BALLISTIC LIMIT VELOCITY IMPACT OF 40 mm CALIBER PROJECTILE ONTO HYBRID COMPOSITE ARMOR


Department of Mechanical Engineering, Velammal Institute of Technology, Chennai, India

Corresponding Author Address:
Moorthy. G
Student Department of Mechanical Engineering,
Velammal Institute of Technology,
Chennai, India.

ABSTRACT
A mathematical model to simulate the ballistic limit velocity (BLV) of bi-layer hybrid composite armour against 40mm projectile (flat ended) and it is derived by varying the thickness of constitutive plates from momentum equation during the impact process. Ceramic material (Al₂O₃ 99.7%) as front plate and Steel 4340 as backing plate are considered. The material constitutive and failure model constants are validated through comparison of simulations performed using ANSYS AUTODYN against the mathematical values. BLV data obtained from simulations are compared with results obtained from mathematical model as well as correlated.

KEYWORDS: Ballistic limit velocity, Bi-layer hybrid composite, Impact, Momentum.

INTRODUCTION:
A. C. Florence investigated the interaction of projectiles and composite armor in both theoretical and experimental way. Facing plate is of hard ceramic while backing plate of flexible fiber glass or aluminum alloy. Theory concerns restraining mechanisms of armor for ballistic limit with aid of computer for evaluating stress fields in brittle facing plate. High speed photography and flash x-ray observes the fracture conoids to demonstrate managing stress gages.

G. H. Liagh at et. al. proposed a modified analytical model for analysis for perforation of projectile into ceramic composite targets. The model utilizes a lumped mass approach for the analytical model. Various phases involved are perforations, erosion, mushrooming which are analyzed employing empirical formulae as stated by Woodward model.

Hybrid composite armors offers superior performance over RHA such armor comprises of a ceramic layer (hard and brittle) backed by a metal layer (ductile). Ceramic front plate helps in the destruction of the projectile nose, increases the area of cross section of the projectile and reduces the impact due to sintering of ceramic layer. The further backing layer serves to absorb the impact force carried by the projectile and ceramic powder, by tensile elongation of the deformed plate.

MECHANISM OF PENETRATION:
The perforation of projectile onto the armor can be depicted in three stages.
During stage I, shear waves generated travel along radial direction and up to thickness of the composite layer inducing brittle fracture and cracking of the plate. Compressive waves are experienced directly below the flat projectile face resulting in conoid formation.

Stage II begins when the impact force reaches back plate of the armor which is subjected to tensile elongation, along with the sintering of ceramic cone (when the velocity of the bullet exceeds that of the plastic wave velocity of the target, erosion of projectiles takes place) and formation of shear plug. The energy of impinging projectile is gradually lost by various mechanisms such as friction loss, heat generation, erosion of projectile tip and absorption of energy by compression of surrounding region back plate. Other losses are neglected.

During stage III, the projectile tip reaches the back face of the target and if it has residual energy (kinetic), it would completely perforate the armor, with some residual velocity after deceleration.

MATHEMATICAL MODEL:
Mathematical equation for the ballistic impact is based on momentum conservation equation and is given by:

\[ M = m * v \]
Where,
- \( M \) - Momentum
- \( m \) - Mass of the impacting object
- \( v \) - Velocity of the impacting object

On the basis of momentum conservation derived from Florence model [2], the minimum momentum that should be imposed by the projectile to penetrate the components as a whole is given by:

\[ M = \sqrt{\pi \beta_2 \alpha^2 t_2 [M_p + M_1 + M_2]} \]

\[ \beta_2 = \frac{\varepsilon_2 \sigma_2}{0.91} \]

\[ a = R_p + t_1 \tan \theta \]

Where,
- \( a \) - Radius of the conoid
- \( \beta_2 \) - Fracture energy for transverse shearing per unit area
- \( \varepsilon_2 \) - Breaking strain of the backing plate
- \( R_p \) - Radius of the projectile
- \( \theta \) - conoid angle
- \( M_p \) - Mass of the projectile
- \( M_1 \) - Mass of the ceramic impacted
- \( M_2 \) - Mass of the steel plate impacted

\[ M_1 = \frac{\pi \rho_1 t_1 [R_p^2 + a R_p + a^2]}{3} \]

\[ M_2 = \pi \rho_2 t_2 a^2 \]

\( \rho_1 \) - Density of Ceramic \( \text{kg/m}^3 \)
\[ \rho_2 - \text{Density of Steel (4340) kg/m}^3 \]
\[ t_1 - \text{Thickness of ceramic mm} \]
\[ t_2 - \text{Thickness of steel (4340) mm} \]
From the above equations ballistic limit velocity is obtained by the below equation:
\[ v_{bl} = \frac{M}{M_P^2} \]
\[ v_{bl} = \sqrt{\frac{\pi \beta_2 a^2 t_2 [M_P + M_1 + M_2]}{M_P^2}} \]

**NUMERICAL SIMULATION AND ANALYSIS:**

1. **Simulation Tools:**
   In this study ANSYS workbench has been used as pre-processing tool. The numerical simulation of non-linear impact and penetration is done by finite element of ANSYS AUTODYN. Analysis is accompanied with deformation, impact velocity, penetration and wave propagation seeking solution from the momentum equation. The energy equation is integrated with time. AUTODYN is chosen as target solver. Both the ceramic plate and backing plate are fixed.

