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# PARAMETRIC STUDIES ON THE EFFECT OF LINER GEOMETRY ON EXPLOSIVELY FORMED PROJECTILES

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## ABSTRACT

Explosively formed projectiles (EFP) are very much used in antiballistic missiles and the indigenous development is under process. Optimization studies have to be carried out for maximum penetration and damage for which the influencing factors are the shape of the projectile formed and its kinetic energy. Liner geometry is one of the important parameters that affects the shape and kinetic energy of the projectile. As parametric studies require lot of experimentation that is costly and time consuming numerical studies are essential to arrive nearer to solution, hence in this work numerical studies are carried out to find the effect of liner thickness and liner diameter on the shape and the energy of the projectile formed.

**Key words:** Explosively formed projectile, Liner, Material model, Equation of state and LS DYNA

## 1. Introduction

A typical explosively formed projectile (EFP) is comprised of a metallic liner, a case, an explosive section, and an initiation train. Very often there is also a retaining ring to position and hold the liner-explosive subassembly in place. EFP warheads are normally designed to produce a single massive, high velocity penetrator. After detonation, the explosive products create enormous pressures that accelerate the liner while simultaneously reshaping it into a rod or some other desired shape. The EFP then hits the target at a high speed, delivering a significantly high mechanical power. The numerical analysis of the EPF is utmost important as the cost of tests for development is very high and analytical solutions are not usually possible because of the complexity of the initial value problem and also due to nonlinearity in the system of equations developed [1].

Even though, the liners used for the formation of EFP are conical in shape the authors in this work considered the liner to be flat as a first approximation and the effect of liner diameter and thickness on the shape, velocity and kinetic energy of the projectile formed is investigated.

## 2. Finite Element Model

The FE model consists of an explosive, air, liner and an adapter ring to place the liner through which the liner moves out after explosion. Explosive and air medium are modeled with solid elements with Arbitrary Lagrangian Eulerian (ALE) formulation. The liner is modeled with lagrangian shell elements at mid plane with Belytschko formulation [2]. The material models selected are explosive burn, null, Johnson-cook and rigid for explosive, air, liner and the adapter ring respectively

As the explosive is ignited the detonation front moves with a velocity called detonation velocity. Behind the detonation front there is a narrow zone called reaction zone, followed by expanding gases released from the decomposing explosive. An ideal explosive releases all its energy in the reaction zone. The plane at the end of reaction zone is called C-J plane (Chapman-Jouget plane) [3].

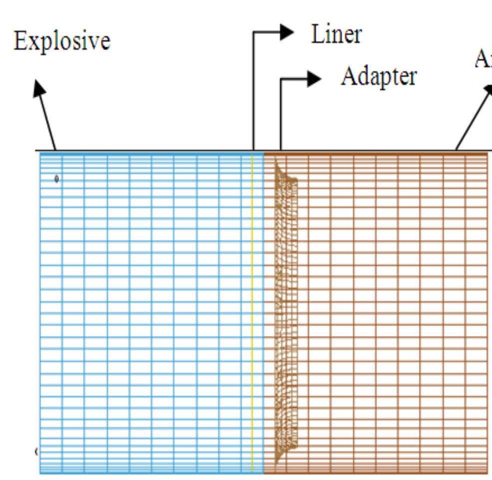


**Fig. 1 Finite Element Model**

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The pressure at the C-J plane is called C-J pressure or reaction pressure (PCJ) of the explosive. The expansion of the gases is the complex function of pressure, density, temperature and energy. The gas expansion is modeled by equation of state (EOS). A number of different equations are developed to describe the expansion process out of which Jones-Wilkins-Lee (JWL) equation of state, (equation 1) is accepted as one of that accurately describes the expansion process [4].

$$P = A\left[1-\frac{\omega}{R_1V}\right]e^{-R_1V} + B\left[1-\frac{\omega}{R_2V}\right]e^{-R_2V} + \frac{\omega E}{V} \quad \text{....(1)}$$

Where P is pressure; A,B,$R_1$,$R_2$,ω are the constants; V is the ratio of detonation product volume to initial high explosion volume and E is detonation energy. The explosive selected for the present work is ‘CompB’ which is a mixture of 59.5% RDX and 39.5% TNT. The JWL EOS parameters of CompB, shown in table 1 are selected for the analysis.

**Table1: JWL EOS Parameters of CompB [5]**

| S. No | parameter | Value |
|---|---|---|
| 1 | A | 524200 Mpa |
| 2. | B | 7678 Mpa |
| 3. | $R_1$ | 4.2 |
| 4. | $R_2$ | 1.1 |
| 5. | ω | 0.34 |
| 6. | E | 8500 Mpa |

The material model selected for the explosive should address the following in order estimate the chemical energy released at a given time.

i. It should able to calculate the lightening time at which the detonation front reaches to each element of the explosive in the model.
ii. The burn fraction of each element at a given time.

The above can be incorporated in the material model Mat_High_Explosive_Burn in LSDYNA. In the initial detonation phase, the lightening time ($t_l$) is calculated for each element by dividing the distance from the detonation point to the center of the element by detonation velocity (D) and the burn fraction is calculated by equations (2) and (3).

$$F = \frac{2(t-t_l)DA_{max}}{V} \quad \text{if } t > t_l \quad \text{........ (2)}$$

$$= 0 \quad \text{if } t \leq t_l \quad \text{.........(3)}$$

Where $A_{max}$ and V are the maximum area and the volume of the element. The parameters for Comp B that are input for the material model described above are listed in table 2

**Table 2: Material Parameters of CompB [6]**

| S. No | Parameter | Value |
|---|---|---|
| 1 | Detonation Velocity | 7.98 X $10^6$ mm/sec |
| 2 | Mass density | 1717 X $10^{-6}$ Kg/mm$^3$ |
| 3 | C-J pressure | 26400 Mpa |

The liner is exposed to very high strain rates and the material softening takes place due to the adiabatic heating. So the material model used for the liner should take care of stain, strain rate and temperature effects.

$$\sigma_y = (A + B\varepsilon^n)(1 + C\ln\dot{\varepsilon}^*)(1 - T^{*m}) \text{.....(4)}$$

For the above requirements the best suited material model is Jhonson-Cook constitutive model which is given by equation (4)

Where A, B, C, n and m are constants ε is the plastic strain $\dot{\varepsilon}^*$ is effective plastic strain rate and T* is homologous temperature defined by equation (5)

$$T^* = \frac{T - Tr}{T - Tm} \text{.......(5}$$

Where $T_r$ and $T_m$ are the room temperature and melting point of the material.

The parameters used for the material selected i.e. OFHC (Oxygen-free High Thermal Conductivity) copper is shown in table 3.

**Table 3: Material Parameters for OFHC Copper [7]**

| S. No | Parameter | Value |
|---|---|---|
| 1 | Elastic Modulus (E) | 124000 Mpa |
| 2 | Poison’s Ratio (μ) | 0.34 |
| 3 | Density (ρ) | 8960 X $10^{-9}$ Kg/mm$^3$ |
| 4 | Melting point | 1356 K |
| 5 | Specific heat | 383 J/Kg-K |
| 6 | A | 90 Mpa |
| 7 | B | 290 Mpa |
| 8 | C | 0.025 |
| 9 | n | 0.31 |
| 10 | m | 1.09 |

The Jhonson-Cook material model uses the Jhonson-Cook fracture model [8] as given by equation (6).

 

$$D = \sum \frac{\Delta\varepsilon}{\varepsilon^{f}} \quad \ldots\ldots (6)$$

Where D is damage to an element, $\Delta\varepsilon$ is increment of equivalent plastic strain that occurs during the integration cycle and $\varepsilon^{f}$ equivalent strain to fracture under current conditions of strain rate, temperature, pressure and stress. Fracture occurs when D=1. $\varepsilon^{f}$ is calculated using equation (7)

$$\varepsilon^{f} = \left[D_1 + D_2^{D_3\sigma^*}\right]\left[1 + D_4 \ln \dot{\varepsilon}^*\right]\left[1 + D_5 T^*\right] \ldots (7)$$

Where $D_1$, $D_2$, $D_3$, $D_4$ and $D_5$ are constants. The fracture model constants for OFHC copper are given table 4.

**Table 4: Fracture Model Constants for OFHC Copper [9]**

| S. No | Parameter | Value |
|---|---|---|
| 1 | $D_1$ | 0.54 |
| 2 | $D_2$ | 4.89 |
| 3 | $D_3$ | -3.03 |
| 4 | $D_4$ | 0.014 |
| 5 | $D_5$ | 1.12 |

Air is taken as adiabatic medium with $\gamma = 1.4$. This is defined by selecting equation of state as linear polynomial with appropriate constants ($C_4 = C_5 = \gamma - 1$).

Adapter is constrained in all degrees of freedom and the explosive and air boundary is given as no slip condition.

