archiwum
termodynamiki
i spalania
VOL. 8 (1977) NR 1

Some phenomena of detonation of solid explosives

TADEUSZ URBAŃSKI

Technical University of Warsaw, Warsaw

Between 1926 and 1939 the author of the present review-article published a number of papers concerning the phenomenon of detonation. Some of the results were confirmed by later investigators with the use of more modern methods, but some of them were overlooked and have only recently been "re-discovered" by other authors.

It seems appropriate to have now a review which could serve as a reminder of the early work, with some up to date comments.

1. Detonation spin

The author published two papers 1926–27 [1] where he described his experiments on open lens photography of detonation of explosives in glass tubes. Particularly interesting patterns were obtained on photographic plates with detonations of mixed explosives, composed of ammonium nitrate (50–80%), trinitrotoluene (8–15%), nitroglycerine (4–25%), potassium perchlorate (0–5%), and woodmeal (0–25%). Some of the explosives contained 10% Al, and some sodium chloride (7–20%).

Also, nitro compounds such as trinitrotoluene showed a similar pattern at low density.

The picture was composed of light and dark bands with clearly a sinusoidal shape. This led the author to express the view that detonation in a tube can progress along a spiral path thus showing "detonation spin".[1)]

At the same period British authors — Campbell, Bone and coworkers — published a number of papers [2]–[4] where they indicated a possible spiral path of gas mixture detonations such as oxygen with carbon monoxide, hydrogen, cyanogen etc. This was indicated not only by film records of the detonations but also by mechanical phenomena, when the inside of the tube was covered with talcum powder [3] or when detonations of mixtures of carbon monoxide with oxygen were carried out in a lead tube inserted inside a wider glass tube [4]. It was calculated that the detonation spin had an approximate frequency of 50000 revolutions/s.

Further experiments with gas mixtures were carried out by Laffitte and Breton [5]. They came to the conclusion that the phenomenon of spiral detonation paths was particularly prominent in gas mixtures containing the combustible ingredient in a concentration close to either the lower or the upper detonation limit.

[1)] Unfortunatelly all photographs were destroyed during World War II

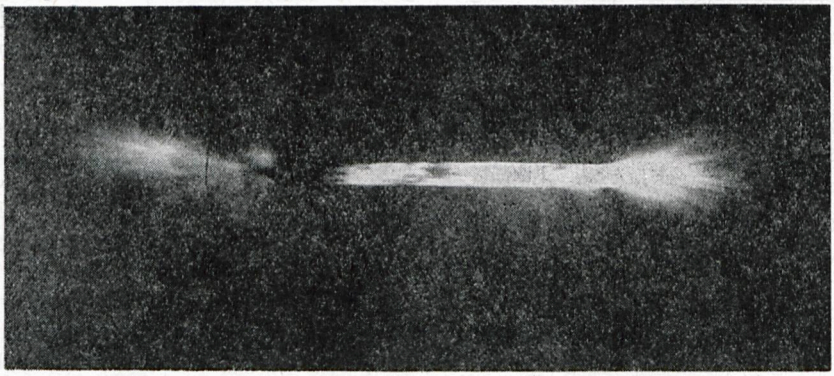

Fig. 1. Detcnation of TNT/Ammonium Nitrate mixture 22/78 in glass tube 21.5/23 mm diamater. Photographs taken at 10^{-4} intervals. The ignition with a No. 8 detonator was on the left. The sinusoidal dark path can be seen

Fig. 2. Detonation of TNT/Nitroglycerine mixture 96/4 in a celluloid tube 27 mm diameter. The source of ignition was a No. 8 detonator. Photographs taken at 10^{-4} interval. The spiral path should be noted

The fact that gas-mixtures could give a spinning detonation encouraged the author of the present article to continue the work by an improved method. An apparatus was built for this purpose recording images at 10^{-4} s intervals [6].

The new experiments [7] confirmed the previous findings, of a detonation spin, particularly when two conditions were fulfilled:

— mixed explosives were used, e.g. those composed of ammonium nitrate and trinitrotoluene (in proportion 78/22) or ammonium nitrate sinsitized by an addition of nitroglycerine (in proportion 96/4),

— explosives were confined in glass tubes.

Figures 1–3 depict some characteristic images recorded by the author.

The reason why the detonation spin exists in solid mixed explosives should probably be explained as indicated in the first paper [1], by the non-uniformity of the detonating medium which is marked not only by a non-homogeneity of the mixed explosives but also by a non-homogeneity of the reacting medium due to various exo- and endothermic reactions.

It is also known that rotation in a gas-flow through a tube can be created when the pressure in the perifery differs from that in the centre. This seems to be the basic cause of cyclones [8].

