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Some Properties of High Explosive Mixtures of Low Sensitivity to External Stimuli

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Abstract: In this paper, a method of obtaining explosive mixtures of low sensitivity to external stimuli is described. The results of measurements of sensitivity to friction are presented. The decrease of sensitivity was obtained by addition of insensitive explosives like: nitroguanidine (NQ) and 3-nitro-1,2,4-triazol-5-one (NTO). Detonation velocity (VOD) and brisance for the chosen explosive mixtures were measured. VOD was determined by short circuit sensor method, and brisance was determined by the Plate-Denting Test. The velocity measurements of metal plate (thickness 2 mm) throwing by detonation products of explosive mixtures were carried out. VOD of tested mixtures are high (8000-8500 m s^{-1}), and their density are at least 90% of maximal theoretic density, so these compositions can be defined as high explosive mixtures. The brisance of tested mixtures is also high, and considerably exceeds the brisance of TNT, in the case of HMX/NTO (49.5/50) compositions this parameter is higher than brisance of desensitized hexogene. The throwing ability for individual mixtures is high. This parameter exceeded 3500 m s^{-1} for almost all cases. The comparison of measured and calculated velocity of throwing plates, measured by different methods showed good compatibility.

Keywords: insensitive high explosive, detonation velocity, friction sensitivity of explosive, brisance

Introduction

In the literature of the last decade concerning explosives and ammunitions, the interest in products of low sensitivity to external stimuli has been growing. The detonation parameters of these explosives stay on a high level [1-3]. This interest arises from care about safety of producers and consumers of discussed mixtures.

Until now, sensitivity criterion of high explosives was selected from the point of view of production security and shell filling security. The decrease of explosive sensitivity to external stimuli can be obtained by desensitization of octogene, hexogene or pentrit. This process consists in covering of explosive crystals by wax, rubber or other plastics with additive of plasticizers. This method of explosive desensitization is not sufficient for contemporary military acceptance specifications, as regards of ammunition resistance to penetration of a bullet, overload during firing or load during fall down with several meters.

The growth of warfare rate on contemporary battlefield, forces the need of decreasing sensitivity of explosives, which are used to shell filling. The necessity of quick reacting to enemies actions, forced the need of quick displacement of weapons and ammunitions. Accidental explosion is possible, during these quick actions, and especially during mechanical loading and unloading. Besides, it is necessary to stress that explosive handling (artillery shells, rockets), is not always treated with appropriate precautions.

Preparation of explosive mixtures

One of the most popular methods of obtaining explosive mixtures having low sensitivity is realized by addition of such explosives like NQ, NTO, TATB, FOX-7 to common high explosives (like hexogene, oktogene, pentryt) [4-6].

In order to obtain homogeneous mixture suitably, the crystals of individual components should be about similar density and grain size. Sometimes, for the facilitation of mixing, the substances decreasing internal friction like graphite, zinc stearate, calcium palmitate can be added.

In our researches, we proceeded in analogical way. The hexogene and octogene were chosen for the tests. They are the most popular high explosives, but their sensitivity should be decreased. Among the explosives of low sensitivity, NTO and NQ were investigated. For these studies, two different explosive concentrations – 50% and 70% were selected. The grain size of mixture compounds ranged from 50 μm to 200 μm. The graphite was used as a facilitating agent of mixing.

The definite mixtures were prepared in the following way. First, the crystals of compound of higher sensitivity were covered (by mixing for several minutes) with graphite dust. Next, the compound of lower sensitivity was added and the mixture was mixed again. In the consequence of these operations, the obtained compositions were uniformly mixed, and the degree of mixing was not changed during manipulation of the mixture. Visual inspection and observations under a microscope of tested mixtures showed a good covering of hexogene and octogene crystals by graphite. For the 0.5% of graphite content (C_{gr}), the covering of crystals was good, therefore the all mixtures contained such the quantity of the graphite.

