Study on Performances of Novel Anti-Detonation Composites

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Abstract. From the optimized wave-absorbed layer aspect, a new light weight anti-detonation composite structure composed of armor steel, Aluminum foam, ceramic, aramide fibers and rubber materials is produced, and detonation tests with 50 g RDX, 6 kg-TNT, 8 kg-TNT, 10 kg-TNT charge were carried out on it. The results show that new anti-detonation composite has the advantages of reducing blast peak value, prolonging the action time for shock wave and absorbing wave to decrease blasting energy. The anti-detonation composite component has high bearing strength and tensile strength; after the detonation test, there is no penetrated destruction and large deformation on the backing plate, which satisfies the NATO protection Standard level two and level three.

1. Introduction

With the development of current international security situation and global military revolution, mine and improvised explosive devices (IEDs) will become not only one of the main threats but also the most dangerous threat that hardest to deal with. Anti-mine and IEDs will be considered into the comprehensive defensibility of tank armored vehicles, especially for low-chassis tracked Vehicles and wheeled vehicles, there is no room for arranging simple V-shape anti-mine structure, only through material and structure designation the vehicles defensibility could be satisfied anti-mine and IED protection requirements[1-3]. On the one hand, the deformation magnitude of the shocked bottom part of the vehicle was reduced by energy absorption and shock wave peak value decreasing through material deformation, on the other hand, the vehicle impact acceleration was decreased by energy consumption and dispersing through prolonging the shock wave acting time, and the which could be the optimum design, that means it achieve the best protection of anti-mine and IED with the simplest way and lowest cost, and it didn’t affect other performance of the vehicle[4-6]. In order to meet the above requirement, it is urgent to develop new generation armored material defense technique with light weight, thin thickness, and good protection to anti-mine and IED[7-8]. Therefore, the research on
the energy absorption and anti-detonation composite material have obvious significance for improving anti-detonation protection technique and developing multifunctional structure materials preparation technique.

2. Experience

2.1. Materials
Various raw materials are commercially available and easy to obtain. The main performance indications of raw materials are shown in Table 1.

Table 1. Density and wave impedance of raw materials used in the experience.

| Classify | Materials      | Density (×10^3 kg·m^-3) | Wave Impedance (×10^7 kg·m^2·s^-1) |
|----------|----------------|--------------------------|-------------------------------------|
| Metal    | Steel          | 7.8                      | 3.9                                 |
|          | Lead           | 11.4                     | 1.38                                |
|          | Aluminum       | 2.7                      | 1.35                                |
|          | foam aluminum  | ~0.26                    | 0.06                                |
|          | Ceramic        | ~3.29                    | 3.79                                |
|          | Glass Fiber    | 1.95                     | 0.53                                |
| Non-metal| Rubber         | 1.0                      | 0.16                                |
|          | Water          | 1.0                      | 0.15                                |
|          | Air            | 1.21×10^-7               | 4.15×10^-9                          |
| Binder   | Polyester film | —                        | 0.30                                |
|          | Polyurethane film | —                   | 0.26                                |

2.2. Experiment device
According to the required sizes of the materials that were used in the experiment, the new anti-detonation composite structure is prepared using armor steel, aluminum foam, ceramic, aramide fibers and rubber materials with significant differences in wave impedance\[9\].

Researchers designed 50 g naked charged equivalent RDX\[^{10-11}\], according to NATO standard STANAG 4569; 6 kg-TNT, 8 kg-TNT, 10 kg equivalent TNT detonation experiment is performed in order to test anti-detonation composite structure’s feasibility and reliability in anti-mine and anti-IED aspects\[^{12-13}\].

3. Results and discussion

3.1. Small scale charge exploded test
The stress wave propagation tests were studied using small scale charge. The result and comparison between incident wave and transmitted waves of 50 g RDX is given in Figure 1. The detonation test results show that the peak value of incident wave is 150.2 MPa with a rising edge of 0.98 μs, and the peak value of transmitted wave is 43.58 MPa with a rising edge of 46.8 μs.Comparing the data of multi-layer anti-detonation composite with aluminum foam and alloy sheets’ data, the rising edge of
transmitted wave peak is the longest and the shock wave impulse is significantly decreased, which significantly reduced the destructive effect of the blast shock wave.

The shapes of the incident wave and transmitted waves were qualitatively analyzed and the results show that during the propagation of blasting wave in the anti-detonation compositestructure; some incident wave pierced the space and continue to propagate, other incident wave was multidirectional-layer upon layer reflected, refracted and transmitted inside the ceramic body, then the incident wave dispersed after going through rubber and foamed metal materials. It resulted in the increase of rising edge of the transmitted wave were flatten out with respect to incident wave, the obvious decrease of shock wave peak value, the prolongation of shock wave’s acting time, and the detonation damage force of transmitted wave was dramatically decreased[14].

