

# HIGH SPEED IMPACT ON CERAMIC PLATES

## A. PROBLEM FORMULATION

Numerical model for high speed impact of a steel projectile (NATO 5.56 x 45 mm) on Ceramic plate which is backed by an Kevlar/Epoxy plate is shown in figure 1.

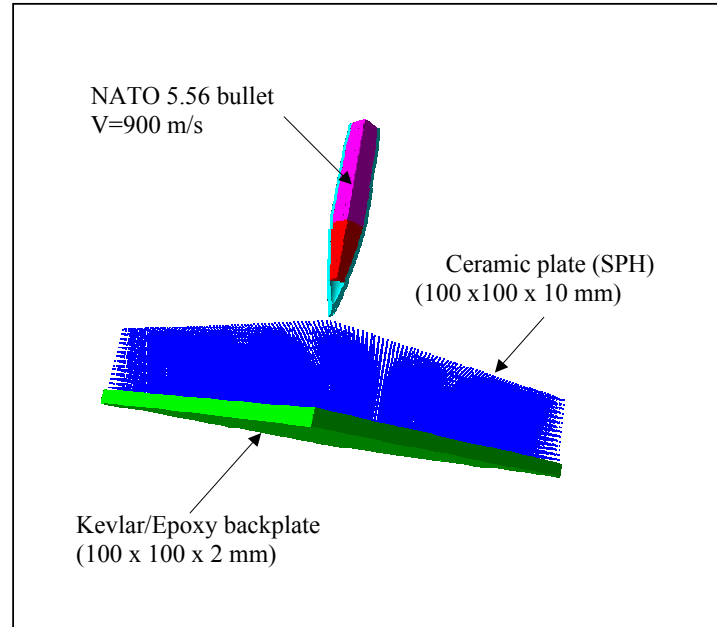


Fig. 1 Numerical model for ballistic impact on Ceramic plate

During the impact event ceramic plate undergo severe deformation. We will therefore model this region of the problem using SPH processor (Smooth Particle Hydrodynamics). The Kevlar/Epoxy backplate, and the steel projectile will model using as a Lagrange subgrid. The problem geometry is given in the above figure, the material properties of the Ceramic and Kevlar/Epoxy plates and steel projectile are shown bellow (Table1, 2, 3). The fragment simulating projectile, defined by NATO 5.56 x 45 mm, was used in the numerical simulation, to determine the V50 and the ballistic performance.

The target is a square (100x 100) Ceramic plate backed by a Kevlar-Epoxy plate, firmly clamped on the edges. The analysis starts with the impactor and the plate in contact, as illustrated in the figure 1. The resulting model, see figure 1, with two plane of symmetry, was obtained using the general purpose mesh generation program TrueGrid (see anexa 1). for model the steel impactor (see Figure 2) and the Kevlar/Epoxy plate.