The compositions of chosen mixtures are presented below:

- Hx/NQ/C_{gr} (29.5/70/0.5), Hx/NQ/C_{gr} (49.5/50/0.5),
- Hx/NTO/C_{gr} (29.5/70/0.5), Hx/NTO/C_{gr} (49.5/50/0.5),
- HMX/NQ/C_{gr} (29.5/70/0.5), HMX/NQ/C_{gr} (49.5/50/0.5),
- HMX/NTO/ C_{gr} (29.5/70/0.5), HMX/NTO/C_{gr} (49.5/50/0.5).

Sensitivity of explosive mixtures to friction

Table 1. The results of sensitivity to friction for the tested explosive mixtures

Composition of explosive mixture	Stamp pressure [N]	The number of sample					
		1	2	3	4	5	6
RDX/NQ/C_{gr} 29.5/70/0.5	353.2	-	-	-	-	-	-
Hx /NQ/C_{gr} 49.5/50/0.5	353.2	-	-	-	-	-	-
Hx/NTO/C_{gr} 29.5/70/0.5	353.2	+	-	+	-	-	-
	282.5	-	-	-	-	-	-
Hx/NTO/C_{gr} 49.5/50/0.5	353.2	-	-	-	-	-	-
HMX/NQ/C_{gr} 29.5/70/0.5	353.2	-	+	+	-	-	-
	282.5	-	-	-	+	-	+
	247.2	-	-	-	-	-	-
HMX/NQ/C_{gr} 49.5/50/0.5	353.2	-	-	-	-	-	-
HMX/NTO/C_{gr} 29.5/70/0.5	353.2	-	-	-	-	-	-
HMX/NTO/C_{gr} 49.5/50/0.5	353.2	+	+	+	-	-	-
	282.5	-	+	+	-	-	-
	247.2	-	-	-	-	-	-

The measurements of sensitivity to friction were made at the Institute of Industrial Organic Chemistry according to PN-C-86019:1994 standard [7]. The upper insensitivity point of mixtures was determinated. It is the pressure of stamp (in newton), which does not cause explosive process during six tests. The lower sensitivity point was also determined. It is the least pressure of stamp (in newton), which causes minimum one positive result (explosive process) during six tests. The results of our experiments are given in Table 1. These results indicate that the tested mixtures are less sensitive to friction than RDX and HMX. The lowest sensitivity point of RDX and HMX is 120 N [8].

Detonation velocity and brisance of tested mixtures

Detonation velocity is one of the most important detonation parameters, which testifies to energy of explosive. The mixtures of explosives were assigned to pressing of charges in order to obtain possible high density of mixtures and, in consequence, high velocities of detonation. The loose mixture was divided in portions (50 g) and was pressed by hydraulic press under pressure of 200 MPa. The inside diameter of die was 40 mm. The obtained blocks were glued together by nitrocellulose lacquer and the sensors were located among them. The formed charges were located in thick-walled steel pipe in order to prevent spreading of detonation products and ensure so-called ideal conditions of detonation. The measurements of detonation velocity (D_0) were made by electrical method. The time of detonation wave transition through the sections was determined. The scheme of the system is presented in Figure 1 and the results of measurements are presented in Table 2. In this table the results of maximal theoretic density (ρ_{max}) calculations, theoretic detonation velocity (D_{th}) and relative values of these quantities calculated by numerical program TIGER are also collected.

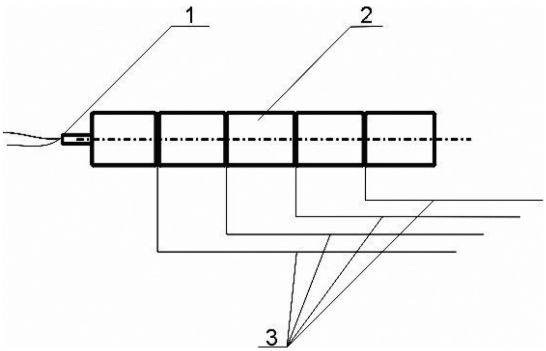

Figure 1. The scheme of system for VOD measurements: 1 – detonator, 2 – charge of tested explosive, 3 – conductors connecting sensors and counter.

Table 2. The results of measurements and calculations of density and detonation velocity for tested mixtures

Composition of explosive mixture	Density ρ_0 [g cm^{-3}]	Maximal theoretic density ρ_{max} [g cm^{-3}] (TIGER)	$\frac{\rho_0}{\rho_{max}}100$ [%]	Deto-nation velocity D_0 [m s^{-1}]	Detonation velocity D_{th} for ρ_0 [m s^{-1}] (TIGER)	$\frac{D_0}{D_{th}}100$ [%]
RDX/NQ/C_{gr} 29.5/70/0.5	1.62	1.78	91	8000	8091	98.9
Hx/NQ/C_{gr} 49.5/50/0.5	1.62	1.79	90	8070	8139	99.1
Hx/NTO/C_{gr} 29.5/70/0.5	1.75	1.89	92	7990	8045	99.3
Hx/NTO/C_{gr} 49.5/50/0.5	1.73	1.87	92	8150	8157	99.9
HMX/NQ/C_{gr} 29.5/70/0.5	1.63	1.81	90	8100	8160	99.3
HMX/NQ/C_{gr} 49.5/50/0.5	1.72	1.84	93	8500	8505	99.9
HMX/NTO/C_{gr} 29.5/70/0.5	1.79	1.92	93	8170	8180	99.8
HMX/NTO/C_{gr} 49.5/50/0.5	1.78	1.92	93	8200	8320	98.5

The tested mixtures can be numbered among high explosives. The comparison of detonation velocities for tested mixtures with detonation velocities of TNT, RDX, and HMX, for the same experimental conditions is presented in Figure 2.

Brisance is the destructive fragmentation effect of explosive on its immediate vicinity. Shock wave and detonation products of explosive generate destructive effect at the distance in the order of charge diameter. Until recently in Poland, the most popular method of determination of explosives brisance was Hess Test. This test consists in measurement of upset of lead block during the detonation of (50 g) tested explosive.

In English literature, a popular method of determination of the brisance is Plate-Denting Test. This method is based on the measurement of the dent in the standard steel plate, which is formed after detonation of the tested explosive charge.

