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Effect of initiation manners on the scattering characteristics of semi-preformed fragment warhead

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ABSTRACT

The lethality of a semi-preformed fragment warhead is closely related to the expand velocity and spatial distribution of the fragments from ruptured metal casing. The topic of how to improve the utilization of charge of have been drawing great attention from researchers and designer in this filed. In present paper, in order to investigate the influence of charge initiation manners on the scattering characteristics of semi-preformed fragment warhead, the numerical simulations and experimental test are conducted. Firstly, the influence of grid density on numerical results is investigated, and a proper numerical model with relatively high accuracy and effectiveness is determined. Then, numerical simulations of three kinds of different initiation position of a semi-preformed fragment warhead are carried out. An experimental test of the explosion of a semi-preformed fragment warhead is carried out. By comparing and analyzing the numerical results and experimental data, it is found that the initiation manners have great influence on scattering characteristics of semi-preformed fragment warhead. The researcher work of this paper would provide an effective alternative method to optimize the design of warhead.

1. Introduction

The pre-controlled technology of fragments refers to controlling the size of fragments formed by the breaking of warhead with specific measures, which can enhance the lethality of warhead. The pre-controlled technology of fragmentation of cased charge is an important issue in the field of ammunition engineering and the design of protective structure. Great efforts have been made by scholars to study the scattering characteristics of preformed and semi-preformed fragments warhead from different aspects. With regard to the study of preformed fragments, many scholars have done plenty of work in theory, numerical simulation and test, while the research on semi-preformed fragments is rare [1].

In order to get the scattering method of pre-formed fragments, Li et al. [2] investigated the expanding and fragments crushing process of a HE shell by employing the explicit code ANSYS/LS-DYNA. The initial velocity and scattering direction angle of fragments along case is determined. The gained results were basically in accord with the statistical results of recovery fragments in crushing experiments and empirical formula and consequently illustrate the accuracy of model simplification and calculation parameters. Peng et al. [3] used AUTODYN to simulate the fragment formation of semi-preformed fragment warhead, which external shell groove has different groove depth and width parameters, was carried out. After comparing and analyzing the simulation results, the effect rules of groove depth and width on the effective formation rate of semi-preformed fragment, average speed of semi-preformed and mass loss were found out, thus the suitable groove width and depth were determined. In order to investigate the effect of groove parameters on the formation of semi-preformed fragments, a numerical simulation of the fragmentation process of 50SiMnVB steel warhead was conducted by Liu et al. [4]. The effect of different groove-parameters on casing-fracture was compared and analyzed. Besides, a method to determine the fracture trace and fracture probability of external grooved casing were proposed and verified by comparing with experimental results.

At present, researches mainly focus on the failure mechanism of

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the metal casing, the average velocity of the fragments and the influence of groove parameters on the scattering characteristics. There are few studies aiming to investigate the influence of different initiation manners on the fragmentation characteristic of a semi-preformed case. In this paper, by employing AUTODYN-3D, the three-dimensional numerical simulation of expanding and subsequent fragmentation process of a semi-preformed warhead is studied, the propagation of detonation wave in the dense charge and the velocity distribution of fragments are obtained under different initiation manners. Additionally, an experiment with the same explosive fragmentation geometry as modeled in the numerical simulation is conducted. The experimental data and theoretical data are compared with the numerical results, based on which the conclusions of present paper are drawn.

2. Numerical simulations

2.1. Numerical model

The warhead that used in numerical simulations in this paper is a cylindrical metal casing filled with TNT charge, which is fabricated from steel #45. The internal diameter, the length and the wall thickness of the cylindrical casing is 50.5 mm, 130.4 mm, and 6 mm, respectively. Along both the length and circumference directions of the metal casing 8 equal split grooves, whose depth is 3 mm and the width is 2 mm to control the size of semi-preformed fragments, are machined. It is estimated that the number of fragments from the case is 64. The mass of metal casing is 948.6 g, with a 400 g TNT charge filled inside it.

The numerical model is developed by employing the finite difference-engineering package AUTODYN, which is particularly suitable for the nonlinear dynamic problems, such as impact or explosion. The symmetry of the problem under consideration allows modeling one eighth of the whole metal casing and TNT charge, as shown in Fig. 1. In order to reproduce the explosive fragmentation process, in which the casing material is plastically deformed and eventually ruptured by the driven load from the expansion of the inner charge, the Euler–Lagrangian method is adopted to model the phenomenon of explosively driven fragmentation.

