Studies of Ceramic Multi-layer Medium Against Penetration
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Keywords: Penetration, Protection works, Multilayer composite medium, Numerical simulation.

Abstract. By using the finite element analysis software ANSYS/LS-DYNA, combining with experimental results, the projectile penetrating the ceramic multilayer composite protective structure is studied. The dynamic response of ceramic multilayer composite protective structures in the penetration process is displayed. The numerical simulation results corresponded well to the experimental results, established the numerical simulation model and the algorithm is correct and effective.

Introduction

Ceramics/metal multi-layer composite protective structure is better than homogeneous metal composite protective structure in strength and protection, at the same time it has so many property such as light to transport, anti-corrosion, anti-temperature, and anti-oxidation, etc. Ceramics/metal multi-layer composite protective could resistance blow of bombs and exploding scrap as protective structure and has great anti-blow effects. It has important military significance and could be used in many ways, such as guard door, bullet-proof wall, bullet-proof plate etc. In this paper, study the progress and theory of ceramic multi-layer medium against penetration interaction mode of jet and ERA with deformed flying-plate by numerical simulation and experimental research.

Ceramic Multi-layer Medium against Penetration Interaction Mode of Jet and ERA with Deformed Flying-Plate

Geometry and Meshing

This paper simulates that the long rod projectiles oblique penetrates ceramic multi-layer medium by ANSYS/LS-DYNA. In order to calculating the long rod projectile models in the condition that length diameter ratio is 24, pellet’s length is 121mm, made by Tungsten alloy, and bullet is round table type, ρ=17.6g/cm³. Ceramic multi-layer structure made by seven layers, and its section size is 240×60mm. Its front and back both made by 685 steel; their thickness are 6mm and 20mm. The second, 4th, and 6th are glass fiber, and their thicknesses are1mm. The third and 5th are both made by ceramics Al₂O₃, and their thicknesses are10mm, as shown in Figure 1. Angle and speed of wolfram long rod projectiles hitting target are same with dates from experiment.

Figure 1. Simulate model.

We can choice the half of the model and simulate, because of symmetry. Mapping and meshing the model by eight nodes and hexahedral solid elements SOLID164. And then we refine the part of
mesh elements in bullets and targets contacting area. The length of unit along the direct of target thickness is 1mm.

**Material Models and Its Parameter**

**The Long Rod Projectiles, Front/Back of Metallic Model and Its Parameter.** In this paper the material model selection of long rod projectiles and material front/back board choice Johnson-Cook model and GRUNEISEN equation of state to describe together. The model could describe strain, strain rate, and strength diversification about temperature in the condition that metallic material is in high pressure. The main parameters are shown in Table 1.

| Parameter | \( \rho (\text{g/cm}^3) \) | \( E (\text{GPa}) \) | \( \mu \) | \( A (\text{GPa}) \) | \( B (\text{GPa}) \) | \( C \) | \( n \) | \( m \) |
|-----------|-----------------|-----------------|-----|--------------|--------------|-----|-----|-----|
| Pellet    | 17.6            | 350             | 0.28| 1.5          | 0.177        | 0.08| 0.12| 1.0 |
| Metal target | 7.85           | 124             | 0.22| 0.792        | 0.18         | 0.16| 0.12| 1.0 |

In the table: \( \rho \) is density; \( E \) is elastic modulus; \( \mu \) is poisson's ratio; \( A, B, C, n \) and \( m \) are constants.

**Ceramic layer Material Models and Parameter.** In ANSYS/LS-DYNA, Johnson-Holm, Quist-Ceramics model used most and widely now to ceramic brittle materials. Its advantages are that better versatility and better to describe ceramic materials’ damage and brittle fracture characteristics were in pounded.

