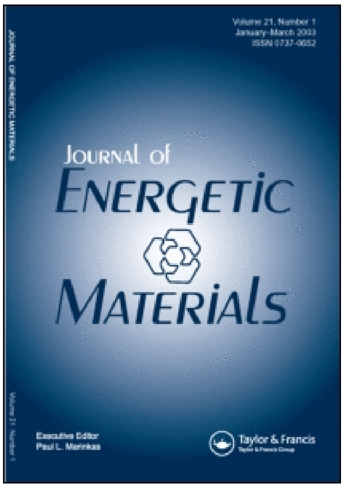

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JiřiA Vágenknecht[a]; Pavel Mareček[b]; Waldemar A. Trzciński[c]
[a] Department of Theory and Technology of Explosives, University of Pardubice, Pardubice [b] Research Institute of Industrial Chemistry Aliachem, a.s., dep. Synthesia, Pardubice [c] Department of Explosives and Physics of Explosion, Military University of Technology, Warsaw

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SENSITIVITY AND PERFORMANCE PROPERTIES OF TEX EXPLOSIVES

Jiří VÁGENKNECHT*, Pavel MAREČEK** and Waldemar A. TRZCIŃSKI***

* Department of Theory and Technology of Explosives; University of Pardubice; CZ - 532 10 Pardubice

** Research Institute of Industrial Chemistry Aliachem, a.s., dep. Synthesia; CZ - 532 17 Pardubice

*** Department of Explosives and Physics of Explosion Military University of Technology, PL – 00 908 Warsaw 49

ABSTRACT

Some sensitivity and performance properties of TEX were studied experimentally and theoretically. The TEX sensitivity to electrostatic spark was determined and tests for transportation were performed. The detonation properties, like the critical diameter, detonation pressure and Gurney energy were determined. Moreover, the detonation velocities of TEX-based cast explosives were compared with those of similar NTO-based ones.

Keywords: TEX, sensitivity, performance, detonation parameters, LOVA explosives

INTRODUCTION

4, 10-dinitro-2, 6, 8, 12-tetraoxa-4, 10-diazatetracyclo [5.5.0.05,9.03,11] dodecane (TEX) is an explosive which evidently fulfils the criteria for the explosive with a low vulnerability (LOVA). Most of its properties do not restrict its broader application in this area. But there is still a lack of confirmed information about serious activities in this field. Although some theoretical and practical analysis of the production and application of the TEX[1] have been already done, basic sensitivity and performance properties of TEX explosives are not fully recognized.

In this paper, the TEX explosive prepared at Research Institute of Industrial Chemistry (Pardubice) was tested. First, the sensitivity of this explosive to an electrostatic spark was established. The TEX explosive was also tested with regards to its classification for transportation. The examination of detonation parameters of pressed TEX includes determination of the critical diameter and the dependence of detonation velocity on the charge diameter. Moreover, the cylinder test (CT) was performed to establish the metal acceleration ability and detonation pressure of TEX. At the end, the detonation velocities of cast mixtures of TEX with a high explosive (HMX) and rubber bonding agent (HTPB) were measured and calculated for different charge diameters. For comparison, the cylinder test was done for another insensitive explosive - NTO and the detonation velocity of cast mixtures containing NTO was measured under the same conditions.

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SENSITIVITY TO AN ELECTROSTATIC SPARK

The sensitivity of explosives to an electrostatic spark is an important and recently frequently monitored sensitivity parameter, which provides valuable information about thermal properties of an explosive. To establish the TEX sensitivity, the special equipment for determining the sensitivity to electrostatic spark [2] constructed at Department of Theory and Technology of Explosives (Pardubice) was used.

The measurement was performed by using two different techniques. In the first measuring method, a tested substance is loaded by long-lasting (range miliseconds) stress generated by an electrostatic discharge. Current and voltage histories are oscilloscopically recorded during the discharging process. Thanks to this, the energy released in spark discharger can be determined. This type of testing technique is suitable for investigation of non-explosive substances, for example, pyrotechnic compositions.

The estimated energy of discharge needed for initiation of the TEX sample in this mode was about 250 mJ. For orientation, the value of the energies for common flash pyrotechnic compositions oscillates around 20 mJ.

In classical methods of testing explosives on sensitivity to electrostatic spark, the stress loading a sample is produced by a high voltage pulse with a short rise time (range microseconds). Loading conditions in this test correspond to those obtained at the shock initiation of explosives.

The estimated energy needed for initiation of the TEX sample in the shock mode was approximately 6,7 J. For comparison, the sensitivity of powdered samples of TNT, RDX and PETN is characterizes by the energies of about 122, 47 and 27 mJ, respectively. Extremely high energy of initiation of the TEX samples is connected with some technical problems appearing during the test. Due to very high energy level, the spark causes the dispersal of the sample and the interpretation of the test results is very difficult. Hence, the cases were only taken into consideration, for which an evident initiation was observed.

CLASSIFICATION FOR TRANSPORTATION

Some tests were performed for the TEX explosive with regards to transportation safety. The sensitivity to an impact was determined in testing apparatus with a 5 kg-hammer. The minimal impact energy (E_{dmin}) changes within the range from 15 J to 22.5 J. The low value corresponds to five negative results (5–) and the upper one to one positive test (1+). Middle height of a fall H_{50} for a 5 kg-hammer was established as 45.5 cm which correspond to the energy 23 J.

For classification of the TEX explosive for the transportation, the following results of the sensitivity and stability are taken into account:

- impact - E_{dmin} = 15 J,
- friction - no response > 360 N (maximal loading of the device),
- vacuum stability test 48 hours at 75 °C - no response,
- small fire - decomposition, carbonise, bubbles.

Thus, TEX was according to results of performed examinations classified in a cover for 1kg as a material of 1.1D class according to ADR 2100(3) for 1.1 D - otherwise it was not classified [3]

It is evident, that properties of the TEX explosive, as already signify the results of performed tests of sensitivity and stability, expecting a classification of the TEX into a category of less dangerous materials than 1.1 D (e.g.1.6 [4]), but performing all the expensive tests, which are needful for this change, is not effective for the present.

DETERMINATION OF THE CRITICAL DIAMETERS

Critical diameters of the explosives (upper and lower limiting diameters) influence the possibilities of their practical usage. Due to the low sensitivity, LOVA explosives characterize rather by high limiting diameters. In some situations this fact can be a serious disadvantage, for example, in dimensional limited applications.

At one of the original tests, the TEX explosive phlegmatized with 3,5 % Svit 3RV wax was investigated on sensitivity to shock wave compression in a small gap test. The sample of density of 1,78 g/cm^3 and 21 mm diameter was dispersed without the initiation of detonation in the test with a minimal barrier. Thus, we expected that lower limiting diameter of TEX is higher, than that of charge used in the gap test. Therefore, the detonation velocity of pressed TEX with 3 % wax was measured for the following charge diameters: 21, 30, 40, 50, 60, and 95 mm. The set up applied for measuring the detonation velocity is shown in Fig. 1. The results are presented in Table 1 and Fig. 2.

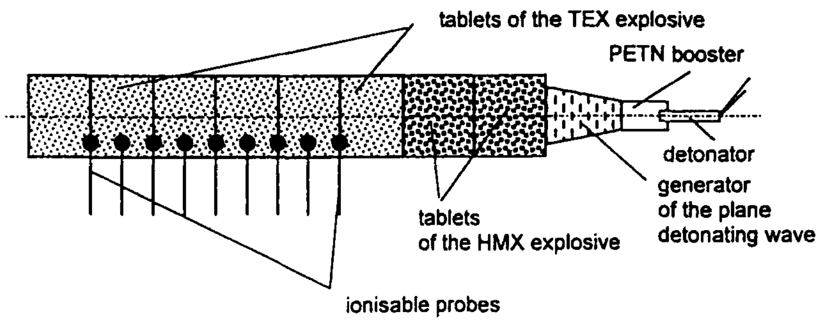

FIGURE 1: Arrangement of the set up for measuring the detonation velocity of TEX charges

TABLE 1: Results of the measurement the detonation velocity of pressed TEX

diameter of the charge [mm]	number of the sensors	distance between the sensors [mm]	total distance between the sensors [mm]	total time [ms]	average density of the measured tablets [g/cm³]	average detonation velocity [m/s]
21	4	~ 21	85,9	14,25	1,836	6028/*
30	6	~ 25	200,8	28,90	1,825	6948
40	7	~ 32	229,9	31,50	1,835	7298
50	7	~ 23	165,8	22,40	1,825	7402
60	7	~ 20	137,0	18,40	1,815	7446
95	8	~ 25	175,6	23,60	1,802	7441

/* detonation velocity decreased from 6500 m/s between the first sensors to 5200 m/s for further ones. The detonation process probably failed, because remains of unreacted explosive were found.

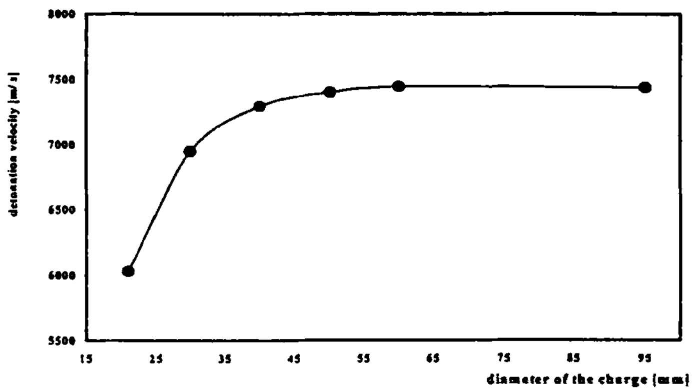

FIGURE 2: Dependence of the detonation velocity on the diameter of TEX charges

From Table 1 it follows that the lower critical diameter of the charge of phlegmatized TEX of the density ρ_0 = 1,836 g/cm^3 oscillates around 21 mm. Although it could seem from the graph shown in Fig.2, that the detonation velocity is almost constant for charge diameters beyond 60 mm, this does not mean that the detonation proceeds ideally. With respect to a less inner pressability of explosives for larger diameters, it was not technologically possible to press TEX always to the identical bulk. The density decreased with increasing diameter of the tablets (see Table 1). It is evident, that for the same density of the charges, the detonation velocity would increase with an increase of the diameter. Thus, the area of an ideal detonation of TEX is probably above the diameter of 95 mm.

All theoretical calculations of the detonation parameters in this paper were performed by means of the TIGER [5] code with the BKWR [6] set of coefficients in the BKW equation of state: $\alpha = 0.5$, $\beta = 0.176$, $\kappa = 11.80$, $\theta = 1850$. Detonation velocities 7689 and 7804 m/s were obtained for pressed TEX of the density of 1.8 and 1.835 g/cm^3, respectively. These results confirm the interpretation of experimental data and the conclusion of the upper limiting diameter of phlegmatized TEX.

CYLINDER TEST RESULTS

One of the modern popular and valuable exams for a determination of the practical performance parameters is a standard cylinder test (CT) [7]. The test consists in recording a initial phase of the acceleration process of a metal tube driven by expanding products of detonation moving along the internal surface of the tube. On the basis of the dependence of radial displacement of the external tube wall on the axial co-ordinate, it is possible to determine the velocity of the expanding envelope and then, the Gurney energy of the explosive[8]. Moreover, a so-called effective exponent of isentrope of detonation products can be calculated by the method in which the expansion flow pattern simulated by the hydrocode is compared with the experimental radial displacement of the tube walls [9].

Radiographs of the copper tubes driven by the detonation products of 3 % phlegmatized TEX and pure NTO explosives are shown in Figs. 3 and 4. The internal diameter of the tube is 25 mm and wall thickness is 2.5 mm. The measured detonation velocities are 7075 m/s for the TEX charge of density of 1.87 g/cm^3 and 7740 m/s for the NTO charge of 1.83 g/cm^3.

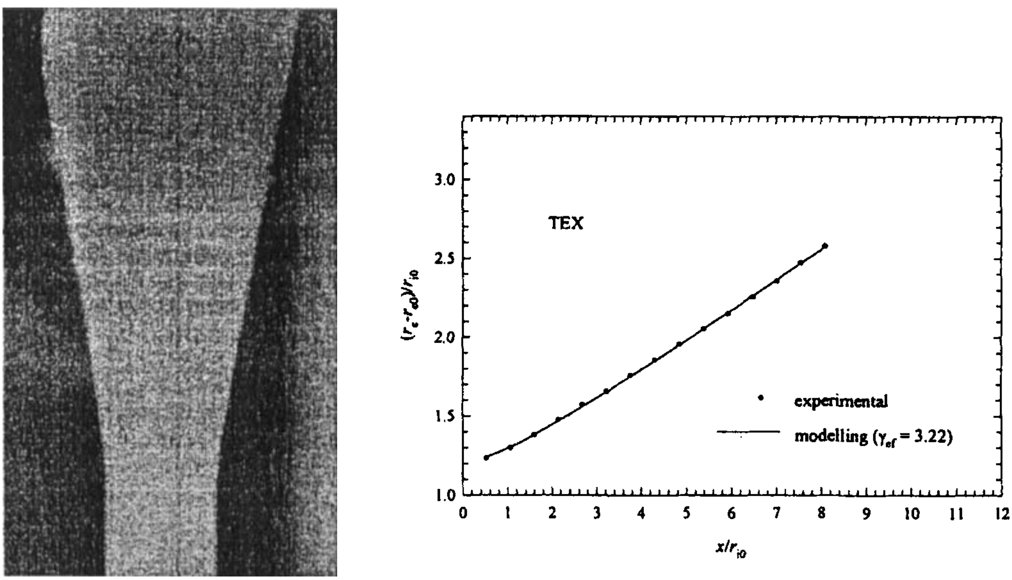

FIGURE 3: X-ray photograph of the copper tube driven by the detonation products of TEX and comparison of measured and modelled profiles of the tube wall
(r_e, r_i – external and internal radius of the copper tube, x – axial co-ordinate)

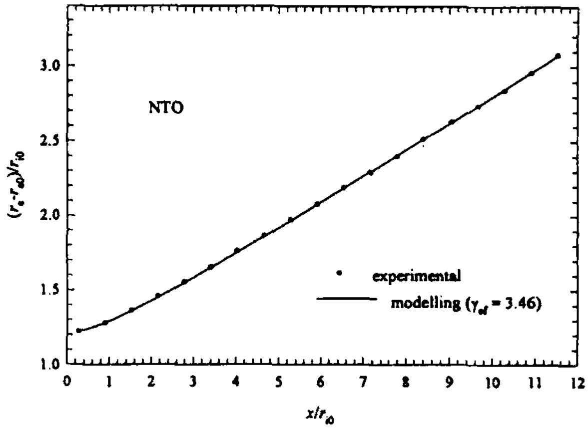

FIGURE 4: X-ray photograph of the copper tube driven by the detonation products of NTO and comparison of measured and modelled profiles of the tube wall

To estimate the effective exponent of isentrope, the process of tube acceleration is modelled by a numerical code, in which the thermochemical properties of the detonation products are described by the γ-constant equation of state. The effective exponent of the detonation products (γ_{ef}) is assumed to be equal to the value of γ, for which the experimental and calculated profiles of the tube wall are sufficiently close to each other (Figs. 3, 4). In this way, the γ_{ef} values of 3.22 and 3.46 were estimated for TEX and NTO, respectively.

