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Overview / Przegląd

Scaled-down test arrangements for characterizing high explosives
Zminiaturyzowane urządzenia badawcze do charakteryzowania materiałów wybuchowych kruszących

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Abstract: *Newly formulated explosives and the optimization of explosive mixtures requires an experimental determination of detonation parameters, especially detonation velocity, pressure and metal accelerating ability. Increasing material and labour costs force researchers to reduce test quantities and therefore to develop smaller scale experiments which provide sufficient data to determine an explosive's properties. Seven test set-ups found in literature are described and compared in this paper.*

Streszczenie: *Otrzymywanie nowych materiałów wybuchowych i optymalizacja mieszanin wybuchowych wymaga eksperymentalnej weryfikacji parametrów detonacyjnych, zwłaszcza prędkości detonacji, ciśnienia i zdolności do przyspieszania wyrobów metalowych. Rosnące koszty materiałów i pracy zmuszają badaczy do minimalizowania testowanych ilości, a tym samym do opracowywania eksperymentów na małą skalę, które dostarczają wystarczających danych do oceny właściwości materiałów wybuchowych. W artykule opisano i porównano pod tym kątem siedem przykładów literaturowych układów badawczych.*

Keywords: *PDV, DAX, cylinder test, detonation velocity*
Słowa kluczowe: *PDV, DAX, cylinder test, prędkość detonacji*

Symbols and acronyms

VoD	Velocity of Detonation [m/s]
M	Mass of metal [g]
C	Mass of explosive [g]
PDV	Photonic Doppler velocimetry
CJ	Chapman-Jouguet equilibrium state
JWL	Jones-Wilkins-Lee equation of state

1. Introduction

Newly formulated explosives and the optimization of explosive mixtures requires an experimental determination of detonation parameters. Detonation velocity, detonation pressure at the Chapman-Jouguet (CJ) point, characteristic Gurney velocity, and subsequent constants of the Jones-Wilkins-Lee (JWL) equation of state are the parameters of greatest interest. In industrial explosives and ammunition testing it is natural to use readily available charges of several hundred grams or kilograms. A typical sample mass required for the standard 1 inch cylinder expansion test is about 250 g. However, with the constantly increasing cost of raw materials, facilities and labour, it is necessary to design a sequence of experiments for characterizing new explosives in such a way that the maximum amount of useful information is obtained with the least number of firings and the minimum consumption of a precious sample material. Therefore, before turning to full scale testing, one or more levels of reduced scale experiments can be highly beneficial. In this short review, various test arrangements previously proposed in literature, are discussed and compared.

2. Test methods

2.1. Reduced scale cylinder expansion test (½” CYLEX)

The half-inch cylinder expansion test was originally instrumented with high speed streak camera and PDV to record wall velocity profiles. Sensitized nitromethane was used as the test material to minimize sample effects. The resulting Gurney velocities were in agreement with the standard scale test but an uncertainty increase from 1% to 4% was reported. The sample mass is reduced eight-fold, compared to the standard cylinder expansion test, to approx. 30 g. Repeatability is probably mostly limited by the manufacturing tolerances of the cylinders. The use of multiple PDV probes would allow the velocity of detonation (VoD) and repeatability of the wall velocities to be determined [1].

2.2. Disc acceleration experiment (DAX)

The DAX was developed as a simple, low-cost alternative to the CYLEX test. The explosive was filled in a plastic tube with an aluminium or copper flyer disc fixed to its end face. The test was validated using pressed PETN pellets and compared to simulation and literature data. VoD was determined using a series of piezo pins and the free surface velocity profile of the disc was measured by a single PDV channel. The free surface velocities were then converted to the CJ detonation pressure values using an impedance matching technique. The disc velocity reproducibility was within 1% with the CJ pressure error being about 2%. The DAX may be a compromise for many as it is highly modular. However, some uncertainty is introduced by extrapolation of the disc velocity profiles. Running a series of experiments with different disc thicknesses or replacement of the disc with an impedance window may be beneficial in order to improve the accuracy of the detonation pressure data [2].