![Figure 1](image)

Figure 1. Contrast curves of incident wave and transmitted wave of new anti-detonation composite.

3.2. Protection test of 6 kg-TNT
According to the NATO standard 6kg equivalent TNT, the protection test with Level-II threat is carried out to new anti-detonation composite. After the explosive text, the backing plate was not penetrated with little deformation and the integral structure of rear layer of anti-detonation composite was in ideal condition. Compared the new anti-detonation composite with V-shape structural anti-mine device, new anti-detonation composite reduced the vehicle seat’s gravitational acceleration further proved that new anti-detonation composite obviously reduced more blast wave and has better damping. Assembled composite before blast test and the deformation of composite and backing plate are given in Figure 2, Figure 3 and Figure 4.
3.3. Protection test of 8 kg-TNT

After finishing the 6 kg test, 8 kg TNT IED test was conducted to new anti-detonation composite. The deformations of anti-detonation composite component and rear plate are shown in Figure 5. Conclude from Figure 5, the backing plate was not penetrated and presented deformation of 150 mm; which
satisfied lever-three protection requirements.

![Figure 5. Appearance of anti-detonation composite and rear plate with 8 kg equivalent TNT test.](image)

3.4. Vehicle Protection test of 10 kg-TNT

The vehicle protection test of 10 kg equivalent TNT was carried out on anti-detonation composite with weight of 250 kg, areal density of 170 kg/m², and size of 1800 mm×840 mm. Peak acceleration, peak velocity, pulse widths and effective peak acceleration were measured and the results were shown in Table 2. The vehicle body assembled with anti-detonation composite has significant advantage compared with the traditional protection structure as the results show that the peak acceleration, peak velocity and equivalent peak acceleration are lower, the pulse acting time is longer, which proves that anti-detonation composite results in extending loading time of shock wave, reducing the peak pressure of shock wave and effectively decreasing instant impact damage of shock wave on the vehicle body.

**Table 2.** Acceleration results of the 10 kg-TNT.

| No | Location                        | Peak acceleration (g) | Peak velocity (m·s⁻¹) | Pulse widths (ms) | Effective peak acceleration (g) |
|----|---------------------------------|-----------------------|------------------------|-------------------|---------------------------------|
| 1  | Front-left of floor Z direction | 1.23×10⁴              | 31.1                   | 6.17              | 1028                            |
| 2  | Front-right of floor Z direction| 2.92×10⁴              | 276.8                  | 6.70              | 8431                            |
| 3  | Right rear of floor Z direction | 1.75×10⁴              | 122.8                  | 7.53              | 3328                            |
| 4  | Left rear of floor Z direction  | 6.09×10³              | 14.1                   | 10.20             | 282                             |
| 5  | Center of floor Z direction     | 3.23×10⁴              | 80.9                   | 6.46              | 2555                            |
| 6  | Center of left side Z direction | 8.61×10²              | 6.3                    | 33.21             | 38                              |
| 7  | Front of left side Z direction  | 1.93×10³              | 4.8                    | 4.34              | 226                             |
| 8  | Front-right of roof             | 8.02×10²              | 3.8                    | 48.96             | 16                              |
Z direction

| Layer         | Z direction | B | T | D |
|---------------|-------------|---|---|---|
| Middle-right of roof | 9           | $3.06 \times 10^3$ | 4.9 | 11.10 | 90 |
| Center-back of roof | 10          | $1.15 \times 10^3$ | 8.3 | 39.60 | 43 |

The structure of new anti-detonation composite unit adopted wave impedance matched principle, it optimized various armor interface components. The unique three-dimensional of aluminum foam limits the deformation effect of rubber; the three-dimensional structure increases the energy consumption of deformation and friction work. Rubber wrapping could restrict and separate steel plater, ceramic block and aramid fiber and prevent expansion of steel plater’s cracks. Aramid fibers could absorb some detonation energy and support the new anti-detonation composite. Reasonable selection of the layer number of fibers could maximize the detonation energy absorption effect[15].

Results shown that new anti-detonation composite could enclose stress wave largely. Through self-deformation could reduce the stress wave, disperse shock wave, prolong shock wave effecting time and reduce the blasting energy. All of these effects reach the goal for attenuating jet flow or interfering fragments to hit the vehicle body[16].

4. Conclusion
A new light weight anti-detonation composite structure made of armor steel, Aluminum foam, ceramic, aramide fibers and rubber experienced detonation tests with 50 g RDX, 6 kg-TNT, 8 kg-TNT, 10 kg-TNT charge. The results show that new anti-detonation composite has the advantages of reducing the peak value of blast wave, prolonging the action time of shock wave, absorbing wave and decreasing blasting energy. The high bearing strength and tensile strength shown in the detonation test of new anti-detonation composite helped the plater not to be penetrated; the new anti-detonation composite shows significant protective effect that reached NATO protection standard Level-II and Level-III.

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