Study of the Effect of Projectile Nose Shape on Permeability in Sandwich Panels for Ceramic/Metal/Foam/Metal Target

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Abstract

Keywords:
Steel projectile, Sandwich target, Output speed, Penetration.

In this study, the penetration of steel projectile with flat, Ogive and half-spherical nose into sandwich target with foam, polystyrene and poly rubber core is simulated using Autodyn software (version12). The behavioral equation used in the simulation is Johnson Cook for projectile and metal layer of the target, Johnson Holmquist for ceramic, and Crushable foam for foam. Also the equation of state used in steel projectile and metal layer of the target is linear, in ceramic layer is polynomial, and in polystyrene and poly rubber is shock. The simulation was performed by using Lagrangian approach. Results have shown that the flat nose is more efficient in destruction of multi-layered target of ceramic/metal /foam /metal, compared to the other two ones.

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1. Introduction

Polymer matrix composites are used in a wide variety of industries including aerospace, automotive, sport equipment, due to its high strength to weight. One of the most important application of these composites is bulletproof vests. Until now many analytical studies have been done on the influence of failure mechanisms and penetration of this composite [1]. Hou et al. considered experimental testing of sandwich panels with aluminum foam core. They examined the effects of different speeds, sheet, core thickness, impacts of projectile nose and core density [2]. Mohan et al. [3] experimentally investigated the impact response on aluminum foam with different face sheet of elastic, ideal elastic-plastic, and elastic-plastic with hardened strain behavior. Rajaneesh et al. [4] presented numerical simulation results of low speed impact on sandwich plates with a 2.65 Kg kicker at 6.7 m/s. They used a three-dimensional finite element software Ls-dyna for numerical simulation. Ni et al. [5] examined the response to the impact and ballistic resistance of sandwich panels with three different types of
hybrid cells. In this study, the penetration of steel projectile with Ogive, flat and hemispherical nose into the sandwich target at the speed of 854 m/s is simulated and the effect of projectile nose shape on the output speed of the target is studies. This research is based on the Lagrangian approach. This view is based on following the path of material particle movement [6].

2. Simulation of penetration into sandwich panel

Autodyn software is the product of Dynamic century Company and its presentation to engineering community dates back to 1986. Multi-purpose software applications are designed so that they can analyze high-rate engineering issues. These analyses are performed by using finite difference and finite volume methods in a wide range of nonlinear problems in solids, liquids and gases dynamics. Issues that usually have such specifications are highly functioning of time and have non-linear geometrical factors such as very large deformations [6].

2.1. Characteristics of target and projectile

Projectile and target of four modeled layers have following characteristics:

<table>
<thead>
<tr>
<th>speed (m/s)</th>
<th>length (mm)</th>
<th>diameter (mm)</th>
<th>Density (kg/m³)</th>
<th>material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>600</td>
<td>3890</td>
<td>ceramic</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>600</td>
<td>2700</td>
<td>aluminum</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>600</td>
<td>486</td>
<td>foam</td>
</tr>
<tr>
<td>854</td>
<td>28.7</td>
<td>7.62</td>
<td>7830</td>
<td>projectile</td>
</tr>
</tbody>
</table>

Three types of simulated projectile head is shown in Figure 1.

![Projectile nose](image)

Fig. 1: Projectile nose: a) Ogive, b) flat, c) hemispherical.

Projectile and target modeling has done in an axial symmetrical way. In part (part), the sandwich panel and projectile were simulated by selecting Lagrangian method. Surrounding environment of the
target was fully bounded. Lagrangian element classification of projectile, target and target arrangement is shown in Figure 2.