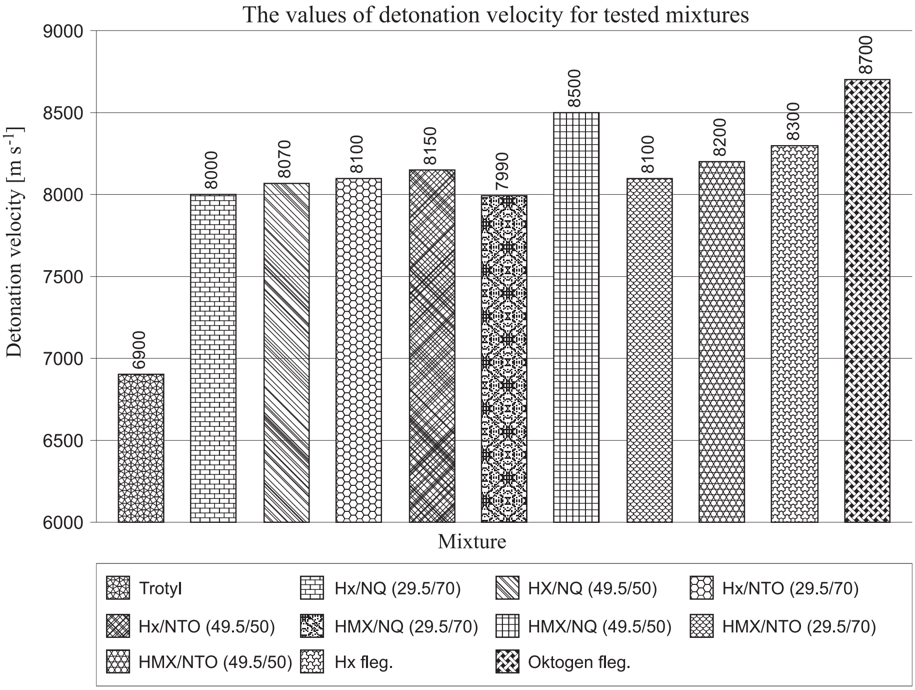

Figure 2. The measurement results of detonation velocity for tested mixtures in the comparison with TNT, RDX, and HMX.

This test was used to determine brisance of selected explosive mixtures. The following assumptions have been made:

a) the used charges are sufficient high diameter and length in order to ensure a stable detonation wave, which propagates with maximal constant velocity,
b) the used plates are sufficient massive and tough, enough to limit their strain to area of dent, and other secondary deformation of the whole plate would not have an influence on dimension of dent.

The explosive is in the form of cylindrical charge of 41 mm in diameter and 200 mm high. The dimensions of steel plates are 150 x 150 mm and 51 mm in thickness. The plates are made of steel of about Rockwell hardness in the range from HRB74-HRB76. The scheme of the test is presented in Figure 3. Three plates are placed one after the other, but only the upper plate is witness plate (4), and two lower are washers (5). The whole plates are placed on the steel or concrete base. The upper surface of witness plate is lubricated – this lubricant assures better joint between the charge and the plate [9].

The charge of explosive (3) is placed at the center of the plate, the booster (2), and the detonator (1) is located on the explosive.

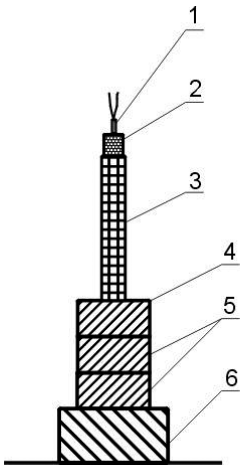

Figure 3. The scheme of Plate-Denting Test: 1 – detonator, 2 – booster, 3 – charge of explosive, 4 – witness plate, 5 – washer plate, 6 – steel base.

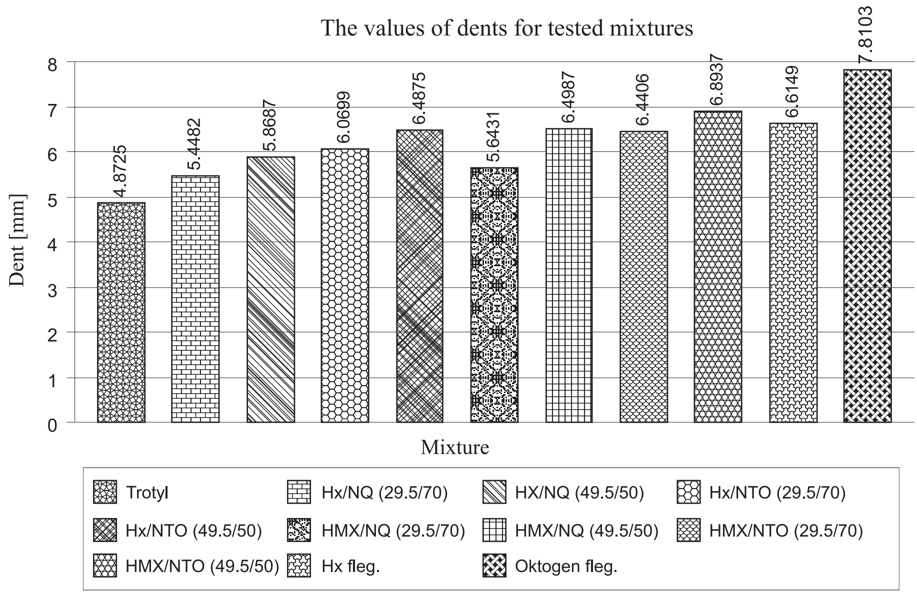

Figure 4. The statement of measured dent for tested mixtures.

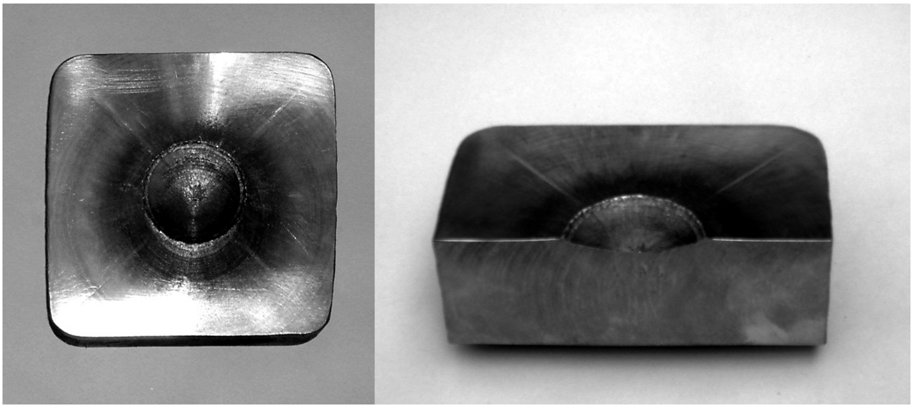

Figure 5. The dent into the steel plate after the detonation of the explosive mixture, and cross-section of plate.

The results of tests clearly show that the brisance of tested mixtures is higher than brisance of trinitrotoluene, and lower than octogene brisance, that is confirmed in our expectations. In addition, we can state that nitroguanidine additive causes higher decrease of brisance than NTO additive, although it is not consistent with the influence of NTO or NQ additive on detonation velocity of explosive mixtures. Contrary to expectations, the mixture of HMX/NTO/graphite (49.5/50/0.5) is of the highest brisance, not the HMX/NQ/graphite, which is about the higher detonation velocity (8500 m s^{-1}). The nitroguanidine additive causes the higher decrease of brisance both in the case of the mixtures containing HMX and RDX.

Throwing of metal plate by detonation products

The brisance causes fragmentation (destruction) of adjacent vicinity and throwing of forming fragments by energy of detonation products. In connection with this fact, the comparison of obtained results of the brisance measurements with the velocity values of aluminium plate thrown by detonation products of tested mixtures was made.

The tested mixtures were pressed (200 MPa) in the same conditions as just like in the Plate-Denting Test. Five blocks of explosive having the weight of 50 g, were glued together by nitrocellulose lacquer. The round duralumin plate having 40 mm in diameter, 2 mm thick and 6.97 g weight, was glued on the one side of the charge. The TNT booster (50 g) with detonator was attached to the surface at the other side of the charge.

The scheme of system for velocity measurements of plate thrown by detonation products is presented in Figure 6. The thin metal tubes (3) of different length were placed in the plexiglass plate (2) and the short circuit sensors (1) were threaded through these tubes. The distances between the tip of needles performed a function of base to record of the movement time of the throwing plate [10]. The knowledge of length bases and particular times allows calculation of velocity of throwing plate. The charge of tested explosive (5) with the glued plate (4) is placed within the distance of 2 mm from the nearest central needle.

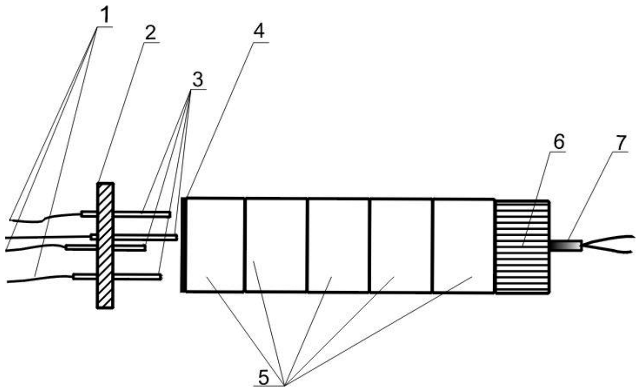

Figure 6. The scheme of system for velocity measurements of throwing plate: 1 – short circuit sensors, 2 – plexiglass plate, 3 – needles with sensors, 4 – throwing plate, 5 – explosive charge, 6 – booster, 7 – detonator.

