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Study of the influence of initiation capacity and their operation time on the explosive characteristics of Emulinite PM explosive
Badanie wpływu zdolności inicjującej zapalników i ich charakterystyk czasowych na charakterystyki wybuchowe Emulinitu PM

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Abstract: *This article presents the results of measuring the detonation velocity and blast wave characteristics for PM Emulinit charges. Two types of detonators differing in initiation capability were used for the detonation initiation process. The different initiation methods did not affect the detonation velocity but significantly affected the blast wave's intensity. The measurements performed for Emulinit charges composed of two cartridges show that the overpressure results of such charges are significantly affected by the initiation capability of the detonators and their operation time characteristics.*

Streszczenie: *W pracy przedstawiono wyniki pomiaru prędkości detonacji i charakterystyki fali podmuchowej dla ładunków Emulinitu PM. Proces inicjowania ładunków do detonacji realizowano za pomocą dwóch rodzajów zapalnika różniących się zdolnością do inicjacji. Różny sposób pobudzenia nie wpływał znacząco na zmierzoną prędkość detonacji, jednak miał istotny wpływ na intensywność fali podmuchowej. Wykonane pomiary dla ładunków Emulinitu złożonych z dwóch naboi pozwalają zauważyć, że na wyniki nadciśnienia takich ładunków istotny wpływ ma zdolność inicjująca zapalników i ich charakterystyki zadziałania (czas zadziałania i jego powtarzalność).*

Słowa kluczowe: *Emulinit PM, prędkość detonacji, nadciśnienie fali podmuchowej*
Keywords: *Emulinit PM, detonation velocity, blast waves overpressure*

1. Introduction

Nonideal explosives are the most commonly used explosives in the economy due to their ready availability, their relatively low cost, and their specific properties. The ability to adjust the parameters of a detonation by changing the quantity and content of individual components and additives, is frequently advantageous when used in various applications. Due to the modifications in composition and the nonideal nature of detonation, it is very important to study the development of a detonation in order to determine the mechanisms leading to the formation of a steady state detonation wave.

The way in which a charge is initiated plays an important role in the development of a steady-state detonation wave in non-ideal explosive charges. The use of a booster generates a shock wave which pervades the explosive charge.

When heterogeneous porous explosives are initiated, behind the propagating wave, areas are created where more energy is released locally than on average in their surroundings. Such areas are often referred to as hot spots. The thermal energy released causes the pressure to rise, generating compression waves which propagate towards the detonation wave front, sustaining it. If sufficient energy is transferred to the wave front as a result of the reaction, the conditions necessary for the formation of a detonation wave are achieved.

One of the main issues under investigation is growth of the detonation. Initiation with a detonator alone or a booster initiated with a detonator will work in different ways. The processes taking place behind a shock wave front result in the gradual formation of a steady state detonation wave. Thus, there is an acceleration of the shock wave propagation process (in the case of initiation with a weak impulse, such as a detonator) or a slowing down of the shock wave propagation speed (in the case of initiation with a booster). In each case, the velocity of the steady-state detonation is the same and does not depend on the type of initiation [1, 2].

In [1], the relationship between the initiating pulse and the distance from the initiating plane at which the steady-state detonation wave is established was investigated. Detonation velocity measurements were carried out on a mixture of ammonium nitrate(V) (AN) with trinitrotoluene (TNT) and aluminium dust, using the short-circuit sensor method and taking time measurements at 10 subsequent points. The sensors (11 pcs) were placed in a cylindrical charge (65 mm in diameter and 330 mm in length) every 30 mm, with the first placed adjacent to the booster. This type of sensor placement enabled changes in average detonation speed to be recorded at successive points along the charge axis. It also allowed changes in detonation velocity to be observed relative to the booster size (two types of hexogen boosters were used: 25 g with a diameter of 30 mm and 100 g with a diameter of 40 mm). The dependence of detonation velocity as a function of distance from the initiation plane was obtained using different compositions and initiation pulses. It was observed that, in each case, the size of the detonator affected the manner and speed at which the parameters of the steady-state detonation were achieved but did not affect its value. The path needed to reach steady-state wave parameters is shorter with the addition of granular TNT than with the addition of flaked TNT. These Al powder inclusions may be due to additional areas of inhomogeneity introduced by the granular TNT, which may be a source of additional hot spots. In the case of mixtures with aluminium additives, fragmentation of the additive grains accelerates the achievement of steady-state detonation parameters. However, its type does not affect the final parameters of the steady-state detonation wave.

It should be noted that when initiated solely by a detonator (depending on its initiating capability), the distance over which the shock wave propagation process transitions into a steady-state detonation wave is relatively large. The initiation of a nonideal explosive charge with a detonator can lead to a portion of the explosive in the area near the detonator not reacting fully and, until a steady state detonation wave is achieved, not participating in the generation of a shock wave pulse in the air or another medium.

The authors of paper [3] investigated the effect of the detonator's position on how the bulk explosive's charge is initiated. In it, they used Emulinit 8L elaborated into a PVC pipe of 50 mm internal diameter. The results of the detonation velocity measurements and observation of the resulting damage enabled them to draw some basic conclusions. They observed that the most reliable initiation occurs when the detonator is placed in the charge precisely along the axis of symmetry. Placing the detonator close to the lateral surface of the charge increases the distance after which steady-state detonation parameters are reached. In addition, placing the detonator on the side of the charge, oriented perpendicular to its axis of symmetry, can result in significant disturbances in the detonation development process, leading to possible disruption of initiation and, hence, unreliable detonation of the charge in the detonator area. The results of the tests described in [3] allow us to conclude that the distance from the point at which a steady state detonation wave is formed is about 3-4 cm for an axisymmetrically initiated charge and about 8 cm for a charge initiated by a detonator placed perpendicular to the charge's axis of symmetry.

2. Tested materials and methods

2.1. Electric detonators

The tests used two electric detonators: the ERGODET 0.2A N electric methane coal detonator (GMN) and the ERG 0.2A detonator (ERG). The detonators differ significantly in their essential performance characteristics: initiating ability and response time. Table 1 shows the basic properties of the detonators.

Table 1. Selected properties of the detonators used

Property	GMN	ERG
Shell material	copper	aluminium
Secondary charge material	PETN	PETN
Secondary charge weight [g]	0.65	0.8

2.2.Tested explosive

The explosive used in this paper was Emulinit PM, methane, special, water-resistant, in the form of cartridges in polyethylene film envelopes with a diameter of 32 mm and a single cartridge weight of 300 g. Table 2 shows the basic properties of the explosive used in the testing.

Table 2. Parameters of the Emulinit PM explosive used in the tests

Property	The value of
Appearance	PE-coated cartridges (diameter min. 32 mm)
Density of the explosive [g/cm^3]	1.15-1.21
Detonation velocity, for the diameter of 32 mm [m/s]	>4600
Oxygen balance [%]	–8.5
Heat of explosion [kJ/kg]	2278.19
Specific energy [kJ/kg]	522.51
Impact sensitivity [J]	≥50
Friction sensitivity [N]	>360

In the experiments, 300 and 600 g charges of Emulinit PM were used. A charge weight of 600 g was achieved by detonating two 300 g cartridges simultaneously. When using charges consisting of two 300 g cartridges, it was found that a significant portion of the charge was scattered and did not undergo explosive transformation, which has a great impact on the generated blast wave from such a charge. Therefore, in the case of a double emulsion charge cartridge, two detonators connected in a parallel were used for initiation. Table 3 shows the charge designations and the means of initiation (the number of detonators used to detonate the charges simultaneously).

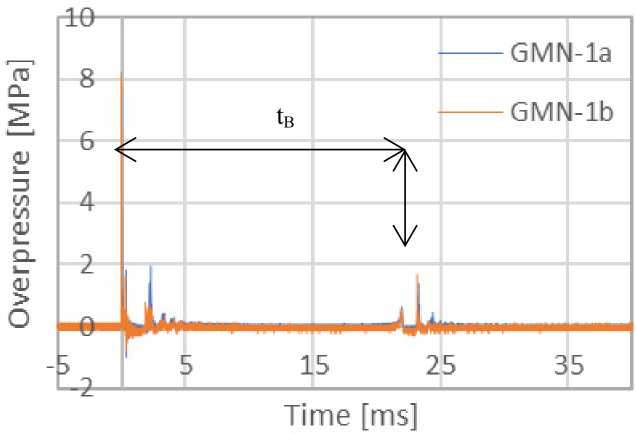
Table 3. Designation of charges of Emulinit PM to be tested