2.3. CYLEX/DAX test (McDAX)

It has recently been suggested that the reduced scale CYLEX test with the DAX test be combined. The CYLEX tube expansion was tracked by multiple PDV probes which allowed VoD and multiple wall velocity profiles to be obtained. An additional PDV probe was focused on a copper disc at the charge end face. The validation experiments, using sensitized nitromethane, resulted in a reproducibility of 1-2%. The detonation pressure was determined in a different way compared to the original DAX test and was 2.5% off the literature values. This arrangement is most demanding in terms of instrumentation as it requires multiple PDV channels but it does provide the maximum amount of data from a single shot. The reported deviation of the detonation pressure value was most probably caused by the evaluation method which did not take into account the shock attenuation in the flyer. As in the case of DAX, replacement of the flyer plate with an impedance window

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is an option [3]. An explosive sample (approx. 30 g) is instrumented for measurements of VoD, wall velocity profiles at two locations, and axially accelerated flyer plate velocity, as shown in Figure 1.

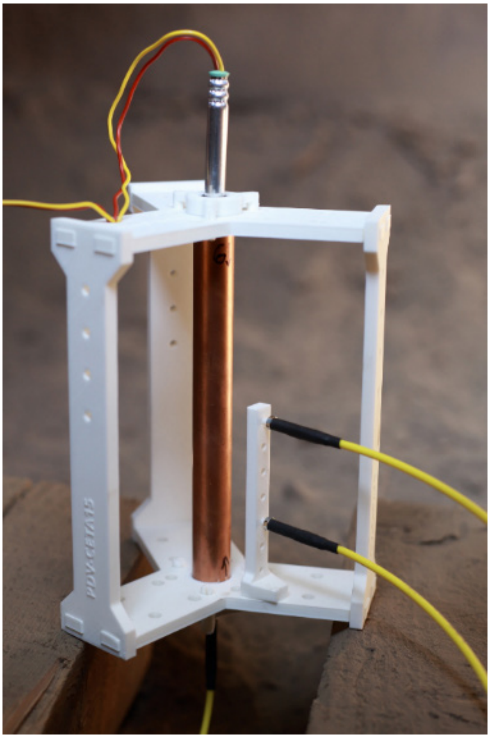

Figure 1. McDAX test fixtures (photo: authors)

2.4. Confined detonation velocity test (CVT)

This test was applied to a series of insensitive explosives based on ammonium nitrate, ethylenediamine dinitrate and various additives. A thick-walled steel tube was used as confinement to ensure stable detonation of these non-ideal explosive mixtures. The VoD was measured using a series of electric pins inserted through the tube with brisance being determined by means of the dent depth in a witness plate. The CVT is an outdated alternative regarding instrumentation as the witness plate measurements only provide a relative comparison of samples. However, it illustrates how helpful the massive confinement can be as the tested mixtures would not be able to sustain detonation when confined lightly. Applying such a massive confinement to the previously discussed DAX test may be useful for the testing of modern insensitive explosives [4].

2.5. Small-scale screening test (SST)

The SST was designed at the Lawrence Livermore National Laboratory for selecting candidate energetic materials. A plastic bonded explosive sample in the form of a small pressed pellet was initiated by a flyer plate accelerated by a separate donor charge. The test was instrumented with a Fabry-Perot interferometer for the impedance window measurement which allowed the particle velocity profile of the detonation wave to be obtained. The VoD was determined indirectly from the timing of the events resulting in the error being up to 3%. The SST allows highly useful impedance window data to be obtained using a minimum amount of explosive thanks to massive confinement. The VoD measurement is compromised but still valuable, considering the sample size [5].

