Comparison between some materials composites in the shock wave attenuation and anti-detonation property

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Abstract. Comparing the anti-detonation property and shock wave attenuation law of the single material structures, composite material structures and sandwich material structures are simulated by AUTODYN. The simulation on the structures with different combination show that, the aramid fiber material as base material in touched with the explosives, can greatly reduce the shock wave in identification board. For different material structures of the attenuation rule of shock wave, numerical simulation results show that the sandwich structure of the shock wave attenuation ability is more effectively than a single material structure. Based on the anti-detonation performance in different arrangement of the material structure, anti-detonation structure optimization design scheme is given according to the simulation results.

1. Introduction
With the wide application of insensitive high energy explosives, the powerful shock wave generated by the explosives has become an important means of killing enemy personnel in the battlefield environment. Therefore, it is of great significance to prevent or weaken the effect of shock wave on human body. In order to prevent the damage caused by impact, the protective layer absorbs most of the impact energy, so that the protected material is not damaged. It is very concerned to know the failure mode and strength of structure under load condition. The method of structural test is time-consuming and costly. With the development of computer science, the use of computer to simulate and predict the destruction process of structure, received a lot of scholars attention. Wang et al. [1] use LS-DYNA finite element software to simulate the dynamic response process of polyurea elastomer composite sandwich structure. Khurana et al. [2] supported theoretical calculation about some shock wave parameters by Autoyne 2D hydro-code simulation. Lan et al. [3] conducted a two-dimensional Lagrangian computational fluid dynamics program to simulate detonation wave propagation in PMMA. Kim et al. [4] defined a multi-material hydrodynamic simulation for LSCT to provide the detonation characteristics of high explosives in contact with a PMMA gap. Qin et al. [5] use LS-DYNA software to simulate the shock wave effect to evaluate flashing detonation grenade non-lethal effect. In this paper, the protective material with relative excellent detonation performance is obtained by designing different material composite structure forms. In this study, different combinations of materials were simulated.

2. Numerical Simulation Research on Shock Wave Attenuation Properties in single material

2.1. Computation model
The dynamics element program AUTODYN is employed to simulate the explosive detonation attenuation rule of shock wave in different materials. Modeling according to figure 1, explosive using RDX which selects the JWL [6] state equation describe the process of detonation product expansion process. Identification board materials choose several common protective materials such as steel plate, aluminum plate, aramid fiber composite material, concrete description. Due to the model is a symmetric structure, setting up a two-dimensional axial symmetric model. Array monitoring points are set in identification board axis. Center point initiation is chosen as the mode of detonation. Explosives and identification board using Lagrange solver.

![Figure 1. Simulation model of single material](image)

### 2.2. Simulation results

Using the simulation method of section 2.1, the pressure distribution at different location of different material are shown in table 1. We can clearly observe from table 1 to get the information of the shock wave pressure of different material at different gauges.

| Gauge | 1       | 2       | 3       | 4       | 5       | 6       | 7       | 8       | 9       | 10      | 11      |
|-------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Material | steel   | 7.21e7  | 3.21e7  | 1.76e7  | 1.03e7  | 6.77e6  | 4.55e6  | 3.92e6  | 3.54e6  | 3.13e6  | 2.35e6  | 2.51e4  |
|        | Aramid fiber | 4.72e6  | 2.58e5  | 1.23e5  | 5.24e4  | 6.35e3  | 3.95e3  | 5.06e3  | 4.35e2  | 1.13e2  | 19.294  | 3.9e-2  |
|        | Concrete | 3.64e7  | 1.25e7  | 3.71e6  | 2.4e6   | 1.93e6  | 1.16e6  | 5.78e5  | 3.42e5  | 1.98e5  | 1.22e5  | 5.73e3  |
|        | Al      | 4.64e7  | 2.56e7  | 1.44e7  | 7.98e6  | 4.96e6  | 3.95e6  | 3.66e6  | 3.37e6  | 3.16e6  | 2.34e6  | 5.85e5  |

We can see from table 1 that the best shock wave attenuation materials are aramid fiber and concrete.

