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THE CRITICAL DIAMETER OF DETONATION OF PETN SINGLE CRYSTAL

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ABSTRACT The plot of detonation velocity vs. inverse radius curves and critical diameters (d_{cr}) were obtained for PETN single crystals shocked parallel [001] and [110] crystal planes. d_{cr} was found dependent on the detonation wave orientation, being 11~14 mm for the [110] and 5~7 mm for the [001] planes. New results were compared with the previous data for PETN single crystal d_{cr} and J. Dick's shock initiation experiments.

KEY WORDS single crystal, critical diameter, detonation.

INTRODUCTION

The published data on critical diameters of detonation (d_{cr}) [1,2] and shock wave initiation sensitivity [3,4] point out unusual properties of single crystal explosives unknown for pressed and liquid samples.

The PETN single crystal shock wave initiation sensitivity was found dependent on the shock direction[3]. Taking into account of correlation between the shock wave sensitivity and d_{cr} based on the explosive decomposition rate and detonation front curvature[5], one can suppose that d_{cr} of PETN single crystal can change depending on the shock wave orientation.

In this paper we present the values of d_{cr} obtained for PETN large single crystals shocked at different shock wave orientations relative to the crystal axes.

1 EXPERIMENTS

PETN crystals were grown from saturated acetone solutions by gradient temperature method[6]. Their characteristics are well known[7]. These crystals are of tetragonal syngony, $P_{42_1}c$ two molecules of $C(CH_2ONO_2)_4$ being

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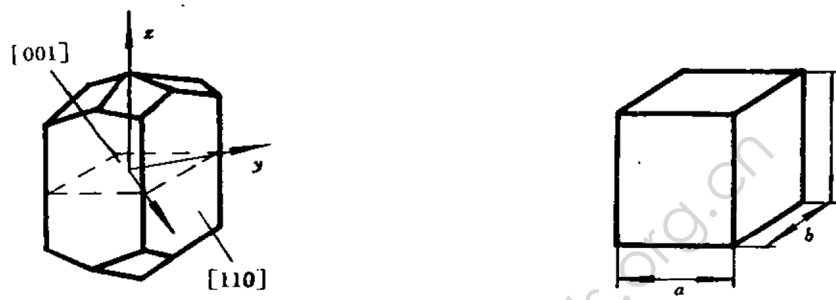
in one unit cell, calculated density 1.78 g/cm^3. The *a* and *b* axes pass through the edges of the facets and the *c* axis-through the top of the crystal. The samples used in experiments had no visible defects. Their density was equal to 1.778±0.001 g/cm^3. Samples were obtained by machining the [001] plane of the original crystal (Fig. 1).



a)　　　　　　b)

Fig. 1

a) PETN single crystal; b) a sample, $a \approx b$

Sizes of the sample detonation failure determined from the plot of detonation velocity vs. radius curve. Detonation velocities were measured by means of the ionization pins method and of the streak-camera records simultaneously. Usually the experimental assembly consisted of 2～5 samples with the similar sizes. Charges initiation was carried out by plane wave lens with average peak pressure 30 GPa. Detonation velocities summarized in Table 1 (column 7) were received from the pin measurements. The streak camera records data were the same.

2 DISCUSSION

The cylindrical charge d_{cr} is often used for the estimation of the detonation expansion limits. Our results correlate with the known d_{cr}[1,2]. If Chen-Kennedy's method for the shock wave evolution in chemically reacting matter is taken to calculate equivalent radii. d_{cr} may be presented as

$$d_{cr}/2 = (xy)/(x+y)_{cr} \tag{1}$$

Where x,y are sizes of the sample (*a*,*b* or *c* on Fig 1,*b*). We used the approximation (1) to calculate equivalent radii (column6,Table 1). The correspondence of equivalent radii to the radii of cylindrical charges was checked

Table 1 PETN single crystal detonation velocities

Shot number	Shock wave orientation	Size *a* (mm)	Size *b* or *c* (mm)	Base (mm)	Equlvalent radius *d*/2 (mm)	Detonatlon velocity *D* (km/s)
1	2	3	4	5	6	7
1	[110]	30.2	35.0	60	16.2	8.28±0.03
2	[110]	21.7	25.0	32	11.6	8.06±0.06
3	[110]	21.3	20.0	25	10.0	8.07±0.06
4	[110]	18.2	22.0	47	9.95	8.14±0.03
5	[110]	18.6	15.9	25	8.6	8.07±0.08
6	[110]	13.8	18.5	38	7.9	7.47±0.04
7	[110]	14.5	17.0	25	7.8	7.44±0.06
8	[110]	12.1	16.0	38	6.9	7.13±0.04
9	[110]	10.6	11.3	42	5.5	failure
10	[110]	9.8	11.9	30	5.3	failure
11	[110]	8.9	9.9	30	4.7	failure
12	[110]	8.5	8.7	70[1]	4.3	failure
13	[001]	17.5	17.5	27	8.75	8.29±0.04
14	[001]	16.0	19.2	22	8.7	8.03±0.05
15	[001]	18.0	16.2	21	8.5	8.26±0.04
16	[001]	15.4	14.1	25	7.35	8.21±0.03
17	[001]	13.1	13.6	17	6.7	8.05±0.06
18	[001]	12.5	12.6	27	6.3	8.13±0.04
19	[001]	12.1	12.7	17	6.2	8.15±0.06
20	[001]	11.2	11.9	17	5.75	8.19±0.06
21	[001]	11.6	12.0	10	5.9	8.16±0.08
22	[001]	9.2	9.1	17	4.6	8.04±0.05
23	[001]	10.0	8.6	15	4.6	7.88±0.08
24	[001]	8.7	8.8	39	4.4	7.81±0.08
25	[001]	6.4	7.0	30	3.4	7.29±0.03
26	[001]	6.1	6.4	12	3.1	6.98±0.07
27	[001]	6.0	5.9	73[1]	3.0	failure
28	[001]	5.3	5.2	15	2.6	failure

1) Detonnation velocity decrease and failure.

for several explosives. For example the dependence of TATB cylindrical charges detonation velocities from inverse radii are given on Fig. 2. Data for TATB charges of the plate form (10 mm width) are given too. The last results show very good agreement with previous ones.

