The characteristics of fragments from embedded warhead

Y G Gao, X M Yan, B Zhang, S Y Wu, X Xiao and Sh Sh Feng *

State Key laboratory of Explosion Science and Technology, Beijing Institute of Technology, Beijing 100081, PR China

Email: ssfeng@bit.edu.cn

Abstract. The Embedded warhead is a kind of warhead which is embedded into the target plate by its own kinetic energy and uses its effective fragments and whole or residual projectile to interdict the target. The fragments generated by the embedded warhead embedded in the target plate will impact the target plate and ricochet, which makes the dispersion of the fragments significantly different from that of warhead which is detonated in the air. However, there are no relevant researches which have been published. Therefore, in this paper, the dispersion of fragment from embedded warhead was investigated based on the experiment results, and the embedded warhead was detonated at center of the tail end. According to the experiment results, the fragments ricocheted from the target plate because the incident angle was too large. According to the statistics of fragments on the distribution plate, the average direction Angle of fragments went up (about 6°) due to part of fragments ricocheting from the target plate, which increased the damage effect of embedded warhead. The blocking diameter was 25m for human being. This study can provide a reference for the optimal design of embedded warhead.

1. Introduction

The characterization of fragmentation of an explosive-filled cylindrical casing is vital for assessing the properties of cylindrical casing and the response of a structure to extreme loads. For the fragments impact on a structure, many researches have pay much attention to the velocity distribution of fragment, fragment shape, fragment mass, and fragment ballistic path. However, studies of the fragment spatial distribution are very rare.

The fragment initial velocity is a very key parameter of the fragment impact, which is usually calculated by the Gurney formula [1]. In Gurney assumption, the fragment velocity was a function of explosive energy and the mass ratio of explosive charge to metal charge. Due to the effect of axial rarefaction waves from two ends, the fragment velocities near the end of charge are lower than the Gurney velocity, which are widely studied [2-4]. Gao [5] indicated that the axial rarefaction waves would not affect the fragment velocities from the middle part of cylindrical casing if the length-diameter ratio is more than 2.

The mass distribution of fragments is also widely investigated. Krapp [6] carried out experiments, and recovered fragment masses within given ranges of angles, which was plotted as a function of the spatial angle. Gullis et al. [7] reported an experiment and a corresponding simulation. According to the witness plates at a given distance from the charge, one can found that the number of fragments was not uniform over the height of each plate. Arnold and Rottenkolber [8] performed experiments with witness plates placed to record the fragment spatial distribution due to an explosive-filled cylindrical casing. It can also be observed that a large mass of fragments impacted in a special area around the
middle area of the plate, while the other area is impacted by some small fragments. Grisaro [9] found that the spatial mass distribution of fragments that struck a protective wall was not uniform. It had been found that there is a ‘intense strip’, which is impacted by the heaviest fragments. They establish a simplified model for the non-uniform spatial distribution of the fragments.

The cylindrical casings mentioned above are all placed in the air, which means there is no boundary affecting the spatial distribution of fragments. However, due to the head embedded in the target plate, the embedded warhead explodes and breaks into a lot of fragments, and part of them will ricochet since the incident angle is too much. As a result, the spatial distribution of fragments from embedded warhead would be different from that of fragments from cylindrical casing in the air. In the present work, the interaction between the target plate and embedded warhead and the spatial distribution of fragments were preliminarily studied, which can provide the basis for the optimal design of warhead and protective device.

2. Experiment

The schematic view of test set-up is shown in figure 1. The cylindrical casing was made of 30CrMnSiNi2A steel, and the explosive charge was made of COMP-B. The length of warhead is 59mm, the diameter of the casing is 60mm, the thickness of the casing is 6mm, the length of the aluminum end cover is 25mm. The target plate is made of equivalent infinite thickness steel plate. The warhead is vertically fixed in the hole of the target plate. The target plate is 1.5m×1.0m×0.05m, and it is placed horizontally on the ground. The dispersion direction target is arranged 1.4m away from the center of the warhead, which is made of 0.2mm iron plate (1m×1m). The vertical and horizontal lines of 0.05×0.05m are drawn on the iron plate to identify the location of fragments, and the ejection angle and dispersion density of fragments can be obtained. Four path-through connected-disconnected probe system were arranged at 1.2m and 1.4m away from the warhead to measure the fragment velocity, and the spacing between two probe was 0.2m. Time was measured by time-measuring instrument.