Fig. 3. Detonation of TNT/Ammonium Nitrate mixture 30/70 in a glass tube 45/48 diameter, perpendicular to the photographic plate. The ignition was with a No. 8 detonator from the side of the photographic apparatus (fowards the outside). The central part is the detonation of the explosive. Below is the secondary flame of gases mixed with air. Both show "cyclone" helics

Later, Muraour [9] and Persson [10] confirmed the early (1926–27) [1] findings of the author of the present paper. Recently Zimmer [11] came to the conclusion that the slow explosion of nitroglycerine is manifested by a spiral mode of propagation.

2. The channel effect

It is well known that explosives which detonate readily in open or semi-tight containers can only partly detonate in a closed space such as a stemmed bore-hole. The phenomenon, known for a long time, appeared to be described for the first time by Stettbacher [12] while reporting on the drilling of the Simplon tunnel.

When shots of an explosive "Venderit" were fires in long bore-holes, some cartridges did not detonate: they were those placed further away from the detonator and from the primed cartridge. It was found that the probability of non-detonation of the cartridges increased when those were air-gaps between the cartridges or when the diameter of the bore-hole was considerably larger than that of the cartridges.

The author of the present paper endeavoured to explain the phenomenon by assuming that the shock-wave sent by the detonation of the primer cartridge could probably move at a higher rate than the detonation-wave, thus compressing some of the undetonated cartridges to a density which made a detonation difficult if not impossible ("dead compression").

With this in view of the author of the present article carried out three series of experiments [1]:

a) the influence of the density of the cartridges on their transmission gaps,

b) the influence of the confinement on the transmission gap,

c) the velocity of the shock-wave sent out by the explosive as compared the velocity of the detonation wave.

2.1. Transmission of the detonation ("gap test") as a function of the density of ammonium nitrate explosives

This was carried out with 100 g cartridges of 30 mm diameter in paper impregnated with paraffin wax. Typical curves for explosives "Ammonit 4", "Bradyt C" and "Bradyt F" (composition — see Table 1) are given on Fig. 4. The shape

of the curves for a number of other ammonium nitrate explosives was very similar and those in Fig. 4 are given as examples.

It follows from the results that the rate of propagation of detonation of ammonium nitrate explosives containing nitroglycerine (Bradyt C and F) fell after the density had increased beyond 1.15. An ammonium nitrate explosives without nitroglycerine (Ammonit 4) was still more sensitive to a change of density and the rate of propagation fell after the density had increased above 0.90.

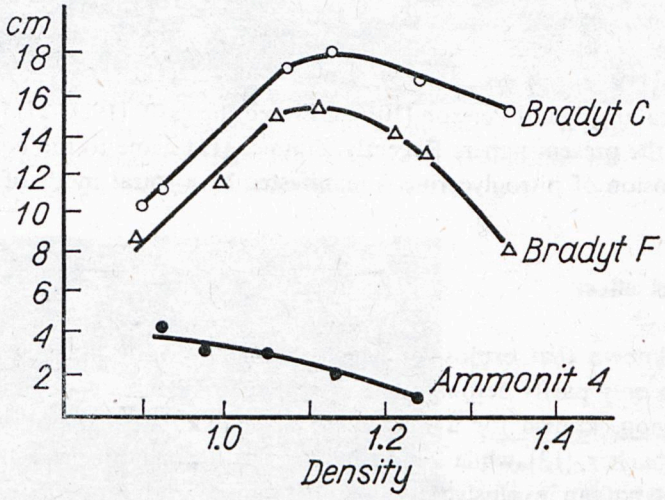

Fig. 4. Gap test in the open as a function of the density of ammonium nitrate explosives (100 g, 30 mm diameter cartridges in paper evelopes)

Table 1

	NH_4NO_3	$KClO_4$	Nitro-glycerine	TNT	Charcoal	Wood-meal	NaCl
Ammonit 4	76.0	10	—	10	—	4	—
Bradyt C	64.7	—	4	8	2	—	20
Bradyt F	77.5	4	4	4	—	1.5	9

2.2. Influence of confinement on the transmission of detonation

Experiments were carried out with cartridges of the same size as in experiments (a), in a mortar of the experimental gallery at Łaziska Górne. The diameter of the borehole was 55 mm. The results are presented in Table 2.