### 3. Numerical Simulation Research on performance of composite material structures

#### 3.1. Computation model

We choose the two best performance materials in section 2.2 as the research object namely aramid fiber and concrete. Using the same modelling method in section 2.1, explosives and identification board size is changeless whereas identification board materials change from a single material into composite materials, recording detonation wave attenuation law shown as figure 2.
3.2. Simulation results
Gauges marked in the same position of identification board whose pressure changes as shown in table 2. Aramid fiber as base material in contact with the explosive has more strong attenuation ability than concrete as base material of contact with explosives.

| Gauge | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|-------|---|---|---|---|---|---|---|---|---|----|----|
| Composite/Concrete | 3.64e7 | 1.25e7 | 3.71e6 | 2.4e6 | 1.92e6 | 3.59e5 | 4.37e3 | 4.2e3 | 4.11e3 | 35.724 | 1.2e-1 |
| Aramid fiber/Concrete | 3.64e7 | 1.25e7 | 3.71e6 | 2.4e6 | 1.92e6 | 3.59e5 | 8.86e3 | 4.08e3 | 4.85e3 | 45.187 | 1.6e-1 |

4. Numerical Simulation Research on performance of sandwich material structure

4.1. Computation model
We still choose aramid fiber and concrete as the research object namely. Using the same simulation method in section 2.1, explosives and identification board size also remains the same. Change the identification board material distribution to sandwich structure and record shock wave attenuation law shown as figure 3.
4.2. Simulation results

Gauges in the same marked position of the identification board whose pressure changes as table 3. Contrast table 1 and table 2, table 3 find the sandwich structure has the strongest anti-detonation ability which detonation wave attenuation rate is about 88.98%.

| Gauge | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 |
|-------|----|----|----|----|----|----|----|----|----|----|----|
| Pressure (KPa) | 4.72e6 | 1.84e5 | 1.07e5 | 1.29e5 | 1.71e5 | 7.37e4 | 3.62e4 | 93.651 | 5.7e-1 | 9.4e-2 | 1.4e-4 |

5. Theoretical analysis of simulation results

5.1. Detonation wave propagation in composite material structure

When detonation wave transmit form wave impedance $\rho_0 C_0$ medium to the wave impedance $\rho_1 C_1$ medium, direction of propagation is perpendicular to the interface, the intensity of detonation wave after interface transmission is $P$:

$$P = \frac{2}{1 + \lambda} P_0, \quad \lambda = \frac{\rho_0 C_0}{\rho_1 C_1}$$  \hspace{1cm} (1)

Because aramid fiber wave impedance is far less than the wave impedance of concrete [7-9], the shock waves attenuation rate from aramid fibers to the concrete is less than from aramid fiber into the concrete which is consistent with the results in table 2.

5.2. Detonation wave propagation in sandwich material structure

Using sandwich structure, in accordance with section 4.1 structure is analyzed. By the continuum mechanics, a sandwich structure attenuation of shock wave strength $P'$ as follows:

$$P' = \left[ \frac{2}{(1 + \lambda)} \frac{2}{1 + \frac{1}{\lambda}} \right] P_0$$  \hspace{1cm} (2)
Due to the formation of the sandwich structure, shock waves at the interface between different materials can be repeated reflection, further consumption of the shock wave energy. So the sandwich structure of shock wave attenuation ability than single structure.

6. Verification experiments
To confirm the validity of the proposed simulation results, a series of experiments are carried out by using eight types. Table 4 shows the experimental conditions. The simulation results traces precisely the experimental results in all cases.

Table 4. Comparison between experimental and simulation pressure

| Material                        | Experiment Pressure (KPa) | Simulation pressure (KPa) |
|---------------------------------|---------------------------|---------------------------|
| Explosive only                  | 8e7                       | 7.53e7                    |
| steel                           | 2e4                       | 2.51e4                    |
| Aramid fiber                    | 0.04                      | 3.9e-2                    |
| Concrete                        | 5800                      | 5.73e3                    |
| Al                              | 5.9e5                     | 5.85e5                    |
| Concrete/Aramid fiber           | 0.15                      | 1.2e-1                    |
| Aramid fiber /Concrete          | 0.18                      | 1.6e-1                    |
| Aramid fiber /Concrete /Aramid fiber 3:4:3 | 1.5e-4                  | 1.4e-4                    |

7. Summary
There are many ways to design anti-detonation material structure. The different simulation progress show single material structure can be chosen as the best two performance shock wave attenuation material, concrete as the base material in touch with the explosive has better performance than aramid fiber and sandwich material structure has the best performance compared with single material structure and composite structure.

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