Research on The Influence of Load Transmission Medium on Sensor Output Characteristics under High Speed Impact

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Abstract. Through the analysis of the process of the projectile penetrating the concrete target board, using the finite element method to establish a finite element simulation model of it. The modeling method and parameter settings are analyzed during the modeling process, the finite element models of metal aluminum block and rigid polyurethane foam were established, performing the numerical simulations of high-speed collisions. By solving the calculations, obtaining the time-domain signals of the sensor positions, and comparing the overload signals through spectrum analysis. evaluating the influence of two transmission medium on the measured acceleration signal of the sensor. The result shows that the effect of different load transmission media on the overload signal of the sensor under high-speed impact is different, and it proves that super-hard aluminum has better shock-absorbing effect.

1. Introduction

In modern warfare, the missile launching arsenals, arsenals, and command centers mainly constructed of concrete are targets on the battlefield. The time-overload curve of a projectile penetrating the concrete target board is a very important parameter. Among the acceleration-test technologies, the missile-borne storage test technology is more advanced, and it can record the real-time acceleration of several processes in the bore and flying through the target. When the projectile penetrates the concrete target board, it can sense the characteristics of the target and control the time of initiation. This requires rapidly analysis and processing the test data to obtain the information about the number of layers of the concrete target board in time. When the projectile penetrates the target, the process is quite complicated, and there are many various vibration signals acting on the projectile. At present, we can obtain the rigid body overload signal after low-pass filtering of the measured penetration acceleration signal.

When the projectile penetrates the concrete target board, it is equivalent to applying an impact force at the front end of the projectile, causing a sudden change in the stress and acceleration at each point in the projectile. Various overload signals pass through the missile body, fuze, and transmission medium, and finally act on the acceleration sensor. The actual measured data is the composite signal of the projectile rigid body overload and the vibration of the projectile and the structure of the test device.
Through the filtering of various acceleration signals by the transmission medium, we can obtain the required rigid body overload signals.

2. Projectile structure

The projectile model used in this experiment is an oval-shaped penetrating body. Its main structure includes the projectile body, ammunition, weighted copper blocks, test equipment, power-supply device and top cover, etc. and it is inserted into the projectile in a certain order. The tail of the projectile is screwed and fixed by means of thread screw connection, the structure of the projectile is shown in FIG 1.

![Figure 1. Projectile structure model](image)

Internal structure of the Projectile: Polyurethane material is encapsulated inside the shell, the acceleration sensor is fixed on the circuit board completely suspended in the polyurethane, without rigid contact with the shell.

3. Material constitutive relationship

The constitutive relationship of materials is to express the stress-strain relationship of materials under various forces. A correct material model is an important prerequisite for effective numerical simulation.

To simulate the dynamics of the projectile penetrating a hard target, it is necessary to establish a constitutive model of the projectile, the penetrating target plate and the buffer material. the projectile is set as a rigid body to obtain the rigid overload, and the target is set as a concrete model. For the cushioning material, polyurethane and super-hard aluminum are used for comparison. The constitutive model and parameters of the cushioning material are obtained through experiments or consulting the literature.

3.1. projectile, shell and top cover

The material of the Projectile, the shell and the top cover is 35CrMnSiA. Among them, the total mass of the projectile is 3.48 kg, the diameter of the Projectile is \( d = \phi 64 \text{mm} \), and the length-diameter ratio \( L/d = 5 \). The material model used in the Finite element simulation is *MAT_PLASTIC_KINEMATIC (plastic follow-up hardening model) provided by LS-DYNA, the basic parameters of this type material are shown in Table 1.

| Densiti | Elasticity modulus | Poisson's ratio | Yield Strength | Shear modulus |
|---------|--------------------|----------------|---------------|---------------|
| 7.83    | 2.158              | 0.284          | 0.024         | 0.0175        |
During the penetrating process, most parts did not have excessive deformation, and they were regarded as rigid bodies during the simulation. The material model selected was *MAT_PLASTIC_KINEMATIC (plastic follow-up hardening model). The materials of some parts are shown in Table 2.

| parts                      | material         |
|----------------------------|------------------|
| Counterweight block        | Copper           |
| Shell of test device       | 30CrMnSiNi2A     |
| Shell of power supply device | 45steel         |

3.2. Concrete Target Board

The material of the target is concrete with a size of 1500mm × φ1200mm. Concrete is one of the widely used engineering materials. The material composition is relatively complicated. During the work process, it not only bears the design load, but also bears dynamic loads such as explosion and impact.

