROCK SPECIMENS

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Crack growth is the decisive factor in rock disintegration by explosion. It is difficult to examine such growth because the growth rate is high in brittle medium, which explains why little has been published, and that for only a restricted range of materials. The general aspects of crack growth in solids are now known [1–9], and it has been shown [1] that there are two phases of growth in glass: accelerated growth and steady-state growth. The first accounts for only a small part of the crack length; it is determined by thermal fluctuations and the rate of increase of the effective stress. In the second the rate is independent of the stress and is dependent only on the properties of the medium.

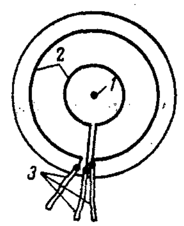

Fig. 1. Specimen with signal layers of aquadog: 1) site of impact, 2) layer of aquadog, 3) leads of Al foil.

It has been shown [2, 3] that cracks in glass [2, 3] and rosin [3] propagate with characteristic velocities independent of the mean stress provided that the stress exceeds a certain limit. It appears [3] that this represents about 0.1 of the technical strength for a brittle medium. Materials that are not entirely brittle, such as polymers, have small crack growth rates relative to the speed of elastic waves, and for these the rate is dependent on the stress for stresses more than 0.1 times the technical strength [4, 5].

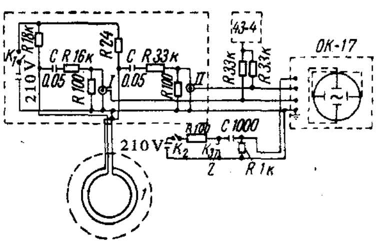

Fig. 2. Circuit for measuring the rate of crack growth: 1) specimen, 2) target.

It is usual to examine [1–6] the kinetics of crack growth on homogeneous materials such as silicate glass, rosin, lucite, and other transparent materials. Much less is known about crack growth in inhomogeneous materials such as rocks. Some measurements have been made [7–9] on small blocks of limestone and similar materials, but the methods were unsuitable for general tests on rocks. We have used 13 different rock specimens in order to correlate the crack growth rate with the mechanical constants of the rock.

The method is based on the deposition of concentric conducting layers, with sequential recording of the instant when these are broken (Fig. 1). The time intervals are measured with an OK-17 dual-beam oscilloscope, which provides measurement of intervals less than 10 μsec, in contrast to the MPO-2 loop oscillograph [7]. The passage of a crack through two successive points produces two pulses, which are passed to the two inputs. The known distance between the layers then gives the mean speed of the crack between them.

Cracking was initiated in two ways: with a high-velocity striker and by detonation of an explosive charge. Figure 2 shows the recording circuit. Switches K_1 and K_2 are closed when the circuit is ready; the conducting layers carry current, while capacitor 0_{1000} charged. The beams are triggered when the striker hits the target 2, which is placed very close to the specimen. The beams are provided with time marks at intervals of 10 μsec (Fig. 3) from a ChZ-4 source. This method eliminates errors due to inexact beam synchronization; the times in the striker method were measured to better than 5%.

The method was developed on glass plates 160 × 160 × 10 mm^3, with current conductors of evaporated aluminum, rings of constantan wire or rings of aquadog. The first and last gave the best results, the values being 1500 m/sec, which agree well with [1–3, 6].

Aquadog has advantages over evaporated aluminum [2] and cemented wire [7] in that it can be applied to any surface and that it undergoes virtually no plastic deformation; further, the application of the layer does not alter any of the properties of the rock (contrast vacuum deposition, which greatly reduces the water content).

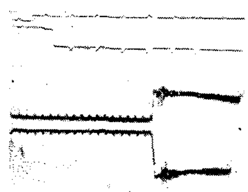

Fig. 3. Examples of oscillograms: top, use of striker; bottom, explosion of charges.

The rock tests were done at the Ioffe Institute of Technical Physics on specimens 70–100 mm in diameter and 10–12 mm thick.

Most of the results were obtained with a soft striker moving at 830 m/sec (Table 1); $\varkappa$ is Protod'yakonov's hardness coefficient, ρ is density (kg/m^3), C is the velocity of longitudinal waves (m/sec), and V is crack growth speed (m/sec).

Table 3 gives V as a function of impact speed U, and also the V corresponding to charges of 0.5 g with l = 10 mm and d = 5 mm.

In the case of the charges the oscilloscope was triggered by the response of a separate detector. Marked fluctuations in the detonation time caused the variations in measured speed to be 10–15%.

The V were found as 1000 to 2700 m/sec, or 0.34–0.51 of the speed of longitudinal waves.

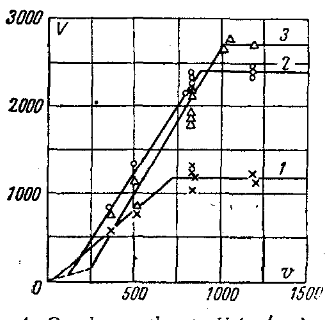

Fig. 4. Crack growth rate V (m/sec) as a function of impact speed v(m/sec) for: 1) serpentinite, 2) schist, 3) limestone.

Figure 4 shows V as a function of v for serpentinite, limestone, and schist; the curves resemble those for glass [2, 3] and rosin [3]. V attains its limit for v of 600–800 m/sec in the serpentinite and schist,

Table 1

Rock	$\varkappa$	ρ	C	V	V/C
Serpentinite	3	2430	3200	1180	0.37
Limestone	10	2670	5750	2150	0.38
Limestone	10	2690	5350	2000	0.37
Diabase porphyry	13	2640	5040	1830	0.36
Schist	13	2650	4850	2250	0.46
Altered tuff	20	2530	4740	1870	0.40
Paragneiss	14	2640	4700	2400	0.51
Diorite porphyrite	16	2750	5040	1850	0.37
Andesite	20	2710	5620	2500	0.44
Listvinite	13	2700	5950	2050	0.35
Sandstone	20	2630	5220	1940	0.37
Hornfels	20	2590	6150	2070	0.34
Gneissoid schist	20	2930	5650	2700	0.48

Table 2

Rock	V	v			
		1200	830	500	350
Serpentinite	1215	1140	1180	815	570
Limestone	2320	2700	2150	850	790
Schist	2500	2400	2250	1350	810

and there are reasons for supposing that the V measured for v = 830 m/sec are nearly the maximal ones, which may thus be considered as characteristics of the rock.

These results, strictly speaking, are the speeds for propagation on free surfaces of unstressed small specimens. The relationships may be different for massive rocks, because the free surfaces are absent, there are no nonuniform compressive stresses, and deep cracks may not follow the laws for surface cracks.

These factors should mainly tend to raise the limiting v without marked effect on the limiting V, but this needs confirmation, especially from the use of large specimens. The present method appears very promising for this purpose.

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