The air is modeled with Euler grid. The size of grid is 100mm × 100mm × 100mm. The Euler method is ideally suited to handling large deformations and fluid flow, which has a good description of the formation, propagation and action process of shock wave. The metal casing is discrete with Lagrange grid and the size of the cubic grid is 0.5 mm. The Lagrange algorithm can cause a large distortion of the structural grid, but it has a clear description of the whole and local evolution process of the structure, which can truly present the whole process of the expansion of the metal casing, the crack expansion and the formation of fragments.

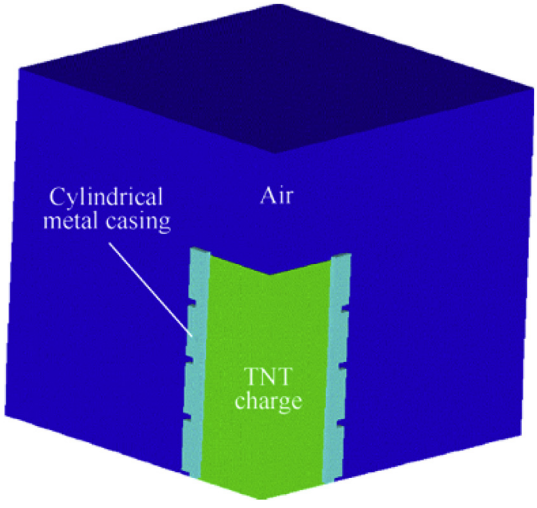

Fig. 1. Numerical calculation model.

The rapid pressurization leads to the large deformations and eventual rupture of the metal casing at high strain rates. The Johnson–Cook constitutive relation [5] and the Gruneisen equation of state are selected to model the material behavior of the metal casing.

$$\sigma_Y = \left(A + B\varepsilon_p^n\right)\left[1 + C\ln\dot{\varepsilon}^*\right]\left(1 - T^{*m}\right) \tag{1}$$

where σ_Y is the dynamic yield stress of the material. *A,B,C,n* and *m* are Johnson–Cook material constants, $\dot{\varepsilon}^* = \dot{\varepsilon}_p/\dot{\varepsilon}_0$ represents the effective plastic strain rate at a reference strain rate $\dot{\varepsilon}_0 = 1s^{-1}$ and the homologous temperature $T^{*m} = (T - T_r)/(T_m - T_r)$, in which T is the material temperature, T_r is the room temperature, and T_m is the melting temperature of material.

The material parameters used in the simulation are listed in Table 1. The failure mode should be defined in the AUTODYN to provide a suitable failure criterion for the casing material. In this study, the principal strain failure model and stochastic failure model based on the Mott [6] distribution is used to simulate the formation of natural fragments.

The JWL (Jones–Wilkins–Lee) equation of state is employed to describe the adiabatic expansion of the detonation products, which represents the pressure as a function of the volume and energy:

$$P = A\left(1 - \frac{w}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{w}{R_2 V}\right)e^{-R_2 V} + \frac{we_0}{V} \tag{2}$$

where *A, B, R_1, R_2* and *w* are constants of the TNT charge. *P, v* and e_0 are the detonation pressure, relative volume and specific internal energy, respectively.

The material parameters and properties used for the JWL equation are shown in Table 2. The ideal gas equation of state is selected to model the material behavior of the air.

2.2. The influence of grid density on the results

The major influence factor of the numerical results is the relative size of the computational model grid units (the ratio between the air domain size and the air domain grid), rather than the absolute mesh size of the model [7]. By changing the mesh size of the air domain, we can change the model grid density. In this section, the grids of the air domain are set as 4 mm, 3 mm, 2 mm, 1.5 mm, 1 mm, and 0.5 mm, respectively. The corresponding grid density of the model is 25, 33, 50, 67, 100 and 200, respectively.

Fig. 2 shows the relation between the maximum velocity at the corresponding gauge point and the different grid density in the model. It is clearly shown that with the increase of grid density the maximum velocity of gauge point is increasing. However, the relation curve is tend to convergence when the mesh density is greater than 100. On the other hand, when the mesh density is greater than 100, the grid number and the computational cost increases rapidly. Therefore, under the premise of ensuring the numerical results to meet the actual demand precision, it is very important to select the appropriate grid density, which can avoid the excessive grid density and cause the unprovoked waste of computing resources. From the above analysis, the grid density of 100 is used in the numerical model.