Charge type designation	Emulsion explosive weight [g]	Detonator	
		GMN	ERG
GMN1	300	1	–
GMN2	600	2	–
ERG1	300	–	1
ERG2	600	–	2

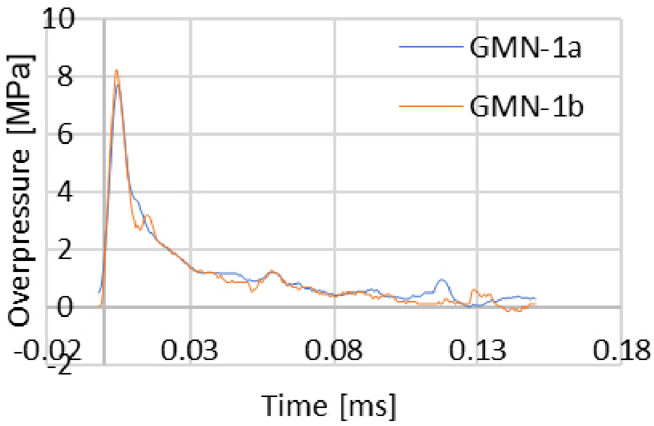
2.3. Test methods and results

2.3.1. Initiation capability in underwater explosion test

The initiation capability of the detonators used in the tests was measured in accordance with the standard [4] and the methodology presented in the paper [5]. By measuring the overpressure in the underwater explosion of the tested detonators, the energy of the primary shock wave and the energy of the gas bubble can be determined. Figure 1 shows an example of the output obtained from a GMN detonator. Three test runs were carried out for each detonator type. Figure 2 shows the results of calculations of average shock wave energy [E(FU)] and gas bubble energy [E(PG)] values. As can be seen from Figure 2, the energy of the shockwave and the gas bubble generated during the explosion exceeds that of the ERG detonator by more than 30%.



(a)



(b)

Figure 1. Results of a GMN detonator's initiating capability measured in an underwater explosion test: a) overpressure registration with time of the first marker pulse (a) and overpressure waveform of the primary shock wave in water (b)

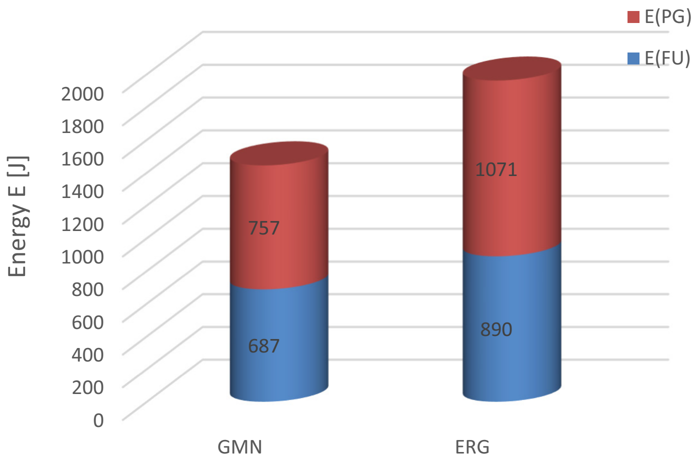


Figure 2. Result of measurement of initiating capability of detonators used in the underwater explosion test

2.3.2. Response time of the detonators used

Because of the need to use two detonators connected in parallel to initiate charges of test material consisting of two 300 g cartridges, the response time of these detonators was measured. The primary source of a delay in the response of an electric detonator is the time required to heat up the resistance bridgewire in the detonator's electric igniter. The combined time to explosion of the detonator's primary and secondary explosive components does not exceed 10 µs. Therefore, an attempt was made to determine the igniter element's response time, which was adopted as the detonator response time.

The detonator response time was measured by measuring the time from applying a pulse to the detonator to the rupture of the bridge wires. The tests used a blasting line with constant circuit resistance parameters, coupled with a KZS-1/02 mining igniter. A WAVEJET 314 oscilloscope was used to measure the rupture time of the bridge wire. Five test runs were carried out for each type of detonator.

The response times of the detonators were 630 ±120 and 190 ±20 µs for the GMN and ERG detonators, respectively. As can be seen, the response time of the ERG detonator is over three times shorter, and the average scatter is six times smaller.

2.3.3. Detonation velocity measurement

The short-circuit sensor method was used to measure the detonation velocity of the test explosives. Detonation velocity measurements were carried out for two types of initiation (two types of detonators).
Four short-circuit sensors were placed in the Emulinit PM cartridges at distances of 4 cm between them and 2 cm from the base of the charge. In this way, the initial sensor was several charge diameters from the initiation point, ensuring that the detonation process could stabilise and reach its steady state.
The velocity results obtained this way were 4610 ±90 and 4600 ±90 m/s for GMN and ERG detonator initiation, respectively. This means that the detonators' initiation energy did not significantly affect the detonation velocity. The results obtained are consistent with this explosive's data sheet.

2.3.4. Blast wave overpressure measurement

Blastwave overpressure measurements were made using Piezotronics, Inc. 137A series PCB pressure sensors by the methodology described in [6, 7]. Four overpressure sensors were used in the study. Two were placed at a distance of 2.0 m and two at a distance of 2.5 m. In this way, each experiment allowed four runs of overpressure changes to be obtained (two for each distance). Figures 3 and 4 show examples of blast wave overpressure waveforms. Table 4 shows the resulting essential characteristics of the blast waves.

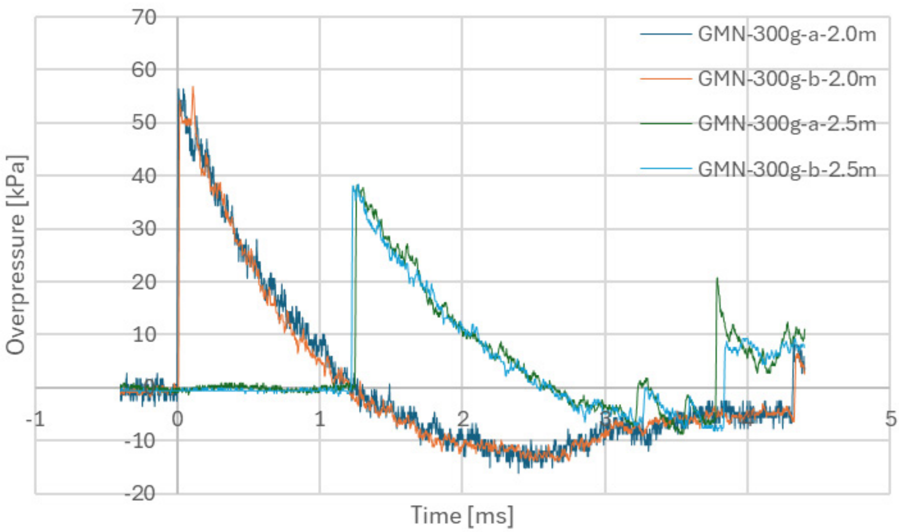


Figure 3. Overpressure of the blast wave generated by the explosion of a 300 g explosive initiated by a GMN detonator

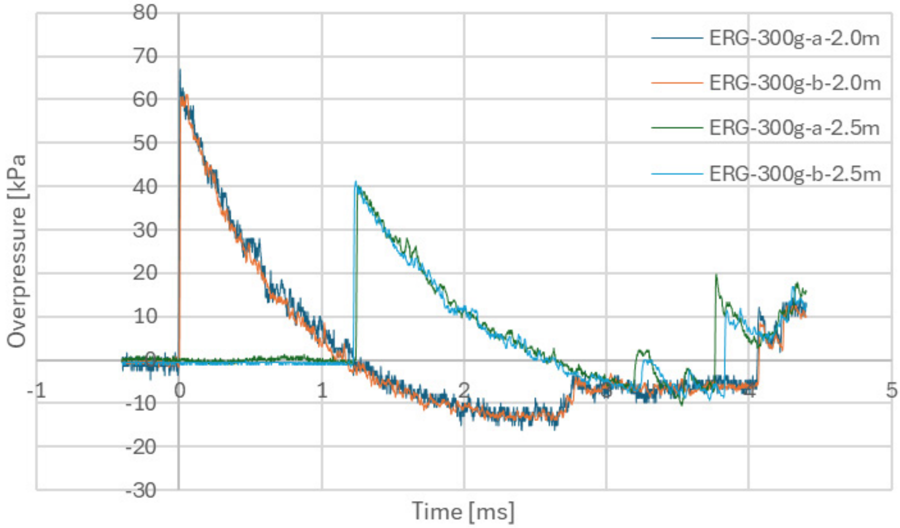


Figure 4. Overpressure of the blast wave generated by the explosion of a 300 g explosive initiated by a ERG detonator

Table 4. Measurement results of air-blast wave characteristics for Emulinit PM charges

Charge weight [g]	Detonator	Overpressure [kPa] at distance		Pulse [Pa·s] at distance	
		2.0 m	2.5 m	2.0 m	2.5 m
300	GMN*)	56 ±2	39 ±1	26 ±2	21 ±1
	ERG*)	61 ±3	40 ±2	28 ± 1	21 ±1
600	GMN**)	79 ±4	55 ±2	39 ±2	32 ±1
	ERG**)	110 ±7	65 ±2	47 ±2	36 ±1

*) – one detonator was used, **) – two detonators were used

Special attention should be paid to the results of the blast wave characteristics for 600 g charges prepared by glueing together two 300 g cartridges of 32 mm diameter. In the case of a wave incident at a distance of 2 m from the charge, the overpressure for a charge initiated with mining detonators is about 30% lower than with ERG-type detonators. The significant difference in overpressure may be due to the pulse of initiation energy of the mining detonators and the greater scatter of their response times. Such a large scatter of the response time can result in an impaired initiation of the second detonator of a charge placed in a parallel manner.

2.3.5. TNT equivalence

In addition, TNT equivalence was determined for the tested Emulinit PM charges by the procedure described in [8]. The TNT equivalence for the resulting overpressure runs was determined using Equations 1 and 2. The values of the coefficients from Equations 1 and 2 are given in Table 5.

$$\alpha_{TI} = \frac{b}{m_x}\left[\left(\frac{I_{sx}}{a}\right)^{1/c} - 1\right] \tag{1}$$

$$\alpha_{TP} = \frac{b}{m_x}\left[\left(\frac{P_{sx}}{a}\right)^{1/c} - 1\right] \tag{2}$$

where: α_{TI}, α_{TP} – equivalence for pulse and overpressure, I_{sx}, P_{sx} – pulse and maximum overpressure, respectively, for the materials tested, m_x – mass of explosive charge, a, b, c – experimental constants describing the dependence of the overpressure and pulse on the mass of TNT charge for the distance at which the measurement was performed.

Table 5. Values of constants in Equations 1 and 2 [8]

Parameter	Distance [m]	*a*	*b*	*c*
I_s [kPa·ms]	2.0	2.1491	3.3640	0.6489
	2.5	5.9630	30.3470	0.6886
P_s [kPa]	2.0	0.8880	1.8437	0.9074
	2.5	4.5513	22.2053	0.9135

The blast wave characteristics obtained allow TNT equivalence to be determined for the charges tested under experimental conditions. Table 6 shows the equivalents determined by the procedure described in [8].

Table 6. Average TNT equivalents with respect to overpressure and pulse for the Emulinit PM tested

Detonator	Charge weight [g]	α_{TP}	α_{TI}
GMN	300	0.64	0.51
ERG		0.68	0.56
GMN	600	0.48	0.51
ERG		0.63	0.64

For 600 g charges, a significant difference is apparent depending on the type of detonators used. Such a significant reduction in the overpressure of the primary shock wave corresponds to a reduction of approximately 200 g in the mass of the explosive's charge.

3. Conclusions

The study of the explosive characteristics of Emulinit PM using detonators with different initiating capabilities allows several important conclusions to be drawn:

- When an explosive charge is initiated by a detonator (weak shock pulse), time is required for the detonation wave to reach a steady state condition.
- The time required for the detonation wave to reach a steady state condition is particularly evident in the case of nonideal explosives (all mining explosives in general), where after being initiated with a detonator, a specific charge length is needed for the explosive decomposition to reach steady state detonation conditions.
- The measurement of the detonation velocity of the charges tested shows that it does not vary with the force of the detonator used, provided the measurement is made at a distance greater than the detonation development distance.
- A charge of two 300 g cartridges linked together cannot be effectively initiated with a single detonator. Even using two parallel detonators to stimulate such a charge does not guarantee reliable initiation.

- The observed significant difference in the results of the blast wave characteristics may be due to the different development distances of steady-state detonation depending on the initiating capability of the detonators.
- To verify the effectiveness of initiating charges using single detonators connected in parallel, it is necessary to carry out experimental tests for a specific charge system and, in particular, to test a single whole charge of 600 g.
- It is necessary to consider developing detonation testing using a continuous detonation velocity recording method.

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