Physical and Technical Evaluation of Possibility Using Low-density Explosives in Smooth-wall Blasting

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The use of low-density emulsion explosives sensitized with expanded polystyrene granules may become one of the promising directions in smooth blasting during open cast mining operations.

At 40-50 kg/m³ bulk density of expanded polystyrene, the porosity of granules allows to use blast hole charges up to 30-40 meters high (I.Y. Maslov, 2013).

By regulating the ratio of emulsion volume to the volume of expanded polystyrene granules, it is possible to obtain low-density EEs with various densities and various detonation properties.

Low densities of EEs will allow using continuous column charges (instead of decked charges) for smooth blasting, which will significantly simplify the mechanization of charging procedures.
Objective

- **Demonstrate** the possibility of stable propagation of the explosive process in low-density emulsion explosive sensitised with expanded polystyrene granules.
- **Develop a method** for calculating detonation parameters of low-density EEs.
First series of experiments
Polystyrene granules
Ø1-2 mm

Emulsion

\[ \gamma(\text{NH}_4\text{NO}_3) = 75\% \]
\[ \gamma(\text{H}_2\text{O}) = 18\% \]
\[ \gamma(\text{Emulsifier}) = 1\% \]
\[ \gamma(\text{Machine oil}) = 6\% \]
\[ \gamma - \text{Mass fraction} \]

\[ \rho_{\text{emulsion}} = 1328 \text{ kg/m}^3 \]
\[ \rho_{\text{bulk}} = 30 \text{ kg/m}^3 \]
\[ \rho_{\text{charge}} = 700 \text{ kg/m}^3 \]
Copper plate
Thickness = 4 mm

Sand

250 mm
Conclusion

If $\rho_{\text{charge}} < 0.7 \text{ g/cm}^3$ there is no detonation transmission through the copper plate.
Second series of experiments
Detonating cord

T-1000-L-P block

Polystyrene granules
Ø4-5 mm
\( \rho_{\text{bulk}} = 40 \text{ kg/m}^3 \)

Experimental result

\( \rho_{\text{charge}} = 1000 \text{ kg/m}^3 \) VOD = 3200 m/s
\( \rho_{\text{charge}} = 520 \text{ kg/m}^3 \) VOD = 3440 m/s
Detonating cord

T-1000-L-P block

Popcorn Ø8 mm

ρ_{bulk} = 40 \text{ kg/m}^3
ρ_{charge} = 600 \text{ kg/m}^3
Popcorn
Average $\bar{d} \approx 8$ mm
\[ \rho_{\text{charge}} = 600 \text{ kg/m}^3 \]
\[ d = 240 \text{ mm} \]
\[ \text{VOD} = 4123 \text{ m/s} \]

Booster – T-1000-L-P block

\[ \rho_{\text{charge}} = 600 \text{ kg/m}^3 \]
\[ d = 130 \text{ mm} \]
\[ \text{VOD} = 4065 \text{ m/s} \]

Booster – T-1000-L-P block
Discussion of experimental data
The calculation of VOD of a low-density EEs sensitized with expanded polystyrene granules based on the shock-wave excitation model.

At a density EEs 600 kg/m³ and bulk density 40 kg/m³ of popcorn granules, we obtain calculation detonation speed 3195 m/s.

This calculated value is significantly lower than the experimental value (4065-4123 m/s).
where is: \( \xi_o \) — ratio of the bulk volume of popcorn granules to the volume of matrix emulsion,

\( \rho_{oo}^* \) — density of the EE sensitized with popcorn granules,

\( \rho_{em} \) — matrix emulsion density,

\( \rho_{pc} \) — bulk density of popcorn granules,

\( k_{pack} \) — packing factor of popcorn granules (ratio of the bulk volume of granules to the own volume of granules)

\( \xi_o = 1.75; \rho_{oo}^* = 600 \text{ kg/m}^3; \rho_{em} = 1328 \text{ kg/m}^3; \rho_{pc} = 40 \text{ kg/m}^3; k_{pack} = 1.6 \)

0.089>0

Connected “sensitizing granules – air pores” system appears in the EE
The structure of the EE under consideration is represented by “fog” of matrix emulsion drops, which are separated from each other by air pockets and (or) light fragile granules.

The presence of end-to-end channels changes initiation mechanism of the EE.
Initiation may take place by the mechanism suggested by V.V. Andreev, A.P. Ershov, L.A. Lukyanchenkov (1979) for low density RDX and PETN, according to which the stream of hot gases filtering from the high-pressure area and igniting the emulsion drops will play the leading role in detonation wave propagation.
If these drops inflame during the period less than the duration of explosive’s decomposition process in the area of violent chemical reaction (the high-pressure area), then propagation of the explosive process throughout the low-density EE will be determined by the propagation speed of this ignition process.

\[ \tau < t_{\text{chem.r.}} \]
Time of chemical reaction in the high-pressure area

\[
t_{\text{chem.r.}} = \frac{R_{dr}}{\nu_{\text{comb}}} \quad \text{- duration time of chemical reaction in the high-pressure area}
\]

\[
\nu_{\text{comb}} = \left(\frac{\rho_e}{\rho_f}\right)^{\frac{1}{2}} \left(\frac{\chi u_*^2}{R_{dr}}\right)^{\frac{1}{3}} \quad \text{- velocity of ablation combustion Andreev, Ershov, Lukyanchenkov (1979)}
\]

- \(\rho_f\) - density of the emulsion
- \(\rho_e\) - density of vapours of a drop’s matter near its surface
- \(\chi\) - the temperature conductivity of explosive gases in the head end of the stream
- \(u_*\) - the speed of the stream of hot explosive gases flowing out from the high-pressure area with respect to a stationary observer
Ignition time of emulsion drop blown over by the air blast wave and the stream of explosives gases

\[ \tau = \tau_9 t_a \]

\[ t_a = \frac{cRT_s^2}{E Q z} \exp \left( \frac{E}{RT_s} \right) \quad \tau_9 = \frac{1 - 0,2 | \Theta_H | + 0,36 \Theta_H^2}{(1 - 0,8 \beta)} \]

(Vilyunov, 1984)

\[ \Theta_H = \frac{E (T_H - T_S)}{RT_s^2} \quad - \text{temperature difference} \]

\[ \beta = \frac{RT_s}{E} \quad - \text{‘reaction speed-temperature’ correlation index} \]
RESULTS OF CALCULATIONS WITH THE MODEL OF STREAM TRANSMISSION OF EXPLOSIVE PROCESS

Duration time of chemical reaction – 56.2 µs;
Induction time of emulsion ignition – 51.7 µs;

Velocity of the gas stream flowing out from the high-pressure area – 3837 m/s
Velocity of the air blast wave propagating in front of the stream – 4221 m/s (Experiment – 4123 m/s)
Polytropic curve factor – 1.907, adiabatic curve factor – 1.289
Heat of explosion – 596.5 kcal/kg
Specific volume of gases – 1093 l/kg
Density of explosion gases in the head end of the stream – 0.0457 g/cm³
Temperature of explosive gases in the head end of the stream – 628ºK
Pressure in explosive gases in the head end of the stream – 20.9MPa
Pressure in the area of violent chemical reaction – 1690MPa
Industrial-experimental Testing

Conventional blasting on «Uralasbest» has assumed the use of garland charges made of ammonite №6ЖВ cartridges with linear charge density 1.0kg/m.

Calculation of the needed charging density for the low-density EE was performed through the empirical formula of V.A. Kuznetsov (2010), which had been suggested for smooth blasting

\[ \rho_{ee} = \rho_{st} \left( \frac{D_{st}}{D_{ee}} \right)^2 \left( \frac{E_{st}}{E_{ee}} \right)^{1.25} \]

where \( \rho_{st}, D_{st}, E_{st} \), and \( \rho_{ee}, D_{ee}, E_{ee} \) are charging density, velocity of detonation, relative performance coefficient for the reference explosive (ammonite 6ЖВ) and the emulsion explosive.

\( \rho_{st} = 96\text{kg/m}^3, D_{st} = 4800\text{ m/c}, E_{st} = 1, D_{ee} = 3200\text{ m/s}, E_{ee} = 0.5 \)

\( \rho_{ee} = 513\text{kg/m}^3 \)
Industrial-experimental Testing


Type of explosive: Emulsion explosive sensitized with expanded polystyrene granules ø5mm. Bulk density = 60 kg/m³. \[ \rho_{\text{charge}} = 485 \text{ kg/m}^3 \]

98 dry holes
Ø115 mm
\[ L_{\text{hole}} = 16.5 \text{ m} \quad L_{\text{charge}} = 12.5 \text{ m} \]
Distance between the holes = 2 m

The quality of smooth blasting with the use of low-density EEs has turned out to be comparable to the quality of smooth blasting with conventional use of garland charges of ammonite №6 cartridges with linear charge density = 1.0 kg/m³.
Conclusions

- In low-density EE’s sensitized with expanded polystyrene granules, it is possible to provide stable propagation of detonation-like wave of emulsion drops combustion in explosive gas streams flowing out of the high-pressure area of the reaction zone. At that, gradual pressure increase is observed in explosive decomposition products, which is advantageous for smooth blasting.

- Industrial-experimental testing has demonstrated the efficiency of using low-density EEs in smooth blasting at OJSC “Uralasbest” quarry.

- The research results allow obtaining useful information for creation of new types of low-density EEs and validation of smooth blasting technology using such explosives.
Thank you for your attention