2. **Model Development:**
   Finite element model of hybrid composite armor under normal impact is studied by flat end cylindrical projectiles onto ceramic composite target. Tungsten projectile of 40mm diameter and 100mm length is modelled. The target is Alumina (Al\(_2\)O\(_3\)) of certain thickness supported by a backing plate, steel 4340.

3. **Material Constitutive and Failure Model:**
   Components like tungsten, steel 4340, Al\(_2\)O\(_3\) (99.7\%) are defined with respective materials types of explicit materials. Correct material constant for tungsten and steel 4340 are found using Johnson-Cook (JC) strength and Failure model whereas for Al\(_2\)O\(_3\), Johnson-Holmquist failure model JH2 is used.

4. **Mesh and Boundary Condition:**
   Axis-symmetric simulations were performed on the ceramic and the steel square tiles with dimensions 200mm x 200mm. The thicknesses of both plates are varied to obtain different ballistic limit velocity. 60mm cylinder is sliced in both plates to assign different mesh sizes for sliced regions. General mesh is assigned as 0.2mm for impact zone and 0.4mm for surrounding region of the projectile impact.

5. **Determination of \(V_{50}\) in simulation:**
   The sample values from mathematical result are taken as reference values for simulation. The ballistic limit velocity was determined by increasing the speed of bullet in the order of 5 m/s until the bullet successfully reaches the back plate of the armor system.
COMPARING THE MATHEMATICAL RESULT WITH NUMERICAL SIMULATION:
Values obtained from both methods are represented in the form of graph as shown in fig. BLV values found by varying parameters such as ceramic plate thickness, backing plate thickness and compared with values obtained from simulation in AUTODYN. A close relationship between two models was found as shown in graph. The error between both the models was found to be maximum of 8%.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>TUNGSTEN ALLOY</th>
<th>STEEL 4340</th>
</tr>
</thead>
<tbody>
<tr>
<td>DENSITY (kg/m³)</td>
<td>13380</td>
<td>7830</td>
</tr>
<tr>
<td>EOS</td>
<td>SHOCK</td>
<td>LINEAR</td>
</tr>
<tr>
<td>Bulk modulus (Gpa)</td>
<td>-</td>
<td>159</td>
</tr>
<tr>
<td>Gruneisen Coefficient</td>
<td>1.34</td>
<td>-</td>
</tr>
<tr>
<td>Reference Temperature</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Parameter C1 (m/s)</td>
<td>4029</td>
<td>-</td>
</tr>
<tr>
<td>Parameter S1</td>
<td>1237</td>
<td>-</td>
</tr>
<tr>
<td>Specific Heat (J/kg/k)</td>
<td>134</td>
<td>477</td>
</tr>
<tr>
<td>STRENGTH MODEL</td>
<td>JC</td>
<td>JC</td>
</tr>
<tr>
<td>Shear modulus (Gpa)</td>
<td>160</td>
<td>77</td>
</tr>
<tr>
<td>Yield Stress A' (Gpa)</td>
<td>1.506</td>
<td>0.792</td>
</tr>
<tr>
<td>Hardening Constant (Gpa)</td>
<td>0.177</td>
<td>0.51</td>
</tr>
<tr>
<td>Hardening exponent B'</td>
<td>0.12</td>
<td>0.26</td>
</tr>
<tr>
<td>Strain rate constant C'</td>
<td>0.016</td>
<td>0.014</td>
</tr>
<tr>
<td>Reference strain rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Thermal exponent, m soften</td>
<td>1</td>
<td>1.03</td>
</tr>
<tr>
<td>Melting Temperature</td>
<td>1723</td>
<td>1793</td>
</tr>
<tr>
<td>FAILURE MODEL CRITERION</td>
<td>JC</td>
<td>JC</td>
</tr>
<tr>
<td>Damage constant, d1</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>Damage constant, d2</td>
<td>0.33</td>
<td>3.44</td>
</tr>
<tr>
<td>Damage constant, d3</td>
<td>-1.5</td>
<td>-2.12</td>
</tr>
<tr>
<td>Damage constant, d4</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

Table-1
The breaking strain for Alumina (pure) is approximated to be 0.001 due to lack of experimental data. Appropriate values may yield concordance between both models.

CONCLUSION:

Study conducted on the ballistic behaviour of hybrid composite armour yields the following results such as the characteristic exhibited by the hybrid composite armour is better than that of RHA in terms of weight reduction as ceramic possess lower areal densities in the ratio of 0.48. Ballistic limit velocity varies uniformly with increase in thickness of ceramic layer. Ballistic limit velocity varies uniformly with an increase in thickness of backing plate and starts to vary non-linearly beyond a certain velocity.

The material of the bullet possesses significant effect on ballistic performance which in turn depends upon the density and hardness of the corresponding material. For normal impact of 40mm projectile, the optimal ratio of thickness of backing plate to that of thickness of ceramic plate is found to be 0.4 above which the ballistic performance increases.

REFERENCES: