
FAILURE OF ROCK SUBJECTED TO HIGH-SPEED IMPACT

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1. Studies of rock failure under a dynamic load are oriented primarily toward blast processes, considering that the quality of blast-induced fracturing assumes paramount significance in the technology of mining operations. In this respect, it is not only the traditional concern with oversized fragments but also the overall fragment size distribution in fractured rock that is important. The problem of achieving a desired fragment size distribution will obviously become all the more critical with time; this is determined by the requirements of the specific technology of raw-material excavation. Determination of experimental and theoretical relationships between the parameters of fragment size distribution and the dynamic-loading conditions is of certain interest in relation to similar problems. Relationships of this kind exist in quasi-static loading [1].

There are far fewer studies for dynamic-loading conditions and they are more indirect in nature. For example, Rodionov et al. [2] describe the results of experiments on the blast-induced fracture of synthetic resin specimens in which the relationship between the size of the average lump and the character of the size distribution and the distance of the concentrated charge during blasting is obtained. Reference [3] in which the author concerns himself with confirmation of the Rittinger and Kirpichev-Kik energy hypotheses, which are known from concentration technologies applied to blast-induced fracture is devoted to energy evaluation of the blast effect on fragment-size formation during brittle fracture of ceramics. In this case, however, the question concerning blast efficiency remains unanswered, since the tests were conducted on thin plates.

2. We conducted a series of experiments on the fracture of rock specimens impacted against a rigid obstacle to define energy relationships for the character of failure more precisely. The hypothesis of the possibility of lowering energy outlays for the excavation of ore materials by loading the ore more vigorously in the initial stages of mine production — in conducting massive blasting — has been expressed in recent years. The vigorous
loading of ore can be accomplished in precisely the same manner using high-speed impact. In this case, this problem can be solved technically by various methods.

In the experiments described below, the in-flight velocity of the specimen toward the obstacle was varied from 50 to 250 m/sec; this corresponds to a change of more than an order of magnitude in the specimen's kinetic energy. The velocity of the specimen was measured by optical methods with an accuracy to 5%. The experiments were conducted on specimens of white marble (Koelga), red marblized limestone (Buravshchin), sandstone (Taldynsk Pit, Production Union Kemerovugol'), and quartz porphyry (Dal'negorsk). Some of the characteristics of the rocks investigated are presented in Table 1. The longitudinal speed of sound was measured for each specimen, and the compressive strength selectively. In all cases, the specimens tested were of cylindrical shape 30 mm in diameter and from 20 to 70 mm high. The specimens were accelerated from rest to the required velocity in a gas gun operating on compressed gas. A massive steel plate 50 mm thick served as the obstacle. After collision with the target, the fragments were collected in a specially constructed trap with a mechanized gate, which operates from an optical signal during the flight of the specimen. From 90 to 100% of the initial mass of the specimen was collected in the tests. After fracture, the gradation was determined for each specimen as a result of a standard sieve analysis. Plots of the fragment size distribution of several fractured specimens are presented in Fig. 1 for similar impact velocities, but for different rock (for the sandstone, which is denoted by the small circle, the impact velocity \( u = 145 \) m/sec; it was 141 and 138 m/sec for the quartz porphyry (+ sign) and red marble (\( \ast \) sign), respectively. In \( x_i \) \( (x_i \) is the mesh size for the sieve analysis) and \( \ln \ln m/m_+ \) \((m_+ \) is the cumulative percent passing, the mass of all fragments having a size greater than \( x_i \)) are used as coordinates. Similar coordinates are normally used in plotting a Weibull distribution. The experimental value of the average fragment was determined from the equation

\[
\langle x \rangle = \sum_{i=1}^{n} x_i \cdot \Delta p_i = \sum_{i=1}^{n} x_i \cdot \Delta m_i/m,
\]

and the dispersion of the grain-size distribution

\[
D = \sum_{i=1}^{n} (x_i - \langle x \rangle)^2 \Delta p_i,
\]

where \( x_i \) is the average size of the \( i \)-th group, \( \Delta m_i \) is the mass of the \( i \)-th group, \( i \) is the number of groups subjected to sieve analysis, and \( \Delta p_i \) is the probability of the formation of a fragment in the range from \( x_i \) to \( x_{i+1} \).

It is expedient to correlate the average fragment size to the specimen's energy in the dimensionless variables \( \langle x \rangle/l \) and \( W/\sigma_{\text{com}} \) (\( W = m u^2/2V \) is the specific kinetic energy of the specimen, and \( V \) is its volume). The corresponding relationships for the red marble, sandstone, and syenite are shown in Figs. 2-4. The straight line drawn through the experimental points in the diagrams of least squares approximations. The experimental \( \langle x \rangle/l \)-(\( W/\sigma_{\text{com}} \)) curves are approximated rather reliably in the velocity interval investigated in the following manner for the red marble and sandstone:

\[
\langle x \rangle/l = 3.99 \cdot 10^{-2}(W/\sigma_{\text{com}})^{-0.725}, \quad D/l^2 = 3.73 \cdot 10^{-3}(W/\sigma_{\text{com}})^{-0.844};
\]  

sandstone

\[
\langle x \rangle/l = 2.02 \cdot 10^{-2}(W/\sigma_{\text{com}})^{-0.697}, \quad D/l^2 = 2.08 \cdot 10^{-3}(W/\sigma_{\text{com}})^{-1.03}.
\]