Two 5mm diameter balls were placed on the top and bottom on the surface of the warhead. Two approximate circular holes near the border of holes on the dispersion direction target represented the top and bottom projection angle of fragments (θ₁, θ₂), the scatter angle is Ω (Ω = θ₂ − θ₁), and the average direction angle is Φ (Φ = π/2 − (θ₂ + θ₁)/2).

The fragment velocity was measured by connected-disconnected probe system, which was shown in figure1. Two layers of foils were used as two probes, which were connected to the resistance and capacitor signal conversion circuit (RC circuit), so that there is a certain voltage between foils. When the fragment hit the foils, the two probes were conductive due to the conductivity of the fragment. The principle of the connected-disconnected probe system is shown in figure2. The charged capacitor C is discharged through the circuit to generate an impulse signal on signal resistor R2, which is fed through the cable into the chronograph (oscilloscope) to record the arrival time of the fragment. Two targets are arranged in the same direction, the distance is calibrated, and the fragmentation velocity can be calculated.

![Figure 1. Schematic view of test set-up.](image-url)
3. Results and discussion

After the detonation of the warhead, the vertical coordinates of the perforation of each fragment on the flying target were calculated, the distance between the distribution plate and the warhead has already been known, so the scatter angle of the fragment could be calculated. If the scatter angle is negative, it indicates that the scatter direction of the fragment is downward. The through-hole with a diameter larger than 5mm is denoted as an effective fragment.

The typical fragment spatial distribution on the distribution plate is shown in figure3, which can be found that the fragments are concentrated within an angle range. When the fragments arrived on the surface of the target plate, they would ricochet since the incident angle is too much. The ricochet fragment and normal fragment stacked together to form an intense strip.

After the explosion of the warhead, the projection angle of each fragment was counted. Since the distribution plate could only count a part of the fragments, the distribution of all fragments along the projection angle can be obtained by multiplying the corresponding fragments of each projection angle on the distribution plate by 9 times (the scatter angle of the distribution angle at the circumference of the warhead was 40°). The relationship between the number of the fragments and projection angle is shown in figure4, and the scatter angle and direction angle of two warheads are shown in table 1. It can be observed that the average scatter angle and direction angle of two warheads were 20° and 6°, respectively. Due to the effect of fragment ricochet, the intensity of fragment distribution from embedded warhead was significantly increased compared with warhead in the air. In addition, the embedded warhead formed an obvious intense strip of fragment.

The velocity of fragments was obtained by the connected-disconnected probe system, the original data was shown in figure5. When the fragments moved in the air, the velocity of the fragments decreased obviously due to the irregular shape of the fragments. Ignoring gravity, the fragment dynamics equation is shown below:

\[
m \frac{dv}{dt} = -\frac{1}{2} \rho_0 C_D A_S H v^2
\]

where \( m \) is the mass of fragment, \( CD \) is Coefficient of air resistance, \( \rho_0 \) is the air density on the ground (1.25kg/m^3), \( A_S \) is Windward area of fragments (m^2), \( H \) is the relative air density at the height of fragment, \( v \) is the instantaneous velocity of the fragment. Further simplified, the fragment velocity attenuation expression is as follows:

\[
v_r = v_0 e^{-\alpha r}
\]

where \( v_r \) is the fragment velocity at the distance \( r \) from the original position, \( \alpha \) is velocity attenuation coefficient.
For natural irregular fragments, the coefficient of air resistance usually was 1.5 \((C_D=1.5)\), and \(A_S\) usually calculated by the following:

\[
A_S = \phi m^{2/3}
\]

(3)

where \(\phi = 5 \times 10^{-3}\) m\(^2\)/kg\(^{2/3}\), and \(m\) can be replaced by the average mass of the fragments, that is, \(m=0.86\) g. After the invalid data were discarded, the logarithm of velocity was taken and the least square method was used to fit the attenuation characteristics of fragment velocity. The fitting curve was shown in figure 6. The fragment velocity was 1.5246 km/s and the attenuation coefficient was 0.2282. The fragment velocity attenuation formula can be obtained:

\[
V_r' = V_0e^{-(C_D\rho_0A_r)/(2m^{1/3})} = V_0e^{-(1.5\times1.25\times5\times10^{-3})r/2m^{1/3}}
\]

(4)

The relationship between fragment velocity and distance from the warhead was shown in figure 7, and the kinetic energy of fragment was also shown in figure 6. For human being, the kinetic energy criterion for serious injury or death was 78 J, which meant that the blocking distance for human being was 25 m. In addition, the average direction angle and scatter angle of the fragments were 6° and 20°, so human being was fully threatened in the blocking distance.

**Figure 3.** The spatial distribution of fragment on the distribution plate.

**Figure 4.** The relationship between the fragment number and the projection angle.
Table 1. The ejection angle and direction angle of the two warheads.

| NO  | scatter angle Ω  | Direction angle Φ |
|-----|------------------|-------------------|
| T-1 | 20° (-3° ~17°)   | 7°                |
| T-2 | 20° (-5° ~15°)   | 5°                |

![Figure 5. The original diagram of test data.](image)

![Figure 6. The fitting curve of fragment velocity.](image)
Figure 7. The velocity and kinetic energy of fragment.

4. Conclusions
As a new type of warhead, the embedded warhead embedded into the target by its own momentum, killed human being and destroyed the equipment by the fragments, and achieved blocking effect on the target using the embedded projectile and residual projectile after explosion. The dispersion characteristics of fragments from embedded projectile was studied. There are following conclusions can be drawn:

1) After the detonation of the embedded warhead, the projection angle of the fragments generated by the casing near the target plate was less than 0, that is, the fragments flied downward. After the fragments impacted the target plate, they ricochet due to the incident angle greater than the critical ricochet angle, forming typical trace rings on the target plate. The ricochet fragments still had high velocity, which can be considered as effective fragments.

2) The average direction angle of the fragments was tilted upward (6°) due to the effect of ricochet of the fragments, which enhanced the damage effect of the fragments from the embedded warhead, and the blocking diameter was 25m for human being.

3) The distribution of fragments from embedded warhead was obviously different from that from warhead in the air, there was an intense strip due to the effect of ricochet of the fragments.

Acknowledgments
The authors wish to thank to the support from State Key laboratory of Explosion Science and Technology, Beijing Institute of Technology.

References
[1] R W Gurney 1943 The initial velocities of fragments from bombs, shell and grenades (Army Ballistic Research Lab Aberdeen Proving Ground Md)

[2] G Y Huang, W Li and S S Feng 2015 International Journal of Impact Engineering 76 20-7

[3] E Hennequin 1986 NASA STI/Recon Technical Report N 86

[4] D Felix, I Colwill and E Stipidis Defence Technology 15 264-71

[5] Y G Gao, S S Feng, B Zhang and T Zhou IOP Conference Series: Materials Science and Engineering 629 012020

[6] R Karpp and W Predebon 1975 Calculations of Fragment Velocities from Naturally Fragmenting Munitions ARMY BALLISTIC RESEARCH LAB ABERDEEN PROVING GROUND MD

[7] I Cullis, P Dunsmore, A Harrison, I Lewtas and R. Townsley umerical simulation of the natural fragmentation of explosively loaded thick walled cylinders Defence
[8] W Arnold and E Rottenkolber *International journal of impact engineering* **35** 1393-8
[9] H Y Grisaro and A N Dancygier *International Journal of Impact Engineering* **112** 1-14