A marked increase in the size of the gap was recorded with ammonium nitrate explosives (e.g. from 15 cm to 24 cm) but the change with chlorate and perchlorate explosives was most striking: Miedziankit and Territ respectively.[2)]

[2)] The composition of the explosives was: Miedziankit — 90% $KClO_4$, 10% Kerosine; Territ — 43% NH_4ClO_4, 28% $NaNO_3$, 27.8% liquid TNT, 1.2% Collodion Cotton

Neither explosive do not transmits detonation from one cartridge to another in the open, i.e. the gap is 0. In the bore-hole, however, the gap with Miedziankit exceeded 40 cm. Territ gave a figure at 35 cm. These figures were lowered when stemming was applied.

Table 2

Explosive	Density	Det. cap No.	Gap test in cm		
			in open	in the mortar 55 mm dia	
				with stemming	without stemming
Bradyt C	1.08	8	18	25	22.5
	1.30	8	15		19
Bradyt F	1.06	8	15	24	23
	1.28	8	10		22
Miedziankit	1.70	8	0	40*)	30*)
	1.70	6	0	40*)	17*)
	1.70	3	0	38	12
Territ	1.45	8	0	35	12

*) The exact figure could not be determined owing to the limited length of the bore-hole

2.3. The rate of propagation of shock-waves in open and in a steel-tube

The same size cartridges as in experiments (a) and (b), of Bradyt F, were used. The rate of propagation detonation was determined by the Dautriche method in the open and in steel-pipes of 35/42 mm diameter. The gap between two cartridges was 100 mm and the velocity of the shock-wave was measured as shown in Fig. 5 at a distance α between 0 and 50 mm, and β between 50 and 100 mm.

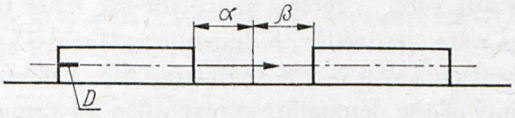

Fig. 5. Determination of the rate of propagation a shock-wave between two cartridges. Gaps: $\alpha = 50$ mm, $\beta = 50$ mm, D — detonator

This clearly slows (Table 3) that the velocity of a shock-wave in a steel-pipe can be higher than the velocity of a detonation whereas in the open it falls rapidly with distance.

Table 3

	In the open	In a steel-tube 35/42 mm dia
Detonation velocity [m/s]	2740	3220
Shock-wave velocity [m/s]		
α	1815	
β	ca 560	3830

Chemisch Technische Reichsanstalt [13] examined the propagation of the luminous effect emitted in vacuo by detonating explosives. They found that the luminosity could have a higher rate of propagation than the detonation wave. Thus, explosives with detonation velocities of 3150–8200 m/s can show rates of propagation of the luminous front of 6200–16200 m/s. Gawthrop [14] reached a similar conclusion while registering the detonation on a film: an explosive detonating at the rate of 2010 m/s gave a luminous effect moving at a rate of 5420 m/s.

3. Detonation in concentric tubes

In 1933 the author described [7] experiments on the detonation of explosives in a celluloid tube placed concentrically inside a glass tube of a larger diameter. The arrangement can be seen on Fig. 6.

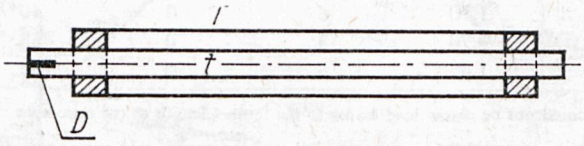

Fig. 6. Arrangement for detonation in two concentric tubes: T — outer glass tube, t — inner celluloid tube, D — detonator

If diameters of both tubes were properly chosen the inner tube could be only partly damaged. This obviously was the result of the fact that in the course of the detonation the gases broke through the inner tube walls and the pressure around the inner tube became the same as inside the tube. When ammonium nitrate-TNT mixture (e.g. 78/22) was used, a typical shape for the inner tubes was that given in Fig. 7. The results were obtained with dimentions $D=33/35$ mm and $d=16$ mm. The initiation was provided by a No. 8 detonating cap. Unevenly distributed holes indicate non-uniformity of the detonation of explosive mixture and the existence of "hot spots".

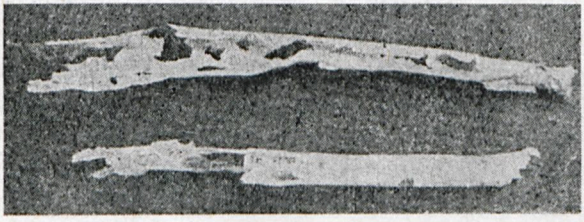

Fig. 7. Inner celluloid tubes, after detonation of ammonium nitrate/ /TNT (78/22) mixture

When pure explosives, such as TNT or picric acid were used no holes in the tubes were found. This evidently indicated a more uniform detonation.

