Blasting properties of low-density emulsion based mixtures

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Abstract

Emulsion explosives are commonly used for civil purpose blasting. In order to decrease impact effect on surrounding rock mass, it is possible to reduce detonation pressure and borehole pressure with reducing of density of proposed explosive emulsion based mixtures.

In that case reduction of the velocity of detonation is also achieved. In focused testing, emulsion matrix has been sensitized with expanded polystyrene. Mixtures with different portion of EPS have been prepared and blasted in rock bore holes. According to measured velocity of detonation values, relationship with density and work ability has been determined.

Keywords: emulsion based explosives; velocity of detonation; work ability

1 Introduction

Low-density explosives usually have a density of less than 0,80 g/cm^3, and the explosives with a density of less than 0,20 g/cm^3 are called ultra low-density explosives [1].

Low-density emulsion explosives are essentially mixtures of an emulsion matrix and a certain amount of gas-phase inclusions that act as hot spots. By adding expanded polystyrene for gas sensitization, the resulting explosive mixture was designed to reduce the peak and pressure pulse of the gaseous detonation products on the surrounding rock. In addition, this resulted in a reduction in rock stress and a reduction in the width of the crack zone outside the minefield boundary. The reduction of damaged zones in underground and open-pit mines has significant implications. It indirectly reduces the cost of both blasting and post-blasting (e.g., by improving the properties of the mined rock). Another advantage of low-density emulsion explosives is a lower volume concentration of energy. This allows for an optimal effect in crushing and fragmenting the rock, which in turn reduces the proportion of fines in the granulometry of the mined material. Finally, the use of low-density emulsion explosives correlates with the reduction of the seismic effect of blasting, more precisely with the reduction of the induced rock vibration velocities.

The decrease of strain and damage of blasted rock is very important in the excavation of tunnels, underground chambers and radioactive waste disposal facilities since not only blasting costs are reduced, but also transport costs due to lower volume of blasted material as well as material needed for rock impermeability. In addition to the aforementioned, low-density explosives are also used in explosive welding, explosive forming, formation of works of art, etc [6].

In order to determine the conditions in the rock, detonation velocity measurements were carried out for different low-density explosive mixtures. The detonation velocity can provide information about the working capability of a particular mixture compared to another explosive.

In addition, the measured values were compared with those calculated by the Explo5 thermochemical computer code.

2 Work ability of explosive

The work ability of the explosive is determined as a measure of the detonation effect in a medium and the conditions of energy transfer into a medium, in this case, rock material. It is not unambiguously defined but its expression depends on the used experimental method. Initially, the work capacity depends on the theoretical detonation energy, energy losses, and the dynamics of energy transfer. Ultimately, the mechanical work done during the expansion of the detonation products in a rock mass is used to fracture, fragment, and generally move the blasted rock mass. It follows from the hydrodynamic theory of detonation that, under ideal conditions, the available energy of an explosive can be expended for mechanical work (Ee) on the surrounding material, reduced by the energy of compression (EC), and, to a lesser extent, for heat losses during the expansion. The graphical representation of the detonation energy available for mechanical work is represented by the surface area under the detonation product adiabatic (Figure 1).

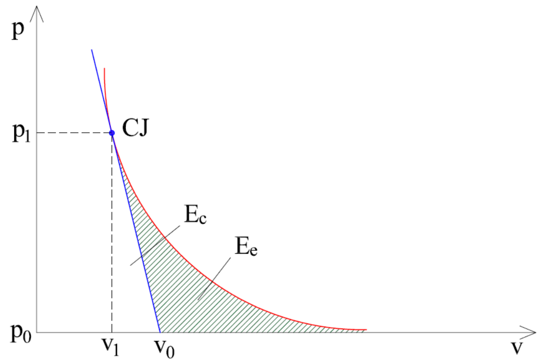

Figure 1. The detonation energy available for the mechanical work [5]

The detonation energy available for mechanical work (Ee) can also be given as:

$$E_e = \int_{v_0}^{v_{cj}} p dv - \frac{u^2}{2} \tag{1}$$

where Ee is the detonation energy available for mechanical work (kJ/kg), p is the detonation pressure during expansion (Pa), v is the specific volume (m3/kg), u is the particle flow velocity (m/s) and u2/2 (or Ec) is the compression work (kJ/kg).

