Electric conductivity of high explosives with carbon nanotubes

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Abstract. The paper presents a technique for introducing carbon nanotubes into high explosives (HEs). For a number of explosives (trinitrotoluene, pentaerythritol tetranitrate, benzotrifuroxan), it was possible to achieve the appearance of conductivity by adding a small amount (up to 1\% by mass) of single-walled carbon nanotubes TUBALL COAT\textsubscript{E} H\textsubscript{2}O (CNTs) produced by OCSiAl. Thus it is possible to reduce the sensitivity of explosives to static electricity by adding an insignificant part of conductive nanotubes. This will increase safety of HEs during production and application and will reduce the number of accidents.

1. Introduction

Presently, the problem with a static electricity in various spheres of human activity is becoming more and more actual, in particular, it is of great interest to obtain high explosives with conductive properties, because of the struggle with accumulating static charge is directly related to the safety of producing and the use of HEs.

Carbon nanotubes, which was discovered in 1991 \cite{1} opened a wide range of new research lines. Theoretical predictions and experimental results have shown that carbon nanotubes demonstrate a range of unexpected properties: electrical, magnetic, optical and thermal \cite{1–5}. Long thin conductive nanotubes easily can formed a contact network inside a non-conductive material. With a qualitative introduction of CNTs, one can expect a low percolation threshold. In \cite{6–10} it was shown that addition of a small amount of CNTs to the dielectric leads to the appearance of conductivity in the composite. It is important to uniformly disperse of CNTs into the initial material, because, CNTs tend to stick together.

We used single-walled carbon nanotubes TUBALL COAT\textsubscript{E}, produced by the OCSiAl company. Their diameter was 1.7 nm and length of about several microns.

As a basis for the composite material, initially non-conductive high explosives: trinitrotoluene (TNT), pentaerythritol tetranitrate (PETN), benzotrifuroxan (BTF) were used. For the uniform application of nanotubes, we used well-known technology of recrystallization (solvent/anti-solvent) of high explosives by dissolution in the acetone.
2. The technique of nanotube insertion into the sample
To introduce nanotubes, the solution of explosives in acetone was poured into an aqueous suspension of nanotubes. In this case, the crystals of explosives were separated. The centers of crystallization were both CNTs and water. The efficiency of the first process is quite large. The dark suspension initially opaque became transparent.

The following step-by-step technology was used:

- HEs was dissolved in the acetone (1:2) at a temperature of about 50°C.
- At intensive stirring into the aqueous suspension of CNTs (the concentration of nanotubes in the aqueous solution was 0.2%) the solution of explosives in acetone was poured in. As a result of the interaction, a gray precipitate of the explosive with captured CNTs disappeared.
- The precipitate was separated from the water and dried. The resulting gray powder is shown in figure 1.
- Then, the resulting material was pressed into a cylindrical charges of 19.6 mm diameter and of various lengths (figure 2).

To control the uniformity and dispersion of CNTs in the sample, photographs using an electron microscope (figures 3 and 4) were made. In the HEs particles the fibers and structures of CNTs are clearly visible.

This technique is possible to achieve a homogeneous introduction of conducting CNTs into the dielectric matrix of HEs. Good mixing allowed us preserving special properties of CNTs and achieve the conductivity of the composite with a low concentration of the additive.

3. Measurement of the conductivity of HEs and experimental results.
For conductivity measurement we used the pressed cylindrical charges which was clamped from the ends with copper electrodes, between which an electrical resistance $R$ was measured (two-contact method). The conductivity was determined from the resistance using the following formula: $\sigma = h/(SR) = 4h/(\pi d^2 R)$, where $h$ – length of the charge, $d$ – diametr, $S$ – area of its section. The experimental values of resistance and conductivity for a series of uniformly pressed samples are shown in table 1.

In Table 2 the average characteristics of the obtained materials from different HEs are shown. The obtained values of the conductivity of composites depend weakly on the matrix material and are mainly determined by the concentration of CNTs.
Figure 3. TNT with embedded nanotubes.

Figure 4. PETN with embedded nanotubes.

Table 1. Characteristics of pressed samples.

| Composite    | h, cm | d, cm | ρ, g/cc | R, Ω  | σ, 1/Ωcm |
|--------------|-------|-------|---------|-------|-----------|
| TNT+0.5% CNTs | 2.53  | 1.96  | 1.60    | 10.1  | 0.083     |
| TNT+0.5% CNTs | 2.76  | 1.96  | 1.60    | 9.7   | 0.094     |
| TNT+0.5% CNTs | 1.86  | 1.96  | 1.52    | 13.2  | 0.047     |
| TNT+0.5% CNTs | 1.85  | 1.96  | 1.40    | 8.7   | 0.070     |
| TNT+0.5% CNTs | 1.84  | 1.96  | 1.31    | 5.4   | 0.112     |
| PETN+0.5% CNTs | 1.85  | 1.96  | 1.43    | 12.5  | 0.047     |
| PETN+0.5% CNTs | 1.85  | 1.96  | 1.43    | 12.3  | 0.057     |
| PETN+0.5% CNTs | 1.85  | 1.96  | 1.48    | 9.8   | 0.062     |
| PETN+0.5% CNTs | 1.85  | 1.96  | 1.48    | 8.2   | 0.074     |
| BTF+0.5% CNTs | 1.97  | 1.96  | 1.38    | 12.5  | 0.052     |
Table 2. Average characteristics of pressed materials.

| Composite                  | ρ, g/cc | σ, 1/(Ωcm) |
|---------------------------|--------|------------|
| TNT+0.5% CNTs             | 1.49   | 0.081      |
| PETN+0.5% CNTs            | 1.51   | 0.060      |
| BTF+0.5% CNTs             | 1.38   | 0.052      |

4. Conclusions
In this paper, we developed a simple technique for introducing CNTs into high explosive materials by recrystallization. It was possible to achieve the conductivity appearance of TNT, PETN and BTF at addition of 0.5% CNTs (the conduction increased more than by 10 orders). It is expected that the addition of such an amount of CNTs will not lead to a deterioration in the detonation properties of HEs. Conductivity of the composites is $\sigma = 0.08 \, 1/(Ω\text{cm})$ for trinitrotoluene, $\sigma = 0.06 \, 1/(Ω\text{cm})$ for pentaerythritol tetranitrate and $\sigma = 0.05 \, 1/(Ω\text{cm})$ for benzotrifuroxan. It was possible to achieve relatively good homogeneity of the introduction of CNTs.

The technique, tested on HEs, will later be used to reduce the sensitivity of primary explosives to static electricity. This will increase the safety of using such explosives and products with them.

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