The detonation pressure, estimated from the relation $p_{CJ} = \rho_0 \, D^2/(1+\gamma_{ef})$, is 22.2 GPa for the TEX explosive and 24.6 GPa for NTO. From calculations performed with TIGER the following detonation parameters are obtained:

for TEX: ρ_0 = 1870 kg/m^3, D = 7894 m/s, γ_{CJ} = 2.99, p_{CJ} = 29.2 GPa,

for NTO: ρ_0 = 1830 kg/m^3, D = 8062 m/s, γ_{CJ} = 3.20, p_{CJ} = 28.3 GPa.

Even from these results it is clear, that the detonation of TEX in given conditions of the cylinder test does not proceed ideally and nor the solid metal cover reduces the critical diameter enough. In the case of NTO, the discrepancy between experimental and calculated detonation parameters is much lower.

On the basis of the cylinder test results, the Gurney energy of 2510 and 2580 kJ/kg was also estimated for TEX and NTO, respectively. This energy was determined at relative volume of detonation products, i.e, the volume of expanding tube related to its initial volume, of eight. The similar values of the Gurney energy indicate, that the metal acceleration abilities of the tested explosives are similar.

DETONATION VELOCITY OF CAST TEX-BASED MIXTURES

Interesting data were found out while measuring the detonation velocity of cast mixture of TEX with HMX and hydroxyl-terminated polybutadien rubber (density of the explosive - 98,7 %TMD) of different charge diameters [10]. For comparison, the mixtures of equivalent content, in which TEX was substituted by NTO (charge density - 98,9%TMD), was also tested. Results of the measuring are summarised in the Table 2.

TABLE 2: Results of measurement of the detonation velocity of cast mixtures of TEX and NTO with HMX and HTPB

explosive	charge diameter	density	detonation velocity
	[mm]	[g/cm^3]	[m/s]
TEX (42,5%), HMX (42,5%), HTPB (15%)	**27,4**	**1,635**	**6605**
NTO (42,5%), HMX (42,5%), HTPB (15%)	27,4	1,620	7582
TEX (42,5%), HMX (42,5%), HTPB (15%)	**42,4**	**1,635**	**6979**
NTO (42,5%), HMX (42,5%), HTPB (15%)	42,4	1,620	7790
TEX (42,5%), HMX (42,5%), HTPB (15%)	**59,4**	**1,635**	**7186**
NTO (42,5%), HMX (42,5%), HTPB (15%)	59,4	1,620	7719

The calculated values of the detonation velocity of the mixture TEX/HMX/HTPB is 7479 m/s and that of the mixture NTO/HMX/HTPB is 7519 m/s (TIGER code). The discrepancy between computed and experimental values for the largest diameter is less than 4 % for both mixtures. The ideal detonation velocity of cast TEX-based mixture is higher than the measured values. However, in the case of NTO-based explosive, the ideal detonation velocity is lower than experimental one. Similar relation was also obtained for cast HMX/NTO/HTPB compositions detonating at low temperatures[11] The under-estimation of the detonation velocity is explained by a behaviour of hydrocarbon-based binders.

CONCLUSION

Although the TEX explosive is considered to be in many respects a very perspective explosive for LOVA, probably has not found a wider use in practical applications so far. The main reason is the fact, that its insensitivity is for the current set-up requirements paradoxically even too high. Exercise of TEX with high efficiency of utilisation of the explosive energy is possible only in applications of really bigger diameters.

In addition, at the present there are possibilities of application of some modern and perspective substances with excellent performance, sensitivity and other parameters, e.g., DADNE (FOX7)[12, 13]. Nevertheless, we can not consider the TEX section definitely closed and the time will show us, whether TEX finally enforces in some special applications.

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