The working capacity of low-density explosives was determined using standard and modified experimental methods selected according to feasibility and availability of data for reference explosives. The effects were determined in relative proportions so that they can be applied to the commercial reference explosives used in blasting operations. Detailed test results have been published in recent articles.

The working capacity of a mixture based on a low-density emulsion matrix was determined by the modified Trauzl test in aluminium blocks and by the double-tube test. The results of the determination of the working capacity by the modified Trauzl test are shown in Table 1.

Tests with emulsion matrix and expanded polystyrene blends under laboratory conditions determined the optimum polystyrene content.

Table 1. The results of determining work ability by the modified Trauzl test [5].

Block no.	Explosive material	Total expanded volume, Vpr (cm^3)	Work ability, Vpr/VREF
1	Pentrite	45,6	1,00
2	Emulsion explosive	23,6	0,52
3	ANFO	9,6	0,21
4	M:E 50:50 (volume ratio)	11,6	0,25
5	M:E 40:60 (volume ratio)	11,6	0,25
6	M:E 30:70 (volume ratio)	9,6	0,21

Borehole pressure can be, with certain limitations, approximately described as a half of detonation pressure which, in the case of ideal detonation gas behaviour and a completely filled borehole, is [2]:

$$p_b = \frac{\rho v_{\mathrm{d}}^2}{8} \tag{2}$$

where:

- ρ – explosive material density (kg/m3),
- vd – velocity of detonation (m/s) and
- pd – detonation pressure (Pa).

Regardless of the final value of the real pressures in the borehole and the reduction of their values at the borehole wall, they are directly related to the velocity of detonation of an explosive. The final influence on rock crushing depends on rock properties and density.

3 Tests and calculations

For research purposes, measurements of the detonation velocity in the borehole were performed. Calculation of theoretical values of VOD was performed using Explo5 thermochemical code.

The tested explosives were obtained by sensitizing the emulsion matrix by expanded polystyrene. Expanded polystyrene was added in different volume ratios resulting in explosive mixtures with different densities.

In order to determine the properties of the mixtures, the possible applications of the obtained explosive mixtures and their use under laboratory conditions, various tests were carried out, the second set of measurements was carried out under field conditions in effusive magmatic rock, diabase. Characteristic of diabase are presented in table 2.

Table 2. Physical and mechanical characteristics of diabase [7]

DIABASE		
Density	2,85 – 3,15	g/cm^3
Spatial mass	2,8 – 3,1	g/cm^3
Porosity	0,1 – 1	% volume
Water absorption	0,2 – 1	% mass
Compression strength	200 – 400	MPa

The low-density explosive mixture was placed in a 40-mm-diameter, 1200-mm-deep borehole with a charge length of 1000 mm and a diameter of 28 mm. The detonation velocity was measured for each blast using the continuous electro resistant method and the discontinuous electro-optical method. The schematic diagram for one borehole is shown in Figure 2.