In order to describe the fracture characteristics and nonlinear deformation of concrete materials, considering the high pressure, high strain rate, and large strain characteristics in the impact process, using the Johnson-Holmquist-Concrete (J-H-C) damage constitutive model to describe it.

\[
\sigma^* = [A(1-D) + B \times p^*N] [1 + C \ln \dot{\varepsilon}^*]
\]

\(\sigma^*\) is the equivalent stress; \(A\) is the viscous strength (material constant); \(B\) is the pressure hardening coefficient; \(C\) is the strain rate coefficient; \(p^*\) is normal pressure; \(\dot{\varepsilon}^*\) is the dimensionless strain rate; \(N\) is the pressure hardening index; \(D\) is the damage factor (0 ≤ \(D\) ≤ 1), which is obtained by adding up the equivalent plastic strain and plastic volume strain.

Johnson-Holmquist-Concrete damage constitutive model corresponding to the material in the LS-DYNA is model *MAT_JOHNSON_HOLMQUIST_CONCRETE. Using equation *MAT_ADD_EROSION provided concrete failure, the relevant parameters in Table 3.

| Densiti                | Shear modulus | Standard viscosity strength | Standard pressure hardening coefficient | Strain force coefficient |
|------------------------|---------------|----------------------------|----------------------------------------|--------------------------|
| 2.40                   | 0.1486        | 0.79                       | 1.60                                   | 0.007                    |
| 4.00E-05               | EPSO          | EFMINT                     | SFMAX                                  | FC                       |
| 1.0E-06                | 0.01          | 7.0                        | 3.0E-04                                |
| U_L                    | P_C           | UC                         | N                                      | P_L                      |
| 0.1                    | 1.6E-04       | 0.001                      | 0.61                                   | 0.0081                   |
| K1                     | K2            | K3                         | D1                                     | D2                       |
| 0.85                   | -1.71         | 2.08                       | 0.04                                   | 1.0                      |

3.3. Super-hard aluminum and polyurethane foam

Super-hard aluminum alloy LC4, at room temperature, its strength can reach 680MPa, has high strength, strong corrosion resistance, heat resistance and high fatigue strength, widely used in casting, high stress structural parts, mold manufacturing and For various machines, the material model is *MAT_PLASTIC_KINEMATIC (plastic follow-up hardening model), and its parameters are shown in Table 4 below.
## Table 4. Material parameters of super-hard aluminum LC4 (cm-g-us)

| Density | Elasticity modulus | Poisson's ratio | Yield Strength | Shear modulus |
|---------|--------------------|-----------------|----------------|---------------|
| 2.7     | 0.72               | 0.3             | 0.00195        | 0.265         |

The polyurethane foam is a kind of polymer with many cells. Because of its special chemical composition, it has strong stability, good thermal insulation performance, and good resistance to impact and deformation.

It has a high yield strength to protect the internal electronic components from vibration under high impact and high overload conditions. We can use *MAT_CLOSED_FOAM (low density rigid polyurethane foam material) in the finite element. The material parameters are shown in the table 5.

## Table 5. parameters of *MAT_CLOSED_CELL_FOAM parameters (cm-g-us)

| Density | Elasticity modulus | Initial foam stress | Foam to polymer density ratio | Initial volume strain |
|---------|--------------------|---------------------|-------------------------------|-----------------------|
| RO      | E                  | P0                  | PHI                           | GAMA0                 |
| 0.58    | 4.612e-03          | 1.010e-06           | 0.125                         | 0.000                 |

In the course of the projectile penetrating the concrete target board board, the simulated ammunition, sensors, circuit boards and other structures installed inside the projectile, only consider the weight of the sensor and the circuit board, and do not consider the failure of the material strength. Therefore, Both the circuit board and sensors use *MAT_ELASTIC (linear elastic material). The main material parameters are shown in Table 6.

## Table 6. Material parameters (cm-g-us)

| name                | Density | Elasticity modulus | Poisson's ratio |
|---------------------|---------|--------------------|-----------------|
| simulated ammunition| 1.84    | 0.1                | 0.3             |
| sensors             | 2.7     | 0.562              | 0.33            |
| circuit boards      | 1.5     | 0.11               | 0.3             |

## 4. Finite element model

Altair HyperMesh is a large-scale general-purpose finite element software that performs pre-processing of finite element models, submits to Ansys for solving, and matlab for data processing.

