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Determination of Initiating Capability of Detonators by Underwater Explosion Test*)

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Abstract: New European standard of experimental procedure EN 13763-15 "Explosives for civil uses – Detonators and relays – Part 15: Determination of equivalent initiating capability" describes two methods enabling determination of initiating capability of detonators: underwater test for determination of detonators' energy and "witness plate" test for determination of influence of temperature on the effectiveness of detonators' function. This article describes the experimental arrangement and examples of test results of energy determined by underwater explosion test.

Keywords: detonators, initiating capability, underwater explosion

Introduction

Sufficiently strong impulse obtained by firing of detonator is a basic condition to create proper circumstances to start detonation of explosives. In such case it is very important to obtain a repeatable impulse with possibility to determinate energy output produced by firing of detonator of the specified type. Some comparative test methods for determination of detonators "strength" were

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used before, however they not always allow to determinate influence of changes in construction, composition, preparation, weight and type of used explosive. Therefore among standardized methods of testing purposed for explosives the European Committee [1] recommends the usage of standard for determination of equivalent initiating capability of detonators in which the basic method is the underwater detonation test.

The underwater detonation generates shock-wave and a bubble of gas products. The latter is submitted to strongly dampened consecutive pulsations. Measurement of the shock wave and time between the primary shock wave and first pulsation of the gas bubble allows to determine the energy of shock wave and gas bubble. These parameters allow us to compare the tested detonators with the reference ones.

The paper presents the initiating capability test results of the chosen types of detonators as well as analysis of sensitiveness of the method to some differences in weight and kind of explosives in detonators.

Underwater explosion test

In underwater explosion the chemical energy stored in explosive is released in various forms. This energy can be divided into the following [2]:

E_{SW} – shock wave energy carried together with the primary shock wave;

E_{BG} – bubble gas energy stored in compressed gases forming the bubble (one of measures of this energy can be the maximum size of the bubble);

E_L – energy lost by the primary shock wave for heating of water.

Correspondingly the total energy released during the detonation of explosive charge can be obtained as an algebraic sum of the indicated forms of energy. Therefore it is necessary to describe the procedure of determination of the energies on the base of experimental measurements which characterize the underwater explosion. In principle the primary shock wave energy and the bubble gas energy can be determined by measurement of overpressure of the shock wave energy generated in water.

The significant part of detonation energy is deposited in the surrounding water in the form of shock wave. The primary shock-wave energy (often described as a measure of destructive or brisance effect of explosive on the environment) can be determined from the following equation:

$$E_{SW} = k_{SW} \int_{t_0}^{t_0 + x\theta} P^2(t)\ dt\ , \qquad (1)$$

where: k_{SW} – factor of proportionality described on the base of the experiment conditions,
t_0 – time of registration of the primary shock-wave,
$x\theta$ – integration range related to the characteristic time of shock-wave.

The limits of integration in the equation (1) are still under discussion [3, 4] because it is important to cover total impulse of shock in the range. However, the length of the range should be enough to do not cause any significant influence of the sensors characteristics on the recorded pressure.

The next kind of energy of explosive detonated under water is the bubble gas energy (often described as the measure of the throwing capability of explosive). The trajectory of shock wave resulting from detonation of explosive is recorded in some distances from the explosion by pressure sensors (Figure 1).

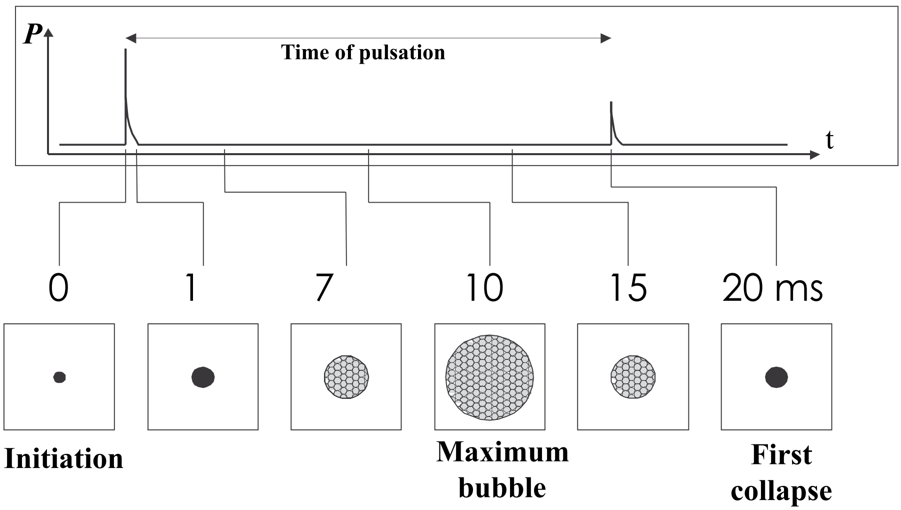

Figure 1. Layout of measurement of gas bubble pulsation time.