The velocity of plate thrown by detonation products may also be calculated using the following equations:

$$u_l(t) = D\frac{1+\eta}{\eta} - \frac{Dt(1+2\eta)-\eta l}{\eta t\sqrt{1-\frac{l}{Dt}}} \tag{1}$$

where: D – detonation velocity, $t \geq \frac{l}{D}$ – time, l – charge length, coefficient $\eta = \frac{16m_w}{27m_l}$; m_w – explosive mass, m_l – plate mass [10]. The other equation for calculating of plate velocity, with formula proposed in [11]:

$$u_l = \frac{0.612\,r}{2+r}, \tag{2}$$

where: $r = \frac{\rho_w l}{\rho g}$; ρ_w – explosive density, ρ – density of throwing plate, g – plate thickness.

This can be described using the equation presented in [12]:

$$u_l = \sqrt{2E}\sqrt{\frac{3}{1+5\mu+4\mu^2}}, \tag{3}$$

where: $\sqrt{2E}$ – quantity characteristic of individual explosive called the Gurney velocity, $\mu = \frac{m}{m_w}$; m – mass of throwing body.

In case of throwing body by detonation products, it is necessary to take into account lateral spread of detonation products. It can be done by using active mass and active length, and the equations for these calculations obtained from [10]: $l_a = 1.2r_0$, when $\frac{l}{r_0} \geq 3.6$, where, l_a – active length of charge, r_0 – charge radius,

$m_a = \frac{6}{5} m_w \frac{l}{r_0}$, when $\frac{l}{r_0} \geq 3.6$, where, m_a – active mass of charge.

The equations mentioned above were taken into account at the calculations of velocity of the duralumin plate.

The results of measurements and calculations of velocity values are presented in Table 3. These data show that the obtained velocities are high and near to theoretical calculations. The deviations not exceeded 5%.

Table 3. The results of measurements and calculations of plate velocity

Explosive	Density [g cm^{-3}]	Detonation velocity [m s^{-1}]	Plate velocity [m s^{-1}]			
			Measured	Calculated according to:		
				Formula (1)	Formula (2)	Formula (3)
Hx/NQ/C_{gr} 29.5/70/0.5	1.64	8000	3420	3880	3810	3680
Hx/NTO/C_{gr} 29.5/70/0.5	1.75	7990	3900	3990	3860	3730
HMX/NQ/C_{gr} 29.5/70/0.5	1.65	8100	3890	3980	3870	3740
HMX/NTO/C_{gr} 29.5/70/0.5	1.78	8160	3980	4120	3960	3830
TNT	1.59	6900	3160	3280	3263	3160

Summary

On the basis of the experiments we can state that:

- in the range of selected compositions, the mixtures show considerable decrease of sensitivity to friction,
- the detonation velocities of tested mixtures are high (8000-8500 m s^{-1}), and their densitys are at least 90% of maximal theoretic density, so these compositions can be defined as high explosive mixtures,
- the brisance of tested mixtures is also high, and considerably exceeds the brisance of TNT, in the case of HMX/NTO (49.5/50) compositions this parameter is higher than brisance of desensitized hexogene,
- both brisance and sensitivity to friction of the mixtures containing nitroguanidine are lower than the mixtures containing NTO. For the same high explosive component, the differences in brisance are about 15%,
- the throwing ability for individual mixtures is high. This parameter exceeded 3500 m s^{-1} in almost all cases. The comparison of measured and calculated velocity of throwing plates, measured by different methods showed good compatibility.

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