### 4.1. Modeling the projectile impact on the target

The structure of the projectile is complex, and the material and mesh density of different parts are different. Importing the established model into Hypermesh for local simplification, removing chamfers and potting holes. Using Solid-164 solid elements. It is an 8-node hexahedral mesh. The finite element model is shown in Figure 2.

![Figure 2. Finite element model of projectile and target plate](image-url)
In order to increase the accuracy of calculation results while reducing machine time, the concrete target board, a semi-infinite thickness model, is used to refine the local grid in the impact area, that is, the grid at the center of the target board is dense and the grid at the edge is relatively sparse.

4.2. **Termination**
Add dynamic display analysis step, the duration is set to 1.5s, the termination is 6s

4.3. **Boundary conditions and loads**
During the test, the initial velocity of the projectile was 350m/s. Therefore, applying the initial velocity vertical with target board to all nodes of the projectile on the finite element model(*INITIAL_VELOCITY_NODE).

The concrete target board plate was fixed on the ground, all nodes on the circumferential end face of the reinforced concrete target model are fully constrained (*BOUNDARY_SPC_NODE).

To eliminate the influence of target plate size on the propagation of stress waves inside the target body, a non-reflective boundary (*BOUNDARY_NON_REFLECTING) is set on the edge of the target plate.

4.4. **Contact Control**
In order to save time and increase reliability under large deformation conditions, selecte the single-point Gauss integration unit, and the zero-energy mode that may be caused is controlled by adjusting the hourglass viscosity damping parameters of the program. In order to avoid large errors in calculation results, compare the hourglass energy with the total energy. The key word is *CONTROL_HOURGLASS.

After consulting relevant data, for the control of unit failure behavior, the method of defining unit failure criteria (* MAT_ADD_EROSION) is used. The failure strain value of the projectile and target in the model is 0.58 and 0.5.

In the contact analysis, due to the complexity of the contact problem, it is difficult to determine the direction of the contact. Therefore, * SURFACE_TO_SURFACE is used as much as possible in the analysis.

The contact *CONTACT_ERODING_SURFACE_TO_SURFACE is used between the projectile and the target board, the contact stiffness is 1.

4.5. **Changes in vibration-damping Material**
In an impact environment, the different of vibration-damping materials used in the test device will cause differences in effects. Aluminum blocks and polyurethane foam are placed at the front of the sensor and analyze the impact of different materials on the sensor output characteristics. Materials are the only difference, other conditions are the same.

5. **Analysis of simulation results**
After the projectile penetrates the finite element model of the concrete target board vertically at different speeds, submit it to the LS-DYNA.

After the calculation is completed, performing a dynamic demonstration of the penetration process by the HyperView a post-processing software, the nonlinear problem of complex materials such as pit formation, collapse and crushing of the concrete structure. The process is shown in Figure 3.
Figure 3. Process of projectile penetrating concrete target board

Time-domain processing of vibration signals is to extract various useful information from recorded process signals. It is an analysis of vibration waveforms. Through different methods, some frequency components of the measured waveform can be selectively filtered or retained. The ideal signal is a smooth and clear overload signal, and the processing of signal is more convenient. LS-Prepost was used to extract the acceleration-time history curve of the sensor component of the test bomb during the penetration process. Considering the inevitable numerical oscillation during the simulation process and the frequency response range of the sensor used in the test was within 10 kHz, Using 10kHz as the cutoff frequency to filter the simulation results as raw data., the comparison of the two simulation results is shown in Figure 4.

Figure 4. Comparison of overload signals of polyurethane and super-hard aluminum

Comparing the two overload curves, it can be seen that the rigid body overload produced by the penetration process, that is, the deceleration characteristics are basically the same, but compared with the polyurethane overload signal, the acceleration signal of the super-hard aluminum is significantly more stable and the overload value is smaller.

6. Conclusion
In this paper, through using finite element simulation methods to establish corresponding finite element models for different shock-absorbing materials under high-speed impact. Setting the constitutive model parameters, contact control, boundary conditions and loads, performing numerical simulation calculations and Frequency-domain evaluation analysis. Through comparison of data results, it shows that different materials have different effects on the overload signal of sensor. Under high-speed impact, super-hard aluminum materials can effectively filter the high-frequency components in the overload signal, making the overload signal more smooth and clear, Has better vibration-damping performance.
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