The model is composed of strength model, damaging accumulating invalid model, and pressure-specific volume model. We can describe the strength of undamaged and total damaged materials by damage degree. It can be achieved that make materials from undamaged to total damaged by damaging accumulating invalid model. To those have not reach the breaking strength it could be regarded as elastic material. But to those have been damaged, it could be regarded as completed materials their strength change with damaging accumulation. The parameters of ceramic material as shown in table 2.

| Parameter | \( \rho (\text{g·cm}^{-3}) \) | \( G (\text{GPa}) \) | \( A (\text{GPa}) \) | \( B (\text{GPa}) \) | \( c \) | \( m \) | \( n \) | \( \varepsilon_0 \) | \( T (\text{GPa}) \) |
|-----------|-----------------|-----------------|--------------|--------------|-----|-----|-----|--------------|-----------------|
| Al\(_2\)O\(_3\) | 3.8             | 152             | 0.88         | 0.3          | 0.007| 0.6 | 0.64| \( 10^6 \)  | 0.262            |

In the table, \( A, B, C, M \) and \( N \) are pending material constants. \( T^* \) and \( P^* \) are normalized the maximum hydrostatic tensile strength and hydrostatic pressure, \( T \) is the maximum hydrostatic tensile strength actually, \( \varepsilon_0 \) is reference strain rate.

**Glass Fiberlayer Material Model and Parameter.** It will decide the bullet proof performance of fiber composites materials that are the anisotropy, decreasing strength of anisotropy, pound response, and status change. Materials of glass fiberboard use Composite-Damage materials model to analysis. Table 5-4 lists the calculating needed parameters of glass fiber materials:

| Parameter | \( \rho (\text{g·cm}^{-3}) \) | \( v \) | \( E (\text{GPa}) \) | \( G (\text{GPa}) \) |
|-----------|-----------------|-----|--------------|--------------|
|           | 1.53            | 0.190| 90.9         | 4.1          |

**Numerical Simulation Results and Analysis**

To verify the results of numerical calculate, we will compare numerical simulation results and experiment results. Picture 2 shows the physical images of front and back damaged boards. The
Numerical simulation results are consistent with experiment results from the shape of penetration hole and the outer peripheral surface of the formation of different degrees of uplift and cuffs.

Figure 2. Comparison chart of experiment phenomenon and simulation phenomenon.

Table 4 lists the experiment penetration depth results and numerical simulation results of bullet penetrating ceramic multi-layer medium.

Table 4. Contradistinction of simulating penetration depth and experimental penetration depth.

| No. | angle/° | speed/ms⁻¹ | penetration depth /mm | Error/% |
|-----|---------|-------------|-----------------------|--------|
| 1   | 68      | 1675        | 35.0                  | 33.0   | 5.71   |
| 2   | 60      | 1625        | 40.0                  | 37.7   | 5.75   |

Figure 3. Penetration process of multi-layer medium θ=60°, V=1625m/s)

Figure 3 is the main process diagram that ceramic multi-layer medium against penetration in the target angle is 60° and speed of 1625m / s.

It is easy to see from damage progress pictures that we can divide the progress from the begin at bulletin touch with ceramic multi-layer dielectric structure to the end into two stages.

1. Start collision stage: When the begin of warhead and composite structural steel panel interaction, front broad penetration holes’ periphery of the outer surface form varying degrees of uplift and cuffs, because characteristics of steel make the bullet serious erosion and part of bullet slag fragments scattered out along the edge of front board. At the same time, the first fiberglass adhesive layer material suffered the strong compression from bullet and steel front board and causes certain deformations.

2. Erosion stage: Blunt bullet and the remaining projectile continue penetration, and the role of the ceramic layer process a large number of ceramic layers broken and forming a ceramic cone crusher. Fiberglass layer have a role for fixing ceramic fragments. Fastening pottery shards increase the abrasive action of the projectile. There was a certain bent in long rod projectiles. In the action of tensile stress, shear stress, and reflected stress wave, ceramic fragmentation increasing and at the end projectile penetrates two layers ceramic layer steel back layer and penetrates steel back board.

Summary

This paper uses numerical simulation gets the physical images of penetration and penetration depth. The result is same comparing with reality. It illustrates the choice of material models, parameters, algorithms, and boundary settings are right. We can reduce the time physical graphics of ceramic
multi-layer medium against penetration by numerical simulation. It also could offer design technical reference for ceramic multi-layer medium against penetration.

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