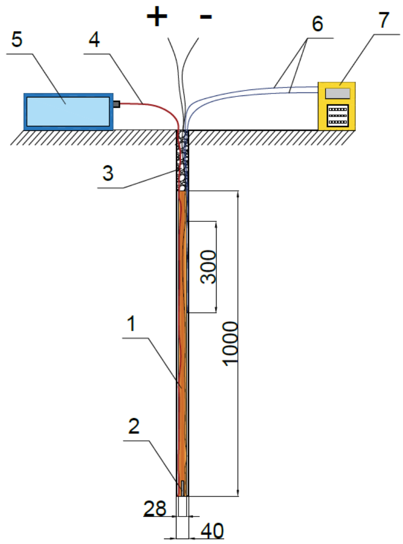

Figure 2. Schematic measurement setup

LD charge, 2 detonator, 3 sand plug, 4. Electro resistant probe, 5. VOD meter continuous, 6. Optical probes, 7. VODmeter discontinuous, 300 mm-distance between optical probes

Low density explosives were used for the tests. The explosive density was reduced by adding expanded polystyrene granules (EPS) to the emulsion matrix. The EPS was declared with mesh sizes ranging from 0,5 mm to 1,5 mm. The volume ratios of emulsion matrix and EPS were 50:50, 40:60, and 30:70, respectively. The mixing ratio of 20:80 ratio failed to detonate in the bore hole conditions.

Emulsion matrix is a colloid mixture of nitrates dissolved in water, dispersed in oil phase and it has no explosive properties. Through sensibilizing by materials which consist of granules containing air (gas phase) in the shape of glass microspheres, granulated ammonium nitrate or clay microspheres – perlite, and that present so called hot spots which are used to support and achieve stable detonation velocity, after initial, sufficiently strong impulse, emulsion matrix turns into explosive [3].

In the tested LD mixtures, sensitization was achieved by adding expanded polystyrene grains. They act also as sensitizer and fuel.

Since the matrix does not contain any substance that is itself explosive, and due to the desensitizing effect of the extremely high water content, it has a high safety level.

The manufacturer's specifications of the emulsion matrix used are shown in Table 3. The mixture based on a low-density emulsion matrix is shown in Figure 3.

Table 3. Data of the emulsion matrix [5].

Quality mark	Unit	Value
Nitrogen	%	24,8-26,5
pH (oxidizer solution)	-	4,3
Density	g/cm^3	1,40
Viscosity at 25°C (spindle n°7, 20 rpm)	poise	270

Figure 3. Low-density emulsion matrix based mixture

EXPLO5 is thermochemical computer code that predicts detonation (e.g., detonation velocity, pressure, energy, heat end temperature, etc.) and combustion (e.g., specific impulse, force, pressure, etc.) performance of energetic materials. The calculation of detonation parameters is based on the chemical equilibrium steady-state model of detonation. The equilibrium composition of detonation and combustion products is calculated by applying modified White, Johnson, and Dantzig's free energy minimization technique. The program uses the Becker-Kistiakowsky-Wilson (BKW) and Exp-6 EOS for gaseous detonation products, the ideal gas and virial equations of state of gaseous combustion products, and the Murnaghan equation of states for condensed products [4].

The calculations were performed in the ideal detonation run mode for low-density mixtures. Low-density mixtures have non-ideal detonation behavior, so the calculated values can be used in a relative proportion and trends can be shown for large-diameter charges.

4 Analysis of results and conclusion

All mixtures except the 20:80 mixture detonated. The effect of filling the borehole with a 40:60 mixture is shown in figure 4., and continuous VOD record for 30:70 mixture is shown in figure 5. The results of measuring the velocity of detonation using the continuous and discontinuous method and the results calculated with the Explo5 code are shown in table 4. Dependence of the density on the measured and calculated VOD is shown on figure 6.

Figure 4. Blast performance for bore hole charged with 40:60 mixture

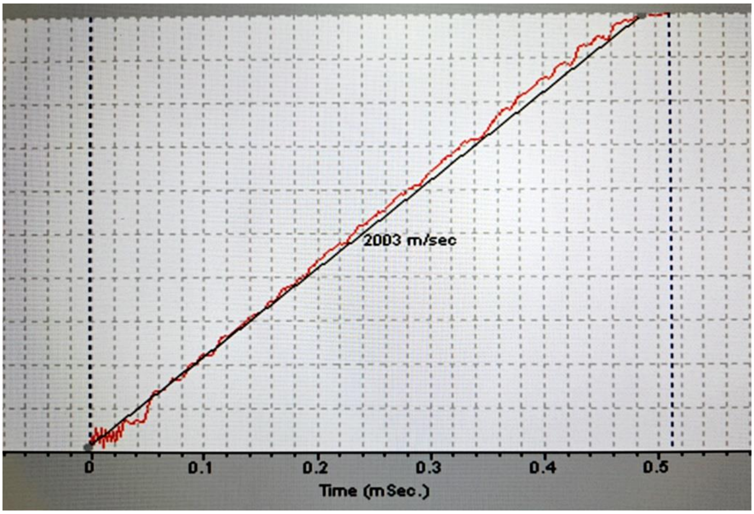

Figure 5. Continuous VOD record for 30:70 mixture

Table 4. Measured and calculated VOD

Mixture (Volume ratio)	Density ρ g/cm3	VOD masured Explomet v (m/s)	VOD masured VODmate v (m/s)	VOD EXPLO5 v (m/s)
50:50	0,709	2785	2740	3982
40:60	0,575	2706	2496	3519
30:70	0,441	2063	2003	3078
20:80	0,308	-	-	2649

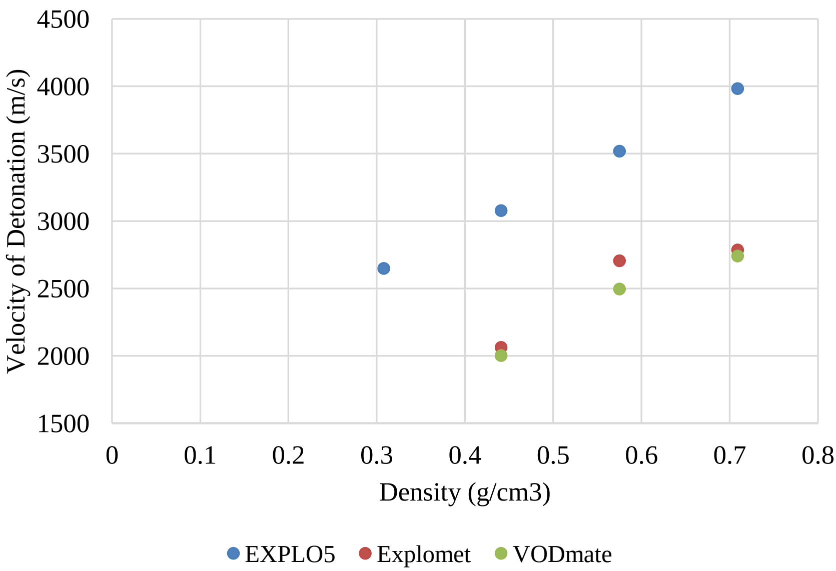

Figure 6. Dependence of the density on the measured and calculated VOD

The results in Table 4 and Diagram 6 show that the mixture of EPS and emulsion matrix with a volume ratio of 50:50 has a charge density of 0,709 g/cm^3 and a stable detonation velocity with measured average values of 2740 m/s to 2785 m/s. The mixture with a volume ratio of 40:60 has a charge density of 0,575 g/cm3 and a stable detonation velocity with measured average values of 2496 m/s to 2706 m/s. The mixture with a volume ratio of 30:70 has a charge density of 0,441 g/cm^3 and a stable detonation velocity with measured average values of 2002 m/s to 2063 m/s. The dissipation of the measurement results for different methods, continuous and discontinuous, is based on the interpretation of the curve slope and the settlement of the borehole probes.

The dependence of the detonation velocity of the low-density emulsion-based explosive corresponds to the non-ideal behaviour in terms of mixture density. Thus, the theoretical ideal values calculated with Explo5 are significantly higher than the measured values. The dependence on charge density is expected and is common for emulsion explosives.

Acknowledgement

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