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# Explosive Mixtures Detonating at Low Velocity

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## Summary

Same explosive mixtures detonating at a low velocity and not containing high explosives were experimentally investigated. As a system providing detonation capability, a mixture of ammonium nitrate and powdered aluminium was employed. Glass or urea-formaldehyde resin beads or lead oxides were used to reduce detonation parameters. Detonation velocity and critical diameter were measured for mixtures differentiated in composition and density. As a result of the investigation, a number of explosives were worked out which are characterized by the capability of stable detonation at a very low velocity (below 1000 m/s) and simultaneously, some of them have a relatively high density (even over 2 g/cm$^3$). An attempt of physical and chemical interpretation of the results obtained is also included.

## 1. Introduction

Explosives that detonate at a low velocity are used in mining industry to excavate block deposits as well as in some methods of high-energy treatment of metals such as cladding with lead or fixing of tubes to sieve bottoms of heat exchangers. Within the range of real density, most molecular explosives are characterized by high detonation parameters. They can be lowered by addition of some amount of inert substances having low bulk density[1,2]. Low detonation parameters are also typical for ammonium nitrate explosives sensitized by nitric esters and containing a lot of sodium chloride. However, the presence of highly sensitive explosives in the mixtures can be dangerous, especially if they are used outside of a mining plant.

In order to work out new explosive mixtures characterized by low detonation characteristics, many tests were carried out with some types of formulations not containing high explosives. Their common feature was the application of mixtures of ammonium nitrate and aluminium powder as a system providing the capability of detonation. The use of flaked aluminium assured small critical diameter of the explosives[3–5]. Additionally, lead oxides or substances characterized by very low bulk density were used to reduce the detonation velocity.

## 2. Experiments and Results

The explosive mixtures were prepared from commercial grade ingredients: crystalline ammonium nitrate (particle size smaller than 800 μm), flaked aluminium (size reduction below 75 μm), urea-formaldehyde resin balloons (bulk density 0.08 g/cm$^3$), glass beads (bulk density 0.37 g/cm$^3$ and dimension smaller than 125 μm), colloidal-sized silicon dioxide (bulk density 0.06 g/cm$^3$) and lead oxides ($PbO_2$ or $Pb_3O_4$, particle size below 200 μm). The explosives were mixed in 2 kg batches and cartridged into different paper shells. The charges were then used to measure the detonation velocity and the critical diameter. Both of the parameters can be used as a criterion of selection of explosives for specific blasting engineering.

The mean values of the detonation velocity were measured with short circuit sensors in charges (18 or 25 mm in diameter) placed into paper tubes. Conical and telescopic charges were employed to determine the critical diameter of detonation. The composition of explosives and the measurement results are given in Tables 1–6. All results are from a single batch of explosive with each value being an average of three experimental results. The average error for any single datum of detonation velocity was not higher than ±100 m/s.

## 3. Discussion and Data Analysis

Several aspects of the data were unusual. The detonation velocity was very low. However, the critical diameter was relatively small, especially when the mixtures contained a small amount of additives (2–5 % of glass beads, $SiO_2$ or urea-formaldehyde resin balloons). An increase in contents of additives caused a decrease in the density and consequently led to a reduction in the detonation velocity and to an increase in the critical diameter. Every one-percent addition of glass beads lowered the detonation velocity by 20–60 m/s and increased the critical diameter by a fraction of millimeter. The higher the contents of glass beads were the higher were the changes of the parameters (Tables 1 and 2).

In the case of mixtures containing urea-formaldehyde resin balloons, there were similar changes of the parameters but the detonation velocity was much higher (Table 3). This fact indicated that the resin behaved as an additional fuel and reacted with the decomposition products of the oxidizer ($NH_4NO_3$). The observed increase in the explosive performance could only be caused by an energy release as a result of the reactions. Glass beads and silica, on the other hand, consist mainly of chemically inert silicon dioxide. Therefore, they absorbed entirely the energy in the detonation wave and

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**Table 1.** Detonation Parameters of Mixtures Containing 2, 3, and 4% of Al and Glass Beads

| Formulations | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| *Composition [%]* | | | | | | | | |
| Flaked aluminium | 2 | 2 | 2 | 3 | 3 | 3 | 4 | 4 |
| Ammonium nitrate | 96 | 91 | 88 | 92 | 87 | 82 | 92 | 89 |
| Glass beads | 2 | 7 | 10 | 5 | 10 | 15 | 4 | 7 |
| *Detonation parameter* | | | | | | | | |
| Density [g/cm$^3$] | 0.97 | 0.90 | 0.85 | 0.99 | 0.90 | 0.85 | 0.93 | 0.92 |
| Critical diameter [mm] | 10 | 12 | 14 | 11 | 15 | 18 | 9 | 9 |
| Detonation velocity [m/s] | | | | | | | | |
| Diameter: 18 mm | 1630 | 1400 | 1220 | 1560 | 1280 | 1060 | 1720 | 1660 |

**Table 2.** Detonation Parameters of Mixtures Containing 5, 6, and 10% of Al and Glass Beads

| Formulations | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| *Composition [%]* | | | | | | | | |
| Flaked aluminium | 5 | 5 | 5 | 6 | 6 | 6 | 10 | 10 |
| Ammonium nitrate | 92 | 89 | 86 | 89 | 84 | 79 | 85 | 80 |
| Glass beads | 3 | 6 | 9 | 5 | 10 | 15 | 5 | 10 |
| *Detonation parameter* | | | | | | | | |
| Density [g/cm$^3$] | 0.94 | 0.89 | 0.82 | 0.96 | 0.93 | 0.85 | 0.98 | 0.90 |
| Critical diameter [mm] | 9 | 9 | 11 | 10 | 12 | 16 | 10 | 19 |
| Detonation velocity [m/s] | | | | | | | | |
| Diameter: 18 mm | 1860 | 1700 | 1600 | 1600 | 1490 | 1150 | 1650 | – |

**Table 3.** Detonation Parameters of Mixtures Containing 3, 6, and 10% of Al and Urea-Formaldehyde Resin Balloons

| Formulations | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|
| *Composition [%]* | | | | | | | | | |
| Flaked aluminium | 3 | 3 | 3 | 6 | 6 | 6 | 10 | 10 | 10 |
| Ammonium nitrate | 92 | 87 | 82 | 89 | 84 | 79 | 85 | 80 | 75 |
| Resin balloons | 5 | 10 | 15 | 5 | 10 | 15 | 5 | 10 | 15 |
| *Detonation parameter* | | | | | | | | | |
| Density [g/cm$^3$] | 0.84 | 0.68 | 0.54 | 0.83 | 0.67 | 0.58 | 0.62 | 0.54 | 0.45 |
| Critical diameter [mm] | 8 | 10 | 16 | 8 | 12 | 18 | 8 | 12 | 16 |
| Detonation velocity [m/s] | | | | | | | | | |
| Diameter: 25 mm | 2230 | 1880 | 1570 | 2450 | 2120 | 1810 | 2430 | 2290 | 1990 |
| Diameter: 18 mm | 1930 | 1610 | – | 2300 | 1930 | – | 2160 | 1900 | – |

were finally responsible for the relatively low detonation characteristics of explosives containing those components. Furthermore, colloidal $SiO_2$ which has a very low bulk density allowed to prepare explosive mixtures with low density and stably detonating at a low velocity (Table 4).

An addition of lead oxides to the mixtures of ammonium nitrate and aluminium powder led to an increase in their density and to a decrease in the detonation velocity (Tables 5 and 6). Stable propagation occurred at a low velocity, in small diameters, even for the case of very large contents of lead oxides. The results obtained enabled us to advance a hypothesis that each of both oxides can react in the

**Table 4.** Detonation Parameters of Mixtures Containing 3, or 6% of Al and Colloidal Silicon Dioxide

| Formulations | 26 | 27 | 28 | 30 |
|---|---|---|---|---|
| *Composition [%]* | | | | |
| Flaked aluminium | 3 | 3 | 6 | 6 |
| Ammonium nitrate | 92 | 89.5 | 89 | 86.5 |
| Silicon dioxide | 5 | 7.5 | 5 | 7.5 |
| *Detonation parameter* | | | | |
| Density [g/cm$^3$] | 0.46 | 0.40 | 0.46 | 0.37 |
| Critical diameter [mm] | 12 | 17 | 12 | 15 |
| Detonation velocity [m/s] | | | | |
| Diameter: 25 mm | 1700 | 990 | 2230 | 1450 |

**Table 5.** Detonation Parameters of Mixtures Containing $PbO_2$

| Formulations | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
|---|---|---|---|---|---|---|---|---|---|
| *Composition [%]* | | | | | | | | | |
| Flaked aluminium | 1 | 1 | 1 | 6 | 6 | 6 | 6 | 6 | 6 |
| Ammonium nitrate | 79 | 59 | 39 | 74 | 54 | 34 | 14 | 9 | 4 |
| Lead dioxide, $PbO_2$ | 20 | 40 | 60 | 20 | 40 | 60 | 80 | 85 | 90 |
| *Detonation parameter* | | | | | | | | | |
| Density [g/cm$^3$] | 0.89 | 1.11 | 1.32 | 0.87 | 1.00 | 1.34 | 1.80 | 2.15 | 2.43 |
| Detonation velocity [m/s] | | | | | | | | | |
| Diameter: 25 mm | 1130 | 890 | failure | 2160 | 1950 | 1600 | 1040 | 840 | failure |

**Table 6.** Detonation Parameters of Mixtures Containing $Pb_3O_4$

| Formulations | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
|---|---|---|---|---|---|---|---|---|
| *Composition [%]* | | | | | | | | |
| Flaked aluminium | 1 | 1 | 1 | 1 | 6 | 6 | 6 | 6 |
| Ammonium nitrate | 89 | 79 | 74 | 69 | 74 | 34 | 14 | 4 |
| $Pb_3O_4$ | 10 | 20 | 25 | 30 | 20 | 60 | 80 | 90 |
| *Detonation parameter* | | | | | | | | |
| Density [g/cm$^3$] | 0.76 | 0.81 | 0.86 | 0.91 | 0.88 | 1.17 | 1.40 | 1.48 |
| Detonation velocity [m/s] | | | | | | | | |
| Diameter: 25 mm | 1010 | 880 | 810 | failure | 2100 | 1320 | 810 | failure |

detonation wave. That is why the mixtures were able to detonate even when the contents of $PbO_2$ or $Pb_3O_4$ were very high — up to 85 %. Due to the low decomposition temperature of lead dioxide (290 °C[6]), it can be incorporated into the explosives in a higher amount than $Pb_3O_4$ (decomposition at 500 °C). But the most important is the fact that in this way explosives can be prepared which stably detonate at a velocity below 1000 m/s (formulations 32, 38, 42, 43, 47) and at the same time can have relatively high density — even over 2 g/cm$^3$ (formulation 38).

## 4. Conclusion

A wide variety of explosive mixtures has been developed. They are characterized by the capability of stable detonation at low velocity (in small diameters) and for that reason can be used for cladding with thin sheets of metal (also with lead) and for fixing of tubes to sieve bottoms of heat exchangers.

Urea-formaldehyde resin and lead oxides ($PbO_2$ and $Pb_3O_4$) were found to be chemically active in the detonation wave of aluminized ammonium nitrate explosives.

The mixtures containing lead oxides were able to detonate at a velocity below 1000 m/s. Simultaneously some of them have a relatively high density — even over 2 g/cm$^3$.

## 5. References

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