2.2. Material models

Material models of Johnson-Cook are commonly used for metals under the impact loading and high-rate strains. In this model, the flow stress in independent terms are considered as a function of plastic strain, strain rate and temperature. One of the requirements of using this model is utilizing the equation of state. Johnson and Cook have been suggested following equation to show the material flow stress:

$$\sigma_y = (A + B\varepsilon^p)(1 + C \ln\dot{\varepsilon}^p)(1 - T^m)$$  \hspace{1cm} (1)

where $\sigma_y$ is the flow stress, $\varepsilon^p$ is effective plastic strain, $\dot{\varepsilon}^p$ is effective plastic strain rate, $T^*$ is dimensionless temperature and A, B, C, n and m are material constants. In this material model, failure strain is obtained according to the following equation in terms of dimensionless stress $\sigma^*$, strain rate $\dot{\varepsilon}^*$ and temperature $T^*$ and material constants D1 to D5 values:

$$\sigma^* = \frac{p}{\sigma_{eff}}$$  \hspace{1cm} (2)

Failure occurs when the damage coefficient is equals to 1 as follows [7]:

$$D = \sum \frac{\Delta \varepsilon^p}{\varepsilon^f}$$  \hspace{1cm} (3)
2.3. Johnson – Holmquist material model

Johnson – Holmquist material model is used for concrete, ceramic, glass and other brittle materials. The equivalent stress in these materials is the function of degradation factor D as follows:

\[ \sigma^* = \sigma^i - D(\sigma^*_i - \sigma^*_f) \]  

(4)

Where

\[ \sigma^*_i = a(p^* + t^*)^n(1 + c \ln \dot{\varepsilon}^*) \]  

(5)

Eq. (4) shows the behavior of not destroyed materials. The sign * indicates normalized quantities. Normalized tensile stress is obtained by dividing equivalent tensile stress to elastic limit stress of Hogoniot (HEL) according to Eq. (5).

Normalized pressure is also obtained by dividing equivalent pressure to elastic limit of hogoniot (HEL) according to Eqs. (2-7). In above equations, c, is the strength parameter for different strain rates and \( \dot{\varepsilon}^* \) is the normalized plastic strain rate.

\[ t^* = \frac{T}{P_{HEL}} \]  

(6)

\[ p^* = \frac{T}{P_{HEL}} \]  

(7)

Degradation coefficient is also as follows.

\[ D = \sum \frac{\Delta \varepsilon^p_i}{\varepsilon^p_f} \]  

(8)

where \( \Delta \varepsilon^p_i \) is plastic strain development and \( \varepsilon^p_f \) is fracture strain, which is defined as follows:

\[ \varepsilon^p_f = d_1(p^* + t^*)^{d_2} \]  

(9)

where \( d_1 \) and \( d_2 \) are coefficients which are determined by the user. The following equation shows the behavior of damaged materials:

\[ \sigma^*_f = b(p^*)^m(1 + c \ln \dot{\varepsilon}^*) \leq sfma \]  

(10)

In the above equation, b is the coefficient d by the user and sfma is the normalized maximum fracture strength. \( d_1 \) is the controller of amount rate and if it equals to zero, complete degradation occurs in a time interval.

In non-damaged materials hydrostatic pressure is as follows:
In this equation $\rho_0$ is the material density and $\rho$ is the material density after deformation. Also according to Hogoniot elastic limit (HEL) and shear modulus (G), the modulus $\mu_{HEL}$ is obtained using the following equation:

$$HEL = k_1\mu_{HEL} + k_2\mu_{HEL}^2 + k_3\mu_{HEL}^3 + (4/3)\rho(\mu_{HEL}/(1+\mu_{HEL}))$$

By normalizing the above equation, equation (14) is obtained [7]:

$$P_{HEL} = k_1\mu_{HEL} + k_2\mu_{HEL}^2 + k_3\mu_{HEL}^3$$

And also

$$\sigma_{HEL} = 1.5(HEL - P_{HEL})$$

Coefficients of steel and aluminum and foam projectile are shown in Tables 4 and 5.

Table 2: Characteristics of ceramic [8].