The expansion process caused by high pressure and temperature inside the gas bubble starts in the same time. The spreading out of the gas bubble sets into motion the surrounding mass of water. In some after time the pressure inside the gas bubble is equalized with the hydrostatic pressure of the surrounding water. However, the inertia of the water set into motion causes further outspreading of gas bubble, which reaches then its maximum size. The movement of water is then stopped and the gas bubble begins to collapse because the pressure inside it becomes to be lower than the hydrostatic pressure of the surrounding water. Then the surrounding water is set into motion towards the centre of the gas bubble. Bubble dimensions decrease till the moment of pressure equalize, but the inertia of the moving water causes its further compression up to the moment when the water movement stops and the next cycle of the bubble expansions begins, as it is visible in the Figure 1. Depending on the weight of explosive and the amount of released energy the gas bubble can make many high-dampened pulsations.

The time measured between the moment of the primary shock-wave registration and consecutive pressure-wave is the principle for calculation of bubble gas energy according to equation (2).

$$E_{BG} = k(t_b)^3, \quad (2)$$

where: k – factor depending on the experiment conditions,
t_b – the time of first pulsation of gas bubble.

Experiments

Arrangement for testing

For the purpose of tests, the arrangement for measurement, build up according to the recommendations of EN standard, was used. The scheme of the arrangement for testing is shown in Figure 2.

Figure 2. The picture of the arrangement for testing (volume *ca*. 1 m^3).

The positioning system for the tested detonators and pressure sensors (Figure 3) was placed inside the arrangement for testing.

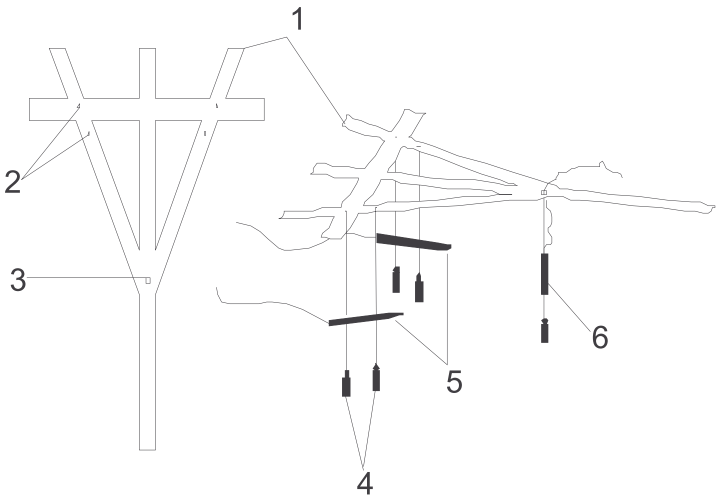

Figure 3. The skeleton of arrangement for hanging up tested detonator and pressure sensors in the proper depth and mutual distance. **1** – skeleton of assembly; **2** and **3** – holes for assembly; **4** – weights; **5** – pressure sensors; **6** – tested detonator [5].

Pressure sensors

The piezoelectric pressure sensors made by PCB series 138 were used for the purpose of testing. Their design allows to record the overpressure of the passing wave. The characteristics of the sensors used in tests are shown in Table 1.

Table 1. Technical parameters of piezoelectric sensors used for measurements

Parameter	Unit of measure	Sensor 138A05	Sensor 138A10
Range of measurement	[MPa]	34.50	69.00
Resolution	[KPa]	0.69	1.37
Sensitivity	[mV KPa^{-1}]	0.15	0.073
Resonance frequency	[MHz]	≥1	≥1
Active element	material	tourmaline	tourmaline

Tested detonators

Detonators made by ZTS NITRON S.A. were used for the testing purpose. They differed between each other by amount and type of explosive in the base charge and kind of shell. The characteristics of the detonators used in tests are shown in Table 2.

Table 2. Technical parameters of detonators used in tests

Detonator	Mass of explosive, [g]	Amount of elements, [cg g^{-1}]		
		Hx	PETN	Al
KM-1	0.25	-	100	-
KM-2	1.00	-	100	-
KM-3	1.00	-	90	10
KM-4	0.70	100	-	-

The detonators were placed in the testing arrangement for measurements. The detonation of explosive base charge generated shock-wave in water, which was recorded by pressure sensors. The signal from the sensors sufficiently amplified by amplification system was recorded by the digital oscilloscope and then transmitted to the computer. The example of primary shock wave pressure recorded for the KM-1 detonator was shown in Figure 4. For the specified type of detonator 10 overpressure courses were obtained as a base for calculations and analysis of the obtained results.