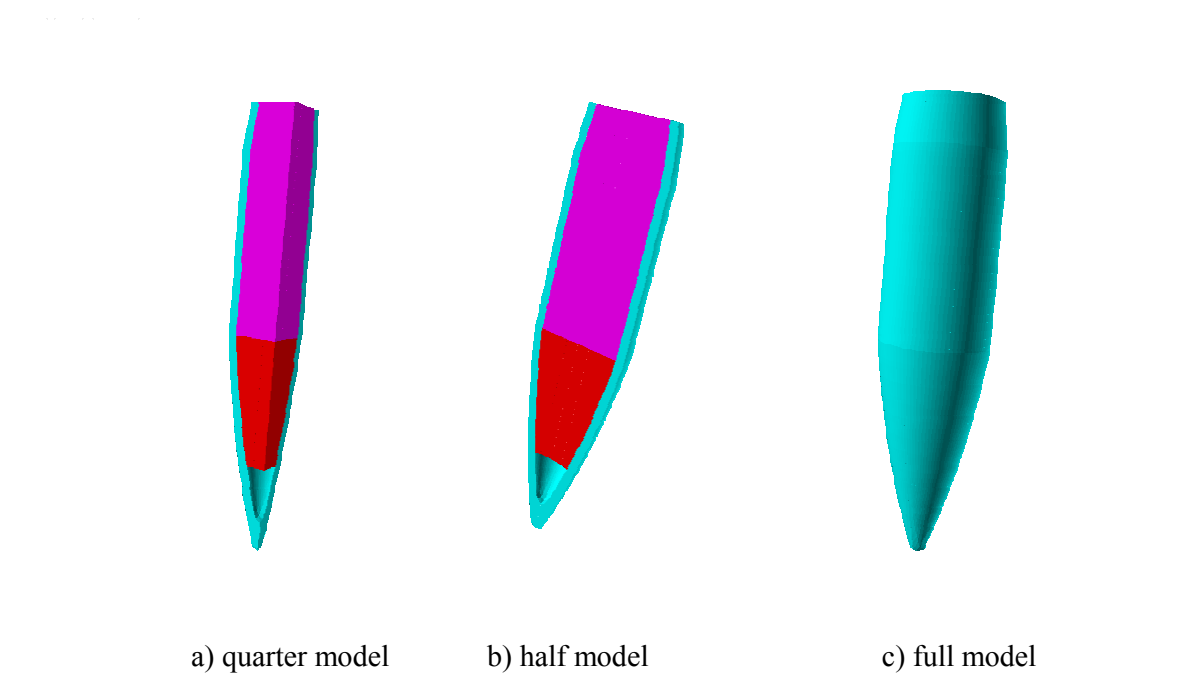


Figure 2. NATO 5.56 x 45 mm bullet

## B. Material properties

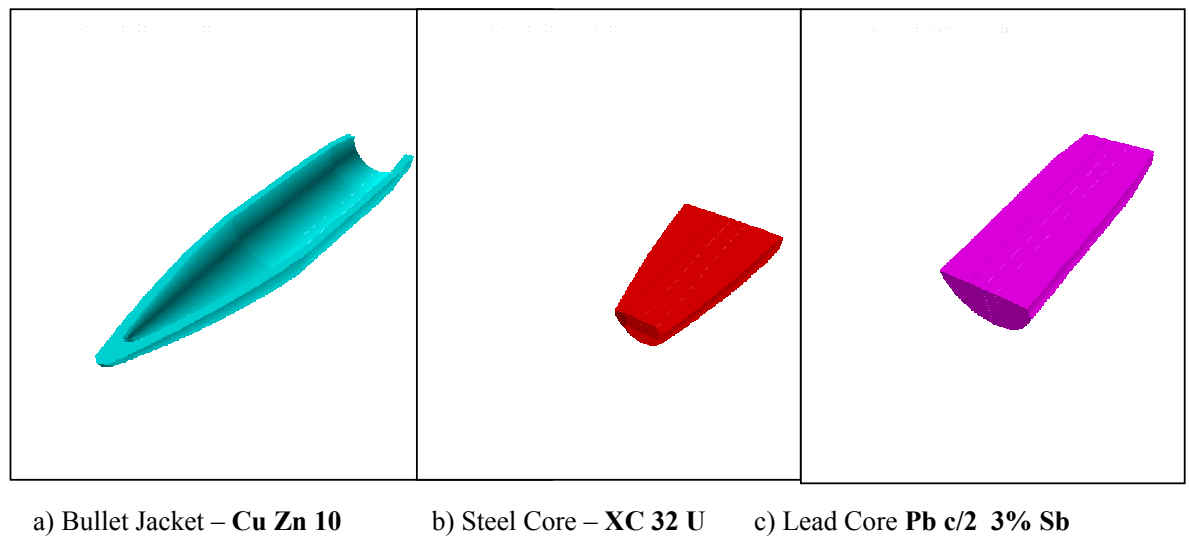


Figure 2. NATO 5.56 bullet materials

### **B.1. Material data for steel impactor**

For bullet jacket, steel core and lead core the following material constants:

#### **Elastic constants**

- Reference density  $\rho(\text{g/cm}^3)$
- Young modulus of Elasticity-E (kPa) or Poison's ratio  $\nu$ .
- Shear Modulus G (kPa)

#### **Nonlinear properties**

- Yield stress
- Strain rate constant
- Hardening exponent
- Melting temperature

### **B.2. Material data for Ceramic plate**

#### **1. Elastic Constants**

- Reference density  $\rho(\text{g/cm}^3)$
- Young modulus of Elasticity-E (kPa) or Poison's ratio  $\nu$ .  
Relation between Young modulus of elasticity (E), Poison's ratio ( $\nu$ ) and Bulk Modulus K(kPa) is:

$$K = \frac{E}{3 \cdot (1 - 2 \cdot \nu)}$$

- Shear Modulus G (kPa)

#### **2. Nonlinear properties (Yield stress-Pressure)**

The strength model that is properly to model the ceramic nonlinear behavior is Mohr-Coulomb model. This is modeled in AUTODYN by a piecewise linear variation of yield stress with pressure (see below figure) up to a value  $Y_{\max}$ . With the introduction of version 4, the Mohr-Coulomb strength model has been modified to allow any number of pressure-yield points, up to a maximum of 10, to define the material strength curve. In tension (negative values of p) such materials have little tensile strength and this is modeled by dropping the curve for Y(p) rapidly to zero as p goes negative to give a realistic value for the limiting tensile strength

**Table 1. Material Data**

<b>Ceramic-Gceramic (Autodyn material libraries)</b>	
Equation of states : <i>Linear</i>	<b>Strength Model: Mohr-Coulomb</b>
Reference density (g/cm <sup>3</sup> ) <b>3.43</b>	Pressure #1(kPa) <b>-5.00E5</b>
Bulk modulus (kPa) <b>1.54E8</b>	Pressure #2(kPa) <b>0.00</b>
Strength : <i>Mohr-Coulomb</i>	Pressure #3(kPa) <b>1.01E20</b>
Shear modulus (kPa) <b>8.30E7</b>	Pressure #4(kPa) <b>1.01E20</b>
Failure : <i>Cumulative Damage</i>	Yield Stress #1 (kPa) <b>0.00</b>
Reference Temperature (K) <b>300</b>	Yield Stress #2 (kPa) <b>3.80E6</b>
	Yield Stress #3 (kPa) <b>3.80E6</b>
	Yield Stress #4 (kPa) <b>3.80E6</b>
	<b>Failure: Cumulative Damage</b>
	Eff. Pl. Strain at Zero Damage: <b>0.01</b>
	Eff. Pl. Strain at Max. Damage: <b>0.03</b>
	Maximum Damage: <b>0.7</b>
<b>Steel 4340 (Autodyn material libraries)</b>	
Equation of States : <i>Linear</i>	Yield Stress (kPa) <b>7.92E+05</b>
Reference density (g/cm <sup>3</sup> ) <b>7.83</b>	Hardening constant (kPa) <b>5.10E+05</b>
Bulk modulus (kPa) <b>1.59E+07</b>	Hardening exponent <b>0.34</b>
Reference temperature (K) <b>300</b>	Strain rate constant <b>0.014</b>
Specific heat capacity (J/kgK) <b>477</b>	Thermal softening exