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EDGE EFFECTS ON FRAGMENTS DISPERSION

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The present work focuses on the problem of end effects influence on the ejection angles of fragments near the ends of an “open sandwich” warhead. In order to minimize end effects, which cause extremely large and difficult to predict projection angles, the use of a peripheral frame confining the fragments, was proposed. Warheads with various confining frames (steel, aluminum, metal powder and plastic) were detonated facing a meshed target steel plate arena. The warheads comprise metal fragments arranged in a flat plane layer. All the warheads contained identical explosives, had the same casing material and were initiated using the same method. The fragments distribution on the targets were mapped and analyzed, in order to evaluate the ejection angles and the efficiency of the implemented methods. In addition, the projection angles obtained in the experiments were compared to theoretical predictions (Taylor's model) and to numerical solutions obtained using Finite Element simulations (LS-DYNA).

The experimental results and the numerical simulations show that the confining frame has a major influence on the projection angle of the edge fragments and the projection angle was found to be highly dependent on the frame material (without frame, plastic, metal powder, aluminum, steel). The steel frame minimized the end effects to a degree in which the ejection angles were similar to the angles predicted using Taylor's equation. Altogether, the use of a peripheral frame of metal was shown to be effective in minimizing end effects, further work should be conducted in order to optimize this method.

INTRODUCTION

The performances of fragmentation warheads are usually described with characteristics of the fragment dispersion. These characteristics include mass, projection angle and direction, velocity and the distribution density of the fragments [1,2]. Hence, fragments spray divergence is a subject for theoretical and practical study in designing fragmentation warheads.

One of the problems in optimizing fragmentation warheads is the problem of end effects influencing the ejection angles of fragments near the ends. It is well known that there is significant difference between the dispersion angles of the fragments located in the center of the charge's surface and the ones located on its edges. The ejection angles of the fragments on the edges are exceptionally large and difficult to predict using standard tools [3,4].

In most of the existing theoretical and semi-analytical models statistic methods are used to evaluate the fragments spatial distribution [3,4,5,6]. These models provide, usually, an approximate result for warhead design with simplified configurations (e.g., cylindrical or open sandwich models) and very few of them refer to edge effects.

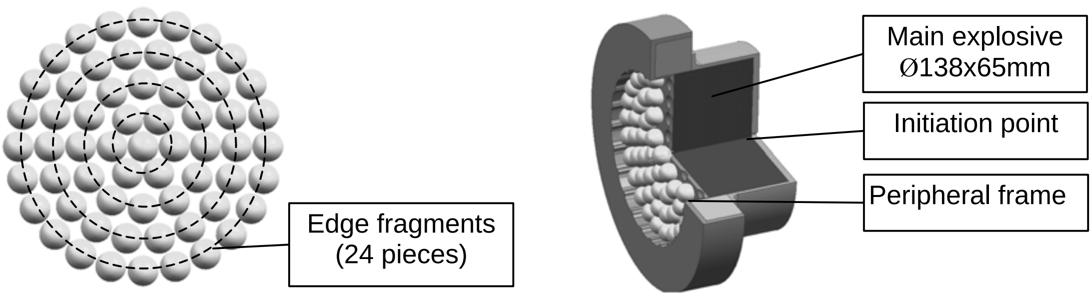
In order to minimize end effects influence on ejection angles of fragments, the use of a peripheral frame, confining the fragments, was proposed. A series of experiments were performed, in which warheads with various confining frames were initiated against a meshed target steel plate target. The fragments ejection angles were evaluated and compared to theoretical models and to finite element simulations.

METHOD

Experimental

Round warheads comprising metal fragments arranged in a flat plane layer were designed and assembled (Figure 1). The experimental set-up allowed estimation of the projection angle for each fragment penetration in the meshed arena by measuring exact hit coordinates. All the warheads contained identical explosives, had the same casing material and were initiated using the same method. The peripheral frames, 30 mm thick, made of either steel, plastic, aluminum or metal powder, where placed around the fragments face. In each warhead 61 steel spheres (ϕ15 mm) were used as fragments. Fragments were arranged in one layer and 4 radii around charge axis (Figure 1a). The charge surface was designed to allow exact positioning of each fragment. The main charge contained Composition C4. A CH-6 booster was used to initiate the main explosive. The warhead casing was made up of acrylic polymer (3 -5 mm thick) which material properties similar to common engineering plastic materials.