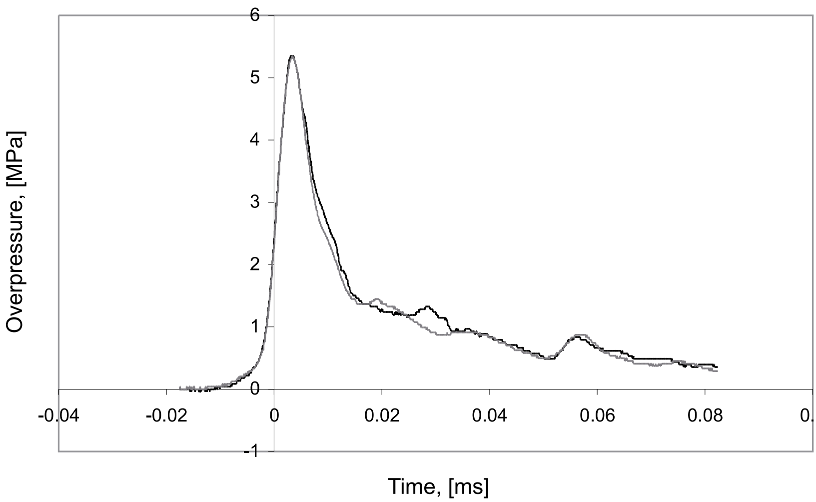

Figure 4. Course of overpressure recorded for KM-1 detonator by means of two pressure sensors.

The very good qualitative and quantitative accordance of the recorded courses of overpressure was observed during the tests. Such accordance was also recorded for the series of the specified type of detonators. It can suggest that the used method of underwater detonation allows for high precision recording of overpressure course of shock wave generated in water by exploding tested detonators.

The measurement of the overpressure in water also allowed to record time of arriving of the first compressed wave generated by the first collapse of gas bubble. The result of pulsation time of gas bubble recorded for the detonator KM-1 is shown in Figure 5.

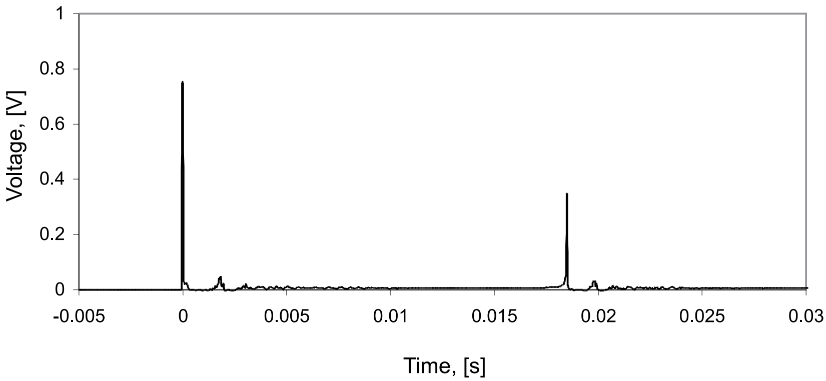

Figure 5. Example of the course of gas bubble pulsation time.

Calculation and analysis of results

The obtained results of overpressure characteristics measurement were the base for determination of shock wave parameters and gas bubble pulsation time. The determined shock wave parameters and results of calculations are shown in Table 3. It includes the values of the maximum overpressure of shock waves generated by explosion of detonators. The width of the overpressure peak determines the characteristic time.

Table 3. Shock-wave parameters and results of calculation

Detonator	θ [μs]	t_b [ms]	Δp [MPa]	E_{FU} [J]	E_b [J]
KM-1	12.47 ±0.53	18.52 ±0.05	5.15 ±0.20	331 ±18	494 ±4
KM-2	15.68 ±0.71	26.08 ±0.12	9.52 ±0.35	1250 ±87	1381 ±19
KM-3	20.87 ±0.80	26.90 ±0.09	9.46 ±0.29	1358 ±92	1514 ±16
KM-4	15.78 ±0.69	23.33 ±0.15	7.72 ±0.32	829 ±32	988 ±19

The obtained results of overpressure for the specific types of tested detonators are shown in Figure 6. There can be noticed a very interesting influence of 10 cg g^{-1} addition of aluminium powder to the explosive base charge in detonator.