Data for PETN single crystals are shown on Fig. 2. One can see the essential differences in velocities and d_{cr} vs. direction of the detonation wave propagation. If the sample was shocked parallelly to the [110] plane, then d_{cr} was 11～14 mm, and d_{cr} diminished to 5～7 mm when shocked parallelly to the [001] plane. These results are in good agreement with data [1,2] where it was found d_{cr} is greater than 8.4 mm for [110] shock initiation plane and 5 mm for the [001] plane.

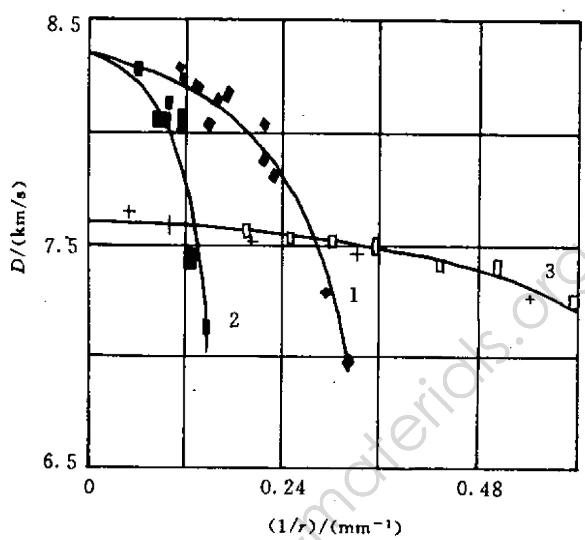


Fig. 2 Detonation velocity vs inverse radius.
1. PETN, initiated on the [001] plane, ◆;
2. PETN, initiated on the [110] plane, ■;
3. TATB, $\rho_0=1.87 g/cm^3$, particle size 1~10μm, cylindrical charges, +; plate charges, □.

Using Chen-Kennedy's equation for the plane shock front acceleration in the chemically reacting matter[5]

$$\frac{\delta u^{-}}{\delta t} = A(u^{-})(\partial_t u^{-} - \lambda_{ch}) \quad (2)$$

Where u^{-} is shock front particle velocity, λ_{ch} is chemical part of the critical acceleration, $A(u^{-})$is a function dependent on the thermomechanical properties of the matter, we obtained relation between λ_{ch} and d_{cr}

$$d_{cr} = -\frac{4(D-u^{-})u^{-}}{\lambda_{ch}(1-\mu)}\cos\beta \quad (3)$$

Where D is detonation velocity, $\mu=-\rho_0^2D^2/\alpha_v P$, β is the angle between the shock front and the charge surface.

All parameters in equations (2) and (3) except λ_{ch} are indepenenton the shock wave orientation[3], thus only λ_{ch} determines the effect of the single crystal orientation. According to equations (2) and (3) the run distance to detonation and d_{cr} decrease with the increase of λ_{ch}, thus our data disagree with Dick's experimental measuremets[3]. Dick J found that the PETN single crystals shocked up to 12.4 GPa, the run distance to detonation is 4.6 mm for [110] and 9.5 mm for [001] planes. We assume that the "hot spots" formation mechanism explains this difference. Explosive chemical decomposition rate $(\partial \xi)$ near the shock front is proportional to the hot spots concentration but this concentration may be different at the plane and curve shock fronts at the same crystal orientation.

The detonation velocities near the d_{cr} summarized in the Table 1 show large scatter which is greater than experimental errors. Joint-effect probably determines those phenomena.

PETN D vs $(1/r)$ curves shown on Fig. 2 point out a considerable difference between the ideal and critical velocities exceeding 10^3m/s. This difference is typical for heterogeneous charges but unusual for homogenous explosives. However, according to the hot spots model for PETN single crystal shock wave initiation[3,4], one can expect heterogeneous behaviour of single explosives.

Using equation (3) and reaction rate parameters for the [110] PENT single crystal[4], we made attempt to calculate d_{cr}. The result was 30 mm twice than the experimental value. We suppose that reaction rate constants obtained from plane wave experiments are incorrect for the calculation of PETN single crystal d_{cr}.

3 CONCLUSION

Experimental observation of detonation velocities and d_{cr} of PENT single crystals shocked parallelly to the [001] and [110] planes allows us to confirm that:

——PETN single crystals show nonhomogeneous explosive behaviour;

——PETN single crystals have different d_{cr} at different detonation direction, i.e. 11~14 mm for the [110] plane and 5~7 mm for the [001] plane.

Comparision of these results with a theoretical calcuiation of d_{cr} and Dick's experiments shows that the hot spot concentration near the front of shock wave is determined by the shock front curvature and not only shock wave parameters at the same direction of the wave propogation.

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