Each charge was carefully aimed to the middle of a meshed target (distance 2.5 meter) and charge axis was perpendicular to target face. The target arena size was sufficiently large (6 x 3 meter) to account for each fragment penetration point and by this to calculate the projection angle.



(a) Fragments arrangement (b) Warhead with peripheral frame

Figure 1. Warhead design.

Semi-analytical model

The Taylor's formula, given in eq. (1), for estimation of the projection angle has been used extensively in the design and study of various types of warheads [6,7].

$$\alpha = \sin^{-1}\left(\frac{V}{2D}\right)\cdot \sin^{n}(\lambda) \tag{1}$$

Where D is detonation velocity; V fragments ejection velocity; δ is angle between detonation front and normal to the explosive/metal interface; α is the projection angle and n is an empirically fitted parameter (in the presented case n = 2/3 [8]).

Fragments velocity for open sandwich geometry can be approximated with Gurney's equation given in eq. (2).

$$V = k \cdot V_g \cdot \sqrt{\frac{\left(1+2\frac{M}{C}\right)^3 + 1}{6\left(1+\frac{M}{C}\right)} + \frac{M}{C}} \tag{2}$$

Where V_g is Gurney velocity (defined by the explosive type); C - explosive weight; M - total fragment weight and k - parameter that depends on the charge geometry, for engineering purposes k can be taken as 0.8 [5,7].

Numerical model

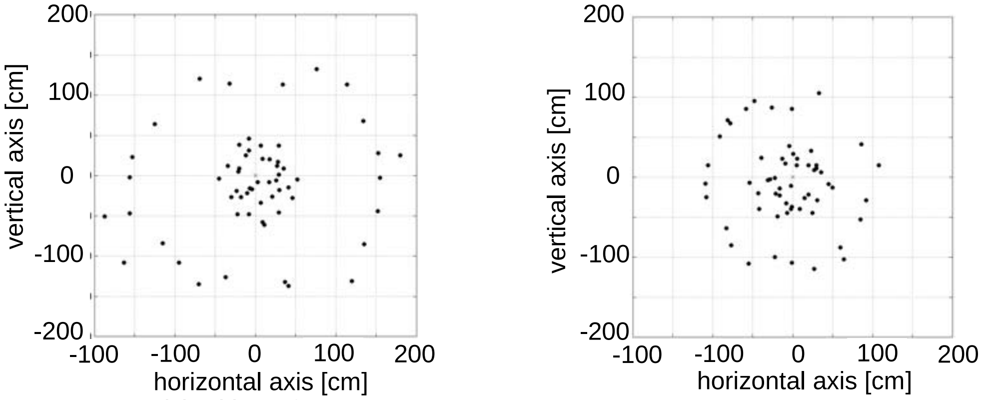
LS-DYNA , a 3-D hydrodynamic finite element computer code with Langrangian-Eulerian coupling algorithm and 400.000 nodes, was used to simulate two extreme cases - reference and steel frame warheads. The main mesh is built using an Eulerian method, while the fragments were built using a Lagrangian method. An infinite-elastic body model was used for the steel spheres, while the casing, the steel frame and the explosive had appropriate engineering properties. Vectors of velocities and ejection angle for fragments placed on different radii were obtained and analyzed.

RESULTS & ANALYSIS

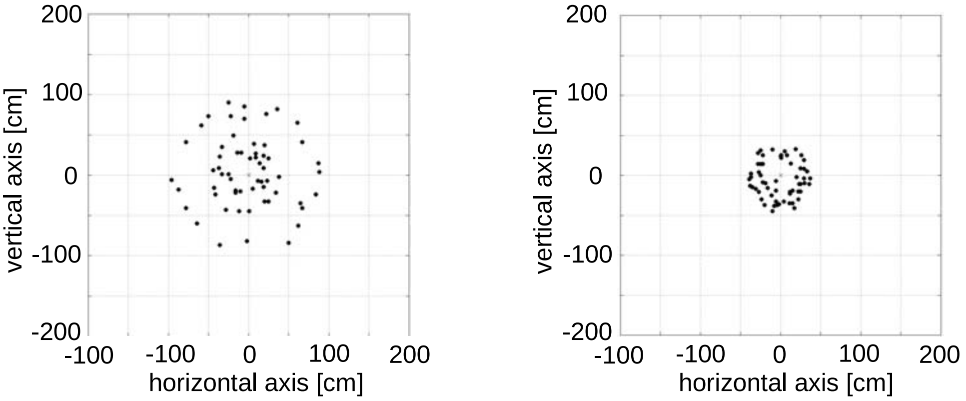
Experimental

A total of five experiments were performed: one without peripheral frame (reference case) and four with frames of different materials - steel, aluminum, plastic (polyacetal) and metal powder. It should be noted that few fragments in some cases were unaccounted for, and it is assumed that they were broken during the explosion. Small penetrations in target arena may be related to these broken fragments.

The fragments hit results are presented in Figure 2. It is evident that the peripheral frame has a strong influence on fragments spray divergence.



(a) without frame (b) plastic frame



(c) metal powder frame (d) steel frame

Figure 2. Hit results - penetrations in target arena

Figure 3 shows the measured ejection angles values of all the fragments sorted in ascending order.

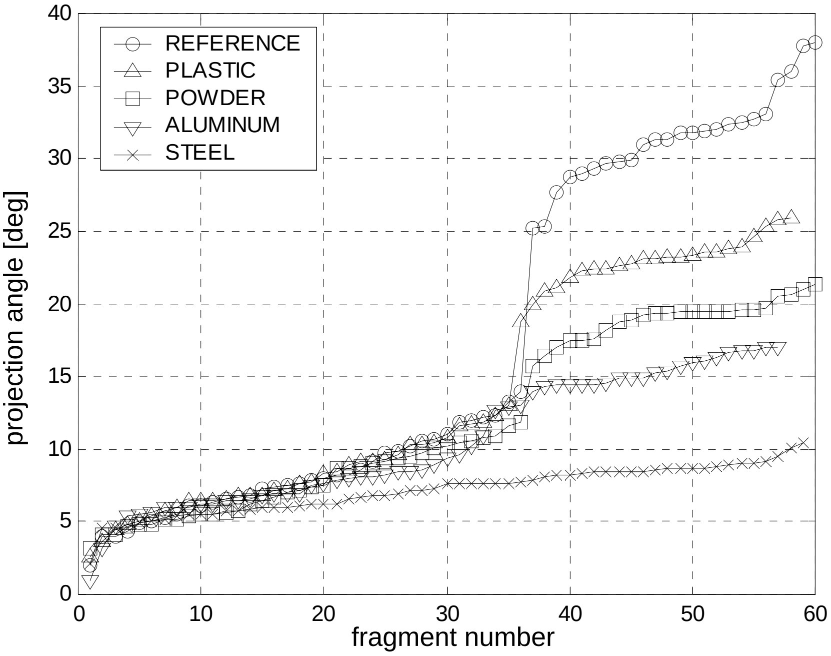


Figure 3. Projection angle sorted in an ascending order

It can be seen that the projection angle of the edge fragments, which are located on the outer radius of fragment face, (fourth fragment radius that include 24 pieces - Figure1a) depends on the frame material. The steep jump in the projection angle fits with the last 24 points in all cases. Additionally, it can be observed that when a steel frame is being used, fragments located on inner (second and third) fragment radius are also affected and have smaller projection angle than in other cases.

Since all the peripheral frames where of the same size it can be assumed that the change in the projection angle is directly related to mechanical properties of material being used. The density of metal powder is slightly higher than the density of aluminum, however powder confinement influence is smaller. The density of steel is greater than the density of aluminum and steel confinement causes a substantial divergence of edge fragments. Therefore it can be assumed that the phenomenon may be slightly dependent on material's density and influenced by other mechanical properties such as elastic modulus or sound velocity - Table 1.

Material	Elastic modulus 10^{10}[N/m^2]	Sound velocity 10^3[m/sec]	Density [gr/cm^3]	Average edge angle [deg]
Plastic	0.4	~2.0	1.4	22.9
Aluminum	6.9	~5.3	2.7	15.5
Steel	19.6	~4.6	7.8	8.7

Table 1 - selected mechanical properties of frame materials

From Table 1 it can be seen that while sound velocity in aluminum is slightly higher then in steel, their elastic modulus differ significantly (ratio ~2.4). The substantial change in the elastic modulus correlates with the changes in the edge angles (ratio ~2). Plastic with the lowest density, elastic modulus and sound velocity has the lowest influence on projection angles. The results presented suggest that the confinement may be influenced by density of the framing material and the elastic modulus.