Inside the celluloid tubes traces of undecomposed explosives were found: ammonium nitrate mixtures or pure substances such as TNT and picric acid. This is a phenomenon similar to that observed by Mallard and Le Chatelier [15] that a thin

layer of the gas mixture close to inner walls of a glass tube remains undecomposed during gas explosions.

The explanation was given by Mallard and Le Chatelier that the gas mixture is not brought to the temperature necessary for decomposition. It is now generally accepted that the detonation of explosives is not a thermal phenomenon, hence the explanation can not be accepted. The author of the present paper would line to suggest that a thin layer of the explosive in the celluloid tube was bonded to the inner walls of the tube through adhesive forces. Since celluloid is a substance which is very difficult to detonate, this produced, a slowing-down effect upon the adhering layer of the explosive and the latter could not detonate.

A similar explanation can also be given for the phenomenon observed by Mallard and Le Chatelier [15]. Here a thin layer of the gas mixture was probably absorbed by the inner surface of the glass tube and the glass inhibited the gas explosion.

Note added to the proofs

Persson [10] confirmed only the shape of the photographs taken in glass tubes. He did not agree with the suggestion of the author of the detonation spin and explained the pattern on the photographs by bursting of the tubes [17].

Praca wpłynęła do Redakcji w czerwcu 1975 r.

References

[1] Urbański T.: Roczniki Chem. **6** (1926), str. 838; Z. ges. Schiess-u. Sprengstoffw. **22** (1927), s. 270
[2] Graig E. F. in Campbell C., Woodhead D. W.: J. Chem. Soc. (1927), p. 1572
[3] Campell C., Finck A. C.: J. Chem. Soc. (1928), p. 2094
[4] Bone W. A., Fraser R. P.: Phil. Trans. Roy. Soc., London A **228** (1929), p. 232;
Bone W. A., Fraser R. P., Wheeler W. H.: Phil. Trans. Roy. Soc. London A **235** (1935), p. 29
[5] Laffitte P., Breton J.: Compt. rend. **199** (1934), p. 146; **202** (1936), p. 316;
Laffitte P.: Roczniki Chem. **18** (1938), str. 195;
Atti del X Congresso Intern. Chim., Roma 1938, vol. V p. 1008
[6] Urbański T.: Roczniki Chem. **12** (1932), str. 715
[7] Urbański T.: Roczniki Chem. **13** (1933), str. 130
[8] Exner F.: *Atmosphärische Bewegung*. Handbuch d. phys. u. techn. Mechanik. Leipzig 1928, vol. 6;
Malone Th. F.: *Compendium of Meteorology*. Boston 1952 American Meteorological Soc.;
Raethjen P.: *Dynamik d. Zyklonen*. Probleme der kosmischen Physik **27** (1953)
[9] Muraour H.: Chimie et Industrie **47** (1942), p. 3
[10] Persson P.-A.: Personal information. Stockholm 1974
[11] Zimmer M. F.: Combustion and Flame **12** (1968), p. 1
[12] Stettbacher A.: *Die Schiess-u.Sprengstoffe*. 1919, s. 47
[13] Urbański T.: Z. O/Schlesischen Berg.-u. Hüttenm. Ver. **65** (1926), S. 217
[14] Jahresber. Chem. Techn. Reichsanstalt **6** (1927), S. 95
[15] Gawthrop D. B., according to Stettbacher A.: Z. ges. Schiess-u. Sprengstoffw. **24** (1929), S. 87 and Chem. Ztg. (Fortschrittsber.) **53** (1929), S. 5
[16] Mallard R., Le Chatelier H.: Ann. des mines **4** (1883), p. 296
[17] Persson P.-A.: *Symposium on Combustion*, 1976

Niektóre zjawiska detonacji stałych materiałów wybuchowych

Streszczenie

W latach 1926–1939 autor niniejszego artykułu przeglądowego opublikował szereg prac dotyczących zjawiska detonacji. Niektóre wyniki zostały potwierdzone przez późniejszych badaczy przy zastosowaniu bardziej nowoczesnych metod badawczych, lecz część z nich pominięto i dopiero ostatnio zostały one „ponownie odkryte" przez innych autorów.

W artykule omówiono te wcześniejsze prace uzupełniając je aktualnymi uwagami.

Некоторые явления детонации твердых ВВ

Резюме

В 1926-1939 годах автор настоящей обзорной статьи опубликовал ряд работ посвященых явлению детонации. В последующих работах других исследователей использующих более современные экспериментальные методы, некоторые результаты, полученные автором, подтвердились, но часть этих результатов была оставлена без внимания и только в последнее время „вновь открыта" другими авторами.

В статье описаны эти ранные работы, дополненные актуальными замечаниями.