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2.6. Coaxial double charge (CDC)

The CDC was developed as a non-intrusive optical technique based on the application of a multi-fibre optical strip coupled with a high speed streak camera for registering the shock and detonation wave of mini and micro samples of plastic bonded explosives. A rectangular explosive sample is surrounded by a "driving" explosive charge which serves as an active confiner. The arrangement was tested using plastic bonded explosive samples. The test outputs were VoD and also detonation pressure determined by the extrapolation of shock velocities in the Kapton foil stack attached to the end face of the charge.
The CDC requires the least amount of explosive and may be able to provide some results for insensitive explosives which would not detonate without being surrounded by the driving explosive. The results may be biased when the confining explosive is considerably more powerful than the tested sample. The resolution is limited by the uncertainty of the streak image reading [6]. An explosive sample (approx. 5 g) is characterized by measurement of VoD using passive optical probes and particle velocity profile in a PMMA window using PDV, as shown in Figure 2.

Figure 2. Modified DAX test fixtures (photo: authors)

2.7. Microsandwich test (MST)

The MST is a smaller scale version of the "Sandwich test", a planar geometry equivalent of the standard cylinder expansion test at Los Alamos National Laboratory. It is the smallest experiment to yield data for determining the reaction products' equation of state for an explosive. The test was developed and utilized for high density samples (hexanitroazobenzene) prepared by physical vapor deposition. The test was instrumented with the PDV and high speed framing camera. The MST provides data of the velocity profile of the metal confiner during explosive loading. This test uses the thinnest layer of explosive of all the tests. The number of explosives able to detonate at such a small dimension, although confined, would be limited. The evaluation of VoD from the framing camera pictures is generally possible but was not attempted by the authors [7].

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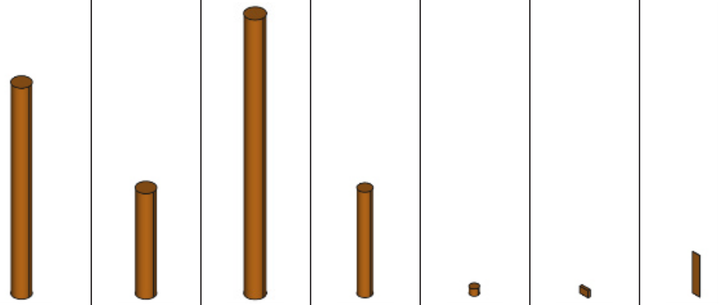
Table 1. Summary of the small scale tests

	½” CYLEX	DAX	McDAX	CVT	SST	CDC	MST
Sample volume [cm^3]	20	10	30	5.6	0.2	0.1	0.04
Charge diameter [mm]	12.7	12.7	13.5	9.7	6.35	1.9*⁾	0.2*⁾
M/C	3.5	2	3.3	30	270	n/a	7
Relative sample size and shape							
VoD	(✔)	✔	✔	✔	✔	✔	(✔)
Gurney velocity	✔	–	✔	–	–	–	✔
JWL coefficients	(✔)	✔	(✔)	–	–	–	✔
CJ pressure	–	✔	✔	(✔)	✔	✔	–
High speed imaging	✔	–	(✔)	–	–	✔	✔
VoD probes	(✔)	✔	(✔)	✔	–	✔	–
PDV	✔	✔	✔	(✔)	✔	–	✔

Note:
**⁾ thickness*

3. Summary

- The tests were compared in terms of sample quantity, diameter and confinement as shown in Table 1. The confinement is quantified by *M/C*, i.e. confiner to explosive mass ratio calculated using sizes and materials given in the original articles. The checkmarks indicate measured quantities and instrumentation applied in the tests. Checkmarks in parentheses indicate options which seem to be applicable but were not utilized by the original authors.
- This paper may help to find the optimal arrangement with regard to sample quantity, available instrumentation and/or parameters of interest.
- The extreme confinement of the SST is massive enough to considerably limit the expansion of detonation products which may allow it to be used for insensitive samples. The PDV is the most widely applicable technique for small scale testing of energetic materials.

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