Simulation Study on the Average Specific Kinetic Energy and Safety Radius of Stun Grenade Fragments for Different Initiation Point

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Abstract. In order to evaluate the lethality and injury radius of fragments and weaken the average specific kinetic energy, the calculation model of average specific kinetic energy of stun grenade fragments is established based on the Monte Carlo subdivision projection simulation. With the joint simulation method of LS-DYNA and programming, the calculation model of the specific kinetic energy of the semi-prefabricated fragments is solved and compared at different initiation points of the same charge. The mass distribution, vertical target distribution, average specific kinetic energy threshold and safety radius of the whole time-domain fragments at the initiation points 1.5cm, 3cm, 4.5cm, 6cm, 7.5cm and 9cm from the top of the shell are obtained. For the same charge parameters, the results show that the number of fragments near the initiation point of the charge center is less, the mass mean value and standard deviation are larger, and the threshold value of specific kinetic energy is lower than that of both ends of charge; the injury radius of the initiation points 1.5cm, 6cm and 9cm is 4.9m, 2.94m and 4.1m respectively. The initiation point near the charge center can significantly reduce the injury radius of the fragments and improve the safety of the stun grenade.

Keywords: Semi-prefabricated fragment; Stun grenade; Initiation point; Average specific kinetic energy; Monte Carlo subdivision projection simulation.

1. Introduction
Stun grenade is a kind of non-lethal ammunition which produces the strong sound and dazzling flash by the explosion of special charge to stimulate the ears and eyes of living targets, making them temporarily deaf and blind [1]. The packaging shell is made of non-metallic materials, and the large-size fragments are easy to cause irreversible damage to living target. Therefore, the average specific kinetic energy model of the whole time-domain fragments needs to be established, which can be used to analyze the influence of different initiation points on the mass distribution, average specific kinetic energy and safety radius of stun grenade fragments.

At present, domestic and overseas scholars have done a lot of research on the fragments of lethal ammunition, especially on the numerical simulation of prefabricated fragment warhead, and put forward many mature simulation models and calculation methods, such as Yang Shuai [2], Choi K [3], Wang H [4], Zhang Chenhui [5], Li Yuan [6], Li Xiangyu [7], Du Ning [8], etc. They have carried out evaluation model,
efficiency optimization and rapid calculation for various warhead fragment fields. However, the research on the safety of non-lethal ammunition fragments, especially on specific kinetic energy of fragments, is relatively less. In the process of establishing the whole time-domain calculation model of the average specific kinetic energy, the average windward area of fragment is mainly obtained by the test method of the uniform orientation theory at present, while the simulation solution method of the average windward area of FE fragments has not been reported.

Therefore, based on the Monte Carlo subdivision projection simulation (MCSPS for short), the average specific kinetic energy calculation model is established, and the specific kinetic energy of arbitrary shape fragments of stun grenade is solved by programming. Combined with the external ballistic dispersion model of fragments, the average specific kinetic energy of FE semi-prefabricated fragments of different initiation points is simulated and calculated. The specific kinetic energy threshold at different distance from the initiation center is obtained. The lethality and injury radius of fragments at different initiation point is evaluated and compared.

2. Calculation Model of Average Specific Kinetic Energy Based on MCSPS

According to the definition of average specific kinetic energy of fragment, the expression is as follows:

$$ e_{di} = \frac{E_{di}}{A_i} = \frac{m_i v_i^2}{2A_i} \tag{1} $$

Where, $e_{di}$ is the specific kinetic energy of the $i$-th fragment; $E_{di}$ is the kinetic energy of the $i$-th fragment; $A_i$ is the average windward area of the $i$-th fragment; $m_i$ is the mass of the $i$-th fragment; $v_i$ is the velocity of the $i$-th fragment.

The MCSPS method is used to solve the average windward area of FE fragments of any shape. With thousands of times of translation, random rotation, projection, triangulation and concave boundary search-sort of node coordinates of FE fragments, the mean value projection area can be obtained. When the times $N$ value tends to infinity, the mean value can be approximately the average windward area of the fragment. The algorithm flow chart of the average windward area based on MCSPS is shown in Figure 1. The expression of each calculation step is shown in (2) to (8):

![Figure 1. The algorithm flow chart of the average windward area based on MCSPS.](image)
3. Finite Element Model and Fragment of Stun Grenade
The finite element model of stun grenade is established by 1/4 symmetrical structure with the CLE fluid-solid coupling method, as shown in Figure 2. The main charge is an aluminized explosive with a length of 9.5cm and a diameter of 3.3cm; the cylindrical shell is PVC with a length of 11cm and a diameter of 3.8cm; the position of the single-point initiation is 1.5cm, 3cm, 4.5cm, 6cm, 7.5cm and 9cm from the top face of the shell respectively.
The shell breaking conditions at different initiation points at 40us time are shown in the Figure 3. With the calculation of average specific kinetic model and external ballistic model, the threshold value of average specific kinetic energy at any position from the detonation center can be obtained.

4. Result Analysis and Discussion
4.1. Mass Distribution Comparison
The FE fragments data are outputted. With the same fragment search-sort algorithm and specific kinetic energy calculation model, the fragment parameters such as the number of fragments, centroid coordinates, centroid velocity, the number of elements, and the average windward area can be obtained. The fragment parameters of the 1.5cm initiation point are shown in Table 1.
The mass frequency distribution histogram of six groups initiation points is shown in Figure 4. The mass distribution of six groups fragments obeys the law of exponential attenuation; most fragments have a mass between 0-1 g.

Figure 4. The mass frequency distribution histogram.

The mass statistics of six groups initiation points was shown in Table 2, which includes the maximum, range, mean and standard deviation of the whole fragments. It can be seen from the table that the number of fragments at the initiation position closer to the charge center is less, but the mass mean value and standard deviation are larger.

Table 2. The mass statistics of six groups initiation points.

| initiation position | fragment number | maximum | minimum | range | mean | standard deviation |
|---------------------|-----------------|---------|---------|-------|------|-------------------|
| 1.5cm               | 18              | 3.31    | 0.02    | 3.29  | 0.57 | 0.74              |
| 3cm                 | 9               | 3.13    | 0.02    | 3.11  | 1.14 | 1.03              |
| 4.5cm               | 7               | 3.20    | 0.05    | 3.15  | 1.47 | 1.17              |
| 6cm                 | 6               | 3.27    | 0.05    | 3.22  | 1.72 | 1.10              |
| 7.5cm               | 8               | 3.25    | 0.08    | 3.17  | 1.29 | 1.11              |
| 9cm                 | 10              | 2.90    | 0.23    | 2.67  | 1.03 | 0.92              |
4.2. Average Vertical Target Distribution and Specific Kinetic Energy Threshold

According to the dispersion model established based on the external trajectory [9], the vertical target distribution and the average specific kinetic energy threshold of fragments are obtained at different distances from the initiation center. The vertical target distribution of six groups initiation points at 2m from the charge initiation center is shown in Figure 5. The dispersion angle of six groups initiation points is not significantly different, and the distribution is incompletely symmetrical. The closer to the initiation point of the charge center, the less the number of fragments striking the target, the rarer the distribution and the lower the threshold of specific kinetic energy.

The specific kinetic energy threshold, range, mean value, standard deviation and dispersion angle of fragments of 6 groups initiation points at different distances can be obtained. From the statistics, the maximum and mean value of the initiation point near the charge center is larger than that at both ends, and the standard deviation is smaller.

![Figure 5. The vertical target distribution of six groups initiation points at 2m.](image)

4.3. Lethality Radius and Injury Radius

According to the minimum specific kinetic energy standard of 160J/cm² for killing personnel and 9.8J/cm² [10] for chafing skin of bullet, fragment and small arrow, the lethality radius and injury radius of fragments at six groups initiation points are obtained, as shown in Table 3. It can be seen from the table that the closer to the charge center the initiation point is, the smaller the lethal radius and the injury radius are. The results show that the specific kinetic energy of fragments can be reduced and the safety radius can be improved by using the initiation point of the charge center compared with the both ends initiation points.
Table 3. The lethality radius and injury radius of fragments at six groups initiation points.

| Lethality radius (m) | Injury radius (m) |
|----------------------|-------------------|
| 1.5 cm               | ≤0.94             |
| 3 cm                 | ≤1.1              |
| 4.5 cm               | ≤0.92             |
| 6 cm                 | ≤0.1              |
| 7.5 cm               | ≤0.48             |
| 9 cm                 | ≤0.55             |

5. Conclusions
The calculation model of average specific kinetic energy based on MCSPS method can be used to solve the average windward area and average specific kinetic energy of arbitrary shape FE fragments. The initiation point near the charge center can significantly reduce the specific kinetic energy of fragments and improve the safety radius compared with the both ends initiation points.

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