## 3. Results and Discussion

Finite Element Analysis is carried out with thickness from 0.5mm to 3mm in the steps of 0.5mm with the diameters 20mm, 25mm, 30mm and the effect of liner thickness on the velocity, Kinetic energy, % reduction in thickness, maximum diameter and length of the projectile formed is investigated and presented. As a sample the results of liner of 3 mm thickness with 25 mm diameter are presented from Fig. 2 to Fig. 4

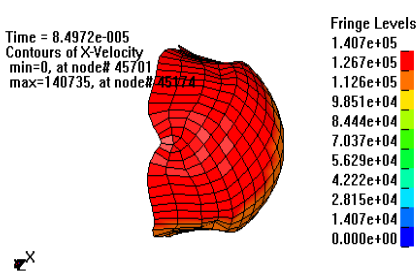


**Fig. 2 Velocity of the Liner of 3mm Thickness and 25mm Diameter**

The velocity and kinetic energy of the liner with the thickness are presented in Fig. 5 and Fig. 6.

From the Fig. 5 it is noted that the velocity decreases almost linearly with the increase of thickness of the liner and increases with the increase of diameter. The variation of liner velocity with diameter is more at lower thicknesses. Fig. 6 shows that the kinetic energy increases with the thickness first and then decreases later. It is observed that the variation is less at lower diameters and considerably high at higher diameters. For all the cases the maximum kinetic energy occurs at the thickness of 1 mm. The kinetic energy also increases with the increase in diameter. It is also observed that the increase in K.E for all the thicknesses considered is small when the diameter is increased from 20mm to 25mm but the difference is considerable with the 20 mm and 30 mm diameters.

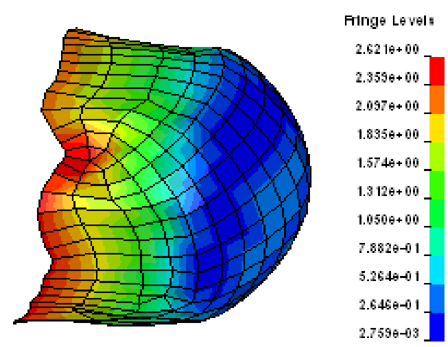


**Fig. 3 Change in Thickness Percentage of the Liner of 3mm Thickness and 25mm Diameter**

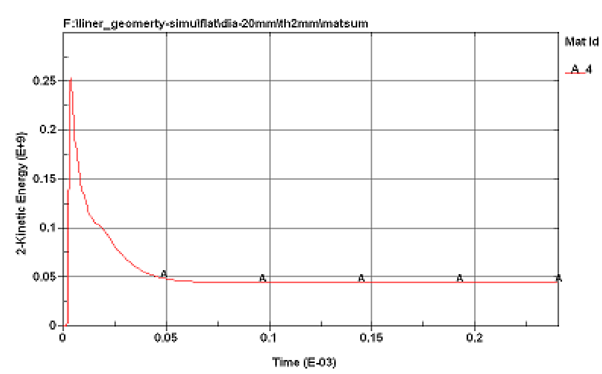


**Fig. 4 Kinetic Energy of the Liner of 3mm Thickness 25 mm Diameter**

Reduction in thickness during formation of the liner is one of the important aspects to be considered as the strength of the projectile formed decreases with the decrease in thickness and thereby decreasing the penetrating capacity. Hence the reduction of thickness with the thickness of the liner is plotted for the diameters 20mm, 25mm and 30mm and is shown in Fig. 7.

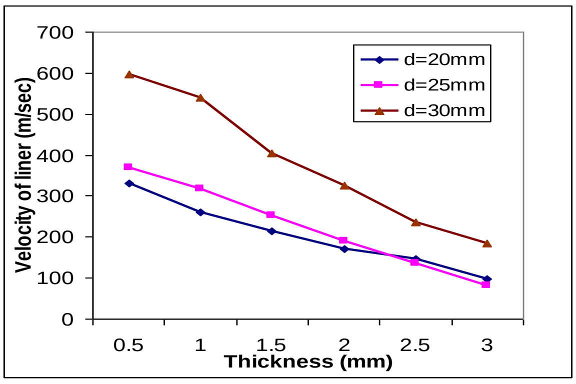


**Fig. 5 Variation of Liner Velocity with Thickness for various Diameters**

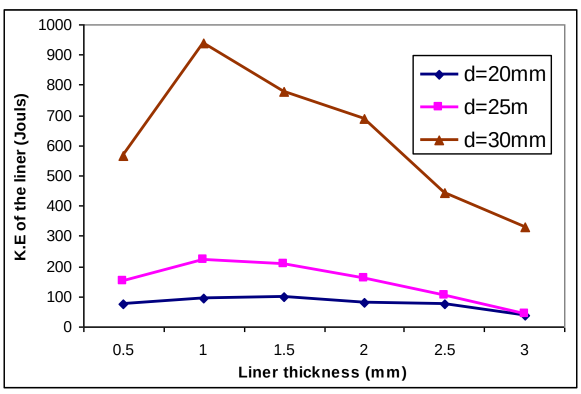


**Fig. 6 The Variation of Kinetic Energy with the Liner Thickness at various Liner Diameters**

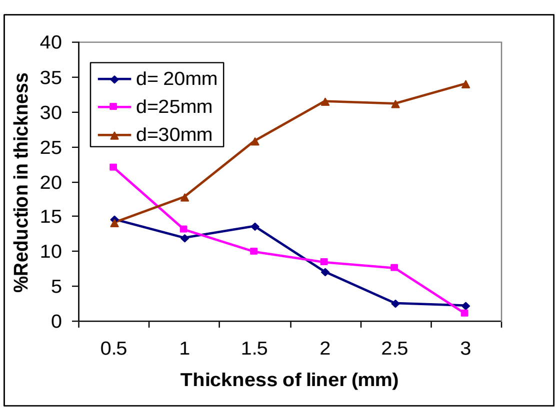


**Fig. 7 The Variation % Reduction in Thickness with the Liner Thickness at Various Liner Diameters**

From the Fig 7 it is evident that as the thickness increases reduction in thickness decreases for 20mm and 25mm diameter. But it increases for 30mm diameter.

For better penetration the projectile length should be higher and diameter should be less. The variation of projectile length and diameter with thickness for various diameters is shown in Fig 8 and Fig 9.

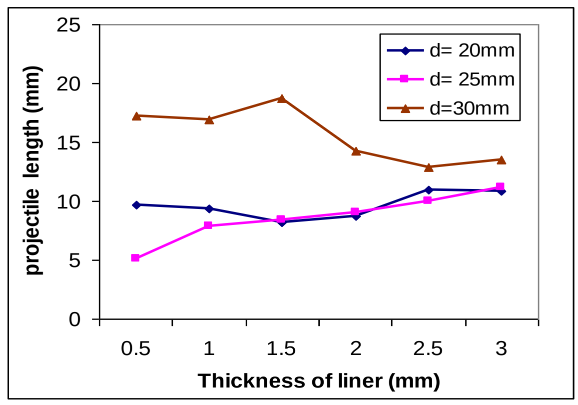


**Fig. 8 The Variation of Projectile Length with the Liner Thickness at Various Liner Diameters**

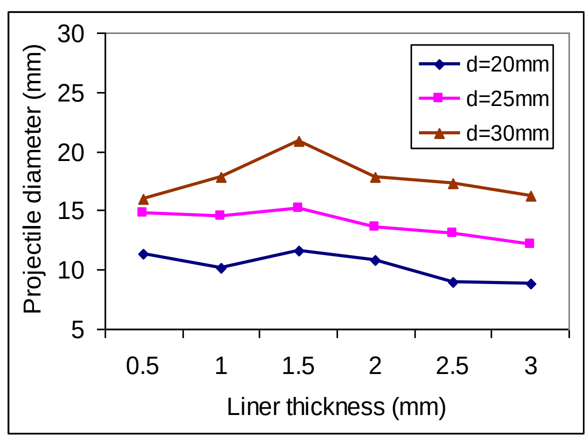


**Fig. 9 The Variation of Projectile Diameter with the Liner Thickness at Various Liner Diameters**

## 4. Conclusions

The following are the conclusions enumerated from the present work.

i. Even though the velocity of the liner continuously decreases with the thickness there exists a peak value of kinetic energy.
ii. The variation in kinetic energy, reduction in thickness and the projectile length with diameter

 

is very less for the liner diameters 20mm and 25mm. but the difference is considerable for 30mm diameter.

iii. Maximum kinetic energy occurs for a liner thickness of 1mm.

iv. Among 20mm, 25mm and 30mm diameters chosen in this work, 30mm diameter liner with 1mm thickness may be treated as the best choice as it produces projectile with maximum kinetic energy and higher projectile length without having much reduction in the thickness.

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## 5. Acknowledgment

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