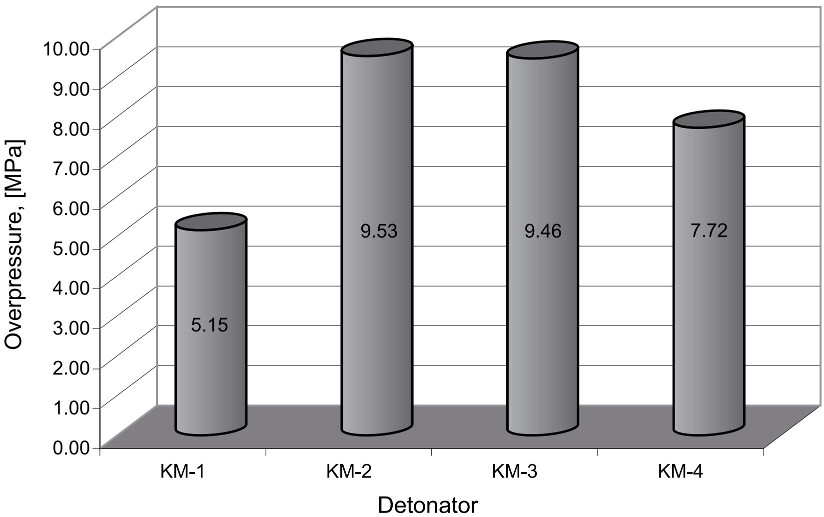

Figure 6. The results of shock wave overpressure measurement.

The addition of high energetic aluminium powder to the explosive base charge in detonator does not cause any significant influence on the measured shock wave overpressure, only decreases it slightly. It results from the character of the reactions between the aluminium powder and the products of explosion. The reactions occur mostly outside the zone of chemical reactions of detonation wave. The particles of aluminium are heated up in this zone and absorb warmth therefore the detonation wave parameters are decreased. Afterwards the particles of aluminium start to react with explosion products supplying additional energy. However the conditions of test (water acts as a heavy casing [6]) cause that some part of aluminium reacts just in the zone of chemical reactions. It is confirmed by the fact that the differences in amplitudes of the measured shock waves are slight.

The width of the overpressure peak for the detonator including the mixture of explosive with aluminium is much bigger than without addition of aluminium powder and it has big meaning in calculation of shock wave energy. Wider overpressure peak in this case can be explained by the reaction of a certain amount of aluminium directly behind the zone of chemical reactions of detonation wave. The next big amount of aluminium reacts with the products of explosion during expansion of gas bubble and influence significantly on the amount of energy. which is accumulated in bubble. The results of calculation of the shock wave energy and gas bubble energy for the tested detonators are shown in Figure 7.

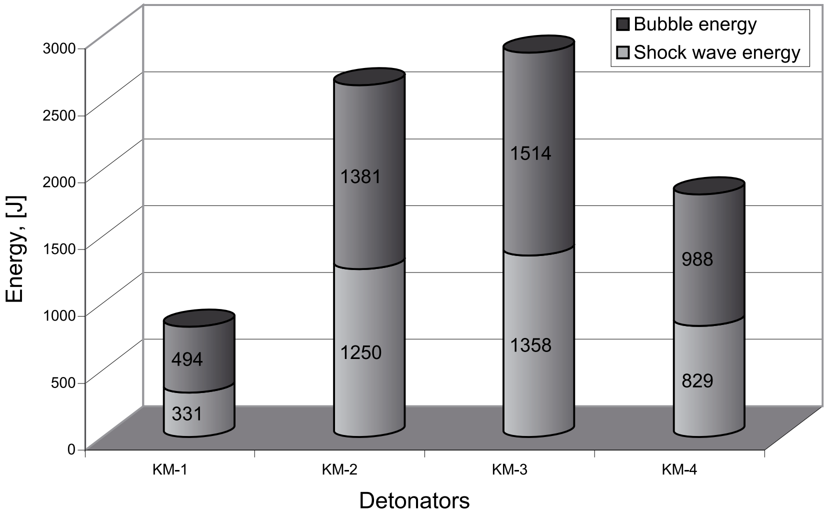

Figure 7. Calculated energy of the tested detonators.

It can be noticed from the above drawing that in spite of decreasing the shock wave amplitude for the detonator including the aluminium powder the calculated shock wave energy for this detonator is slightly bigger than for the detonator without aluminium additive. The fact of widening of the overpressure peak has decisive meaning in this case. The gas bubble energy for this case is significantly bigger what can be the evidence of additional exothermic reactions occurred between the aluminium powder and the products of explosion.

Conclusions

The results of measurement presented in this work allow to state that the proposed by UE test of underwater detonation as one of the tests for determination of initiating capability of detonators is a good method for determination of influence of various factors on this capability. The method of underwater detonation allows us to compare the tested detonators with the references ones.

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