ROCK BREAKING

DETONATION OF COMMERCIAL EXPLOSIVES PARAMETERS OF THE SHOCK WAVES PRODUCED AT THE EXPLOSIVES/ROCK BOUNDARY BY THE DETONATION OF AMMONITE 6ZhV CHARGES

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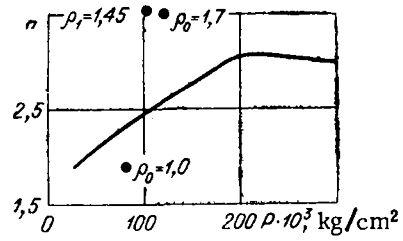
UDC 622.235.2

If the pressure at the Jouguet point has been determined and the shock adiabatic curve of the detonation products of a given explosive charge is known, one may calculate the pressure and mass velocities at the interface with rock, the shock adiabatic curves of which are known. Determination of the detonation parameters of a charge of given density gives only one point on the shock adiabatic curve of the explosion products (Jouguet point). To construct the shock adiabatic curve of the detonation products, we must know the equation of their state.

However, as shown by Kuznetsov et al. [1], for these purposes the power-law relation between pressure and density, of the form $p = A\rho^n$ (assuming that A and n are constant, or taking account of the n vs ρ curve), is sufficiently accurate. To obtain the dependence of the polytropic exponent on the density of the products in powerful explosives, we may use the dependence of the detonation parameters on the initial density, assuming that the composition of the products does not vary greatly [2].

It was initially felt that such a procedure could be used in the case in question. However, the results of investigations in [3] revealed that the pressure and density of the explosion products do not increase markedly with increasing initial density of the explosives, whereas the polytropic exponent does show a marked increase. For comparison, Fig. 1 shows the n vs ρ curve constructed from experimental data on hexogen, based on the D vs ρ_0 and u vs ρ_0 curves. This figure also gives the points for ideal detonation conditions of ammonite 6ZhV of different densities. The composition of the detonation products of ammonite 6ZhV may differ markedly from that of the detonation products of hexogen, as may be seen from the polytropic exponents at the same pressures. However, this difference is not very great for ammonite 6ZhV with density $\rho_0 = 1.0$ g/cm^3; for $\rho_0 = 1.45$ and 1.7 g/cm^3 the analogous points are located at a considerable distance from the n vs ρ curve of hexogen. This difference between the polytropic exponents for ammonite 6ZhV of different initial densities is apparently due to the change in the composition of the products with the density. The change in the polytropic exponent affects the shape of the shock adiabatic curves. This may be seen from Fig. 2, which gives the shock adiabatic curves of the explosion products of ammonite 6ZhV charges with $\rho_0 = 1.0$ g/cm^3 and d = 80 mm, with the following parameters at the Jouguet point: $p_1 = 75 \cdot 10^3$ kg/cm^2 and $u_1 = 1.62$ km/sec (curves 1 and 2, starting from point A toward u > 1.62 km/sec). Curve 1 was constructed on the assumption that n = const = 1.8, in accordance with data for charges with ρ_0 = 1.0 g/cm^3; curve 2 was constructed with an allowance for the n vs ρ curve from experimental data of $D(\rho_0)$ and $u_1(\rho_0)$. Mirror reflections of the corresponding adiabatic curves (see Fig. 2, curves 1' and 2') were constructed on the u < 1.62 km/sec side. It will be seen from the position of the curves that an increase in the polytropic exponent from 1.8 to 4.0 increases the pressure on the absolute rigid wall (u = 0, axis of ordinates) from $188 \cdot 10^3$ to $246 \cdot 10^3$ kg/cm^2 (by ~ 31%). In real media with specific rigidity, this difference will be somewhat less. For example, for copper the points at which the shock adiabatic curve (see Fig. 2, curve 1) intersects the same retardation curves [n = 1.8 and n(ρ)] give pressures of $157 \cdot 10^3$ and $188 \cdot 10^3$ kg/cm^2, respectively, which is an increase of p by ~ 20%.

Institute of Chemical Physics, Academy of Sciences of the USSR, Moscow. Translated from Fiziko-Tekhnicheskie Problemy Razrabotki Poleznykh Iskopaemykh, No. 2, pp. 34-37, March-April, 1971. Original article submitted February 9, 1970.



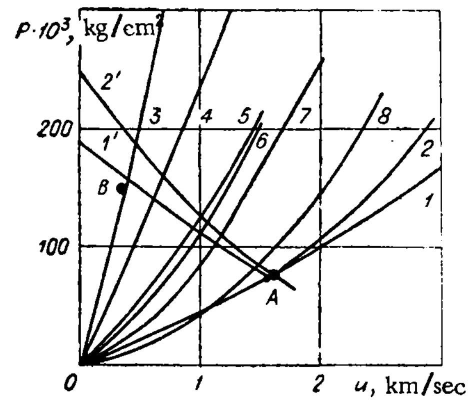


Fig. 1

Fig. 2

Fig. 1. Polytropic exponent of detonation products of hexogen and ammonite 6ZhV vs pressure (curve – hexogen, points – ammonite 6ZhV).

Fig. 2. Shock adiabatic curves of detonation products of ammonite 6ZhV charges with ρ_0 = 1.0 g/cm³ and certain dense media: 1) ammonite 6ZhV, polytropic exponent n = 1.8; 2) ammonite 6ZhV, n = n(ρ); 3) copper; 4) dunite; 5) granite; 6) basalt; 7) limestone; 8) argillaceous siltstone.

TABLE 1. Shock Wave Parameters in Certain Rocks

Rock / Ammonite 6ZhV, ρ_0 = 1.0 g/cm³	Dunite		Granite		Basalt		Limestone		Argillaceous siltstone	
	$p\cdot 10^3$, kg/cm³	u, km/sec	$p\cdot 10^3$, kg/cm³	u, km/sec	$p\cdot 10^3$, kg/cm³	u, km/sec	$p\cdot 10^3$, kg/cm³	u, km/sec	$p\cdot 10^3$, kg/cm³	u, km/sec
d=80 mm	138,0	0,62	110,0	0,99	108,0	0,96	99,0	1,1	89,0	1,42
d → ∞	149,0	0,67	126,0	1,00	122,3	1,05	115,0	1,19	92,9	1,54

To determine which one of the shock adiabatic curves [with n = 1.8 or with n (ρ)] corresponds most closely to actuality, we measured the parameters in copper. In copper plates loaded by detonation of an ammonite 6ZhV charge of diameter 80 mm with ρ_0 = 1.0 g/cm³, the velocity of the shock wave varied. The thickness of the plate was selected so that it excluded the effect of high pressure in the zone of the chemical reaction of the detonation wave. In accordance with this, the measurements were performed on a base 12 mm from the explosives/metal boundary. The pressure and mass velocity were calculated from the recorded values of the velocity of the shock wave and the shock adiabatic curve of copper (Fig. 2, curve 3 [4]). The values of the parameters p = 150 · 10³ kg/cm³ and u = 0.36 km/sec are denoted in Fig. 2 by the letter B. The position of this point is close to the value calculated with n = 180.

Note that the use of the polytropic exponent n = 3 for calculating the shock-wave parameters at the interface from known values of the detonation velocity may lead to serious errors, because in this case, as well as the inaccuracy of the shock adiabatic curve of the explosion products, the overall error is affected by the inaccuracy of the determination of the detonation pressure, which is sensitive to a change in n($p = \rho_0 D^2/n$). The coincidence of the experimental and calculated values of the shock-wave parameters in copper indicate that to construct the shock adiabatic curve of the detonation products and to calculate from this curve the shock wave parameters at the interface, in dense media we may use with reasonable accuracy the power law $p = A\rho^n$, where A and n are constants determined from the detonation parameters at the Jouguet point of a charge of explosives of a given type, diameter, and density.

As an example, Fig. 2 shows the shock adiabatic curves of certain rocks (curves 4-8), taken from [5-8]. Table 1 gives the pressures and the mass velocities created by them at the interface by ammonite 6ZhV charges with ρ_0 = 1.0 g/cm³ and, for comparison, the values of the shock wave parameters, obtained from 6ZhV charges with d = 80 mm and d → ∞. In all cases, the parameters were obtained graphically from the points at which the corresponding shock adiabatic curves of the rocks intersect the retardation curves.

TABLE 2

Rock	ρ_0, g/cm^3	A	B	Reference
Basalt	2.67	2.6	1.60	[6]
Gabbro	2.98	3.5	1.32	[5]
Granite	2.67	3.6	1.00	[6]
Halite	2.16	3.5	1.33	[6]
Argillaceous siltstone	1.77	0.577	1.78	[8]
Dunite	3.30	6.3	0.65	[5] $\leq p = 298 \cdot 10^3$ kg/cm^2
Dunite I	2.90	4.5	1.29	[7] $p > 300 \cdot 10^3$ kg/cm^2
Dunite II	2.96	4.54	1.37	[7]
Dalerite	3.05	4.10	1.325	[7]
Limestone	2.50	3.4	1.27	[6]
Limestone	2.40	1.136	2.215	[8] $\leq p = 148 \cdot 10^3$ kg/cm^2
Olivine	3.0	5.0	1.14	[9]
Olivinite I	3.31	5.08	1.287	[7] $\leq p = 136 \cdot 10^3$ kg/cm^2
Olivinite II	3.21	5.23	1.27	[7] $p > 327 \cdot 10^3$ kg/cm^2
Olivinite dialogite	3.01	5.33	1.12	[7]
Olivinite diabase	3.13	4.48	1.326	[7]
Ore olivinite	3.69	4.96	1.324	[7]
Slate	2.0	3.6	1.34	[6]
Ecstatic rock	3.23	5.3	1.265	[7]
Ecstatic gabbro with olivine	3.15	4.66	1.355	[7]

To simplify calculation of the shock wave parameters at the interface, the shock adiabatic curve of the detonation products of ammonite 6ZhV charges with $\rho_0 = 1.0$ g/cm^3 and d $\geq$ 80 mm may be approximated by a single analytic equation: $p = 43\,u + 2u^2 + 0.8\,u^3$, where u is in km/sec and p in 10^3 kg/cm^2. A previous communication [3] gives the pressures at the Chapman–Jouguet points of charges of different diameter, necessary for the calculations.

Using a similar procedure, we may determine the parameters at the interface, created by the detonation of ammonite 6ZhV charges with $\rho_0 = 1.0$ g/cm^3 in different rocks, the shock adiabatic curves of which are known. Table 2 gives the shock adiabatic curves of a number of rocks, taken from various sources. This table also gives the values of the initial density and the coefficients A and B in the equation of the shock adiabatic curve of D vs u: $D = A + Bu$ (D and u are expressed in km/sec).

We would like to thank M. N. Khadakhanov, S. F. Kuznetsov, and L. A. Sinel'nikova for their help.

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