Semi-theoretical model

In Figure 4 Taylor's angle is plotted against corresponding fragment number.

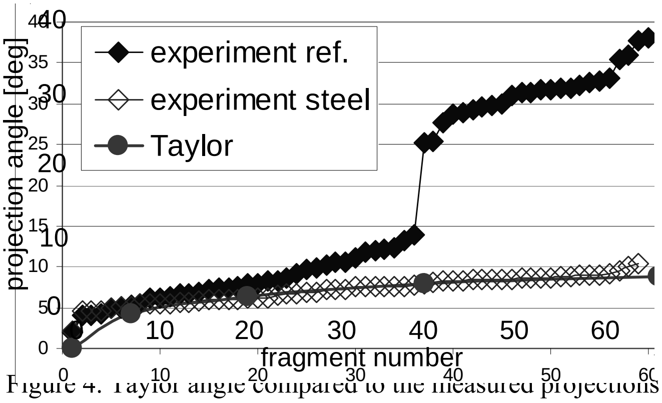


Figure 4. Taylor angle compared to the measured projections angles

From Figure 4 it can be seen that there is a good correlation between Taylor's angles and the actual projection angles of the center fragments, however, those located on the edges have a significant deviation from Taylor's prediction due to edge effects. In the case of a steel frame, Taylor's angles are in agreement with the experimental values.

According to König [3] rapid pressure drop near the edge results in reduced fragments speed, while the release-wave gas flow over the fragments causes the fragment spray to diverge to a much greater values than predicted by Taylor formula.

König's paper refers to cylindrical charges where fragments are placed around the cylinder and not on the base. Nevertheless, edge fragments in those cylindrical warheads deviate up to 30deg from expected values (in a similar manner to the presented case) and have to be taken into account. The results presented here suggest that confinement discs at the ends of warhead may be helpful in controlling the fragmentation end effects.

Since the steel peripheral frame affected not only the outer but also the inner (close to center) fragments, it can be assumed that the peripheral frame affects both gas-flow and internal explosive ballistics processes.

Finite Element Simulations

The finite elements simulations (LS-DYNA) show good correlation with experimental data - Figure 5. The extreme projection angle for the reference case is 26[deg] and for the warhead with steel frame about 7[deg]. These values are in agreement with the experimental results (Figure 6) and fragments velocities are similar to values obtained by Gurney equation. Moreover, the simulation results confirm the steep jump in projection angles for outer fragment radius.

(a) reference warhead (b) warhead with steel frame

Figure 5. Simulations results - velocity vector, t=0.15[msec]

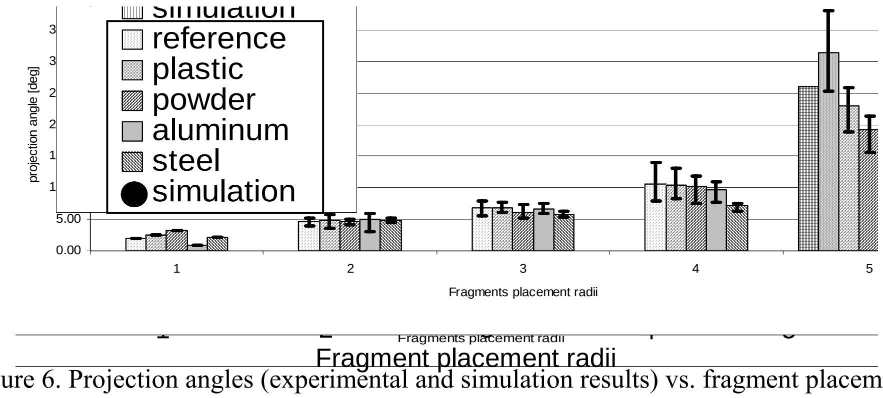


Figure 6. Projection angles (experimental and simulation results) vs. fragment placement radius

CONCLUSSION

The use of a peripheral frame was shown to be effective in minimizing the projection angle of edge fragments. The influence on end effects was found to be dependent on the type of material used for confinement. Further experimental work and 3D finite elements simulations should be conducted in order to optimize confining frame configuration, properties and geometry.

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