<table>
<thead>
<tr>
<th>Equation of State</th>
<th>Polynomial</th>
<th>Strength</th>
<th>Johnson-Holmquist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Modulus A1</td>
<td>$2.31 \times 10^9$ (kPa)</td>
<td>Shear Modulus</td>
<td>$1.52 \times 10^5$ (kPa)</td>
</tr>
<tr>
<td>Parameter A2</td>
<td>$-1.6 \times 10^6$ (kPa)</td>
<td>Strain Rate Constant C</td>
<td>0.007 (none)</td>
</tr>
<tr>
<td>Parameter A3</td>
<td>$2.774 \times 10^9$ (kPa)</td>
<td>Intact Strength Constant A</td>
<td>0.88 (none)</td>
</tr>
<tr>
<td>Parameter B0</td>
<td>0 (kPa)</td>
<td>Erosion Strain</td>
<td>0.5 (none)</td>
</tr>
</tbody>
</table>

Table 3: Characteristics of foam[2]

<table>
<thead>
<tr>
<th>Equation of State</th>
<th>Linear</th>
<th>Strength</th>
<th>Crushable Foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk modulus</td>
<td>$4.166 \times 10^4$ (kPa)</td>
<td>Shear Modulus</td>
<td>$1.923 \times 10^4$ (kPa)</td>
</tr>
<tr>
<td>Reference Temperature</td>
<td>293 (K)</td>
<td>Max Tensile Stress</td>
<td>$4.79 \times 10^3$ (kPa)</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>0 (J/mKs)</td>
<td>Erosion Strain</td>
<td>1 (none)</td>
</tr>
</tbody>
</table>
3. Results and discussion

As shown in Table 6, the lowest output speed relates to the projectile with Ogivenose and highest output speed relates to the projectile with flat nose, because the flat headed projectile absorbs quite a bit of speed through passing ceramic layer. In Fig.3 we see that in each three samples, while projectile is passing through ceramic layer, the slope of velocity graph is high, and as we gradually move into the metallic region, the slope of the graph is reduced, until it reaches almost to zero in the foam region. This issue indicates that ceramic decelerates projectile and foam absorbs projectile energy.

Table 6: Numerical results

<table>
<thead>
<tr>
<th>Nose shape</th>
<th>Initial speed (m/s)</th>
<th>Output speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>hemispherical</td>
<td>854</td>
<td>506</td>
</tr>
<tr>
<td>flat</td>
<td>854</td>
<td>576</td>
</tr>
<tr>
<td>Ogive</td>
<td>854</td>
<td>500</td>
</tr>
</tbody>
</table>

As shown in figures 4 to 6, due to the penetration of projectile into the target, ceramic was destroyed as the primary layer, and failure occurred and it caused the loss of projectile head and the velocity reduced due to the hardness and high density. The projectile enters the ceramic layer in 20 microseconds and cause the ceramic to be destroyed and passes through it. The projectile passes through ceramic in 40 microseconds and changes the curvature of the aluminum layer. Then, the curvature of the back aluminum layer changes and rupture occurs in 60 microsecond.
Fig. 4: Penetration of semi-spherical projectile into the sandwich panel at different times: A) 20 microseconds, b) 40 microseconds, c) 60 microseconds.

Fig. 5: Penetration of flat projectile into the sandwich panel at different times: A) 20 microseconds, b) 40 microseconds, c) 60 microseconds.
Fig. 6: Penetration of Ogive projectile into the sandwich panel at different times: A) 20 microseconds, b) 40 microseconds, c) 60 microseconds

Full passing of projectile and sandwich panel became perforated is shown in three different nose in Figure 7. The radius of target fracture in hemispherical nose has the highest and in flat nose has the lowest value.

![Image of projectile penetration]

Fig.7: Full passing of projectile through the target a) semi-spherical b) flat c) Ogive

4. Conclusions

In this research, the penetration of steel projectile with flat, Ogiveand semi-spherical nose into the foam cored sandwich target is simulated using Autodyne software. In each model, the output speed of projectile and ballistic limit velocity is calculated and the effect of projectile nose shape on ballistic resistance of foam cored sandwich panel is studied. The results show that, firstly, in simulated models, the bulk of projectile velocity in the first ceramic layer decreases and, second, the projectile with Ajayv nose has the lowest and the projectile with flat head has the highest output speed. Thus the efficiency of flat headed projectiles compared to hemispherical and Ogiveheaded projectiles is more effective in destroying the ceramic layer. On the other hand, the target radius of destroyed cavity of hemispherical projectile has the highest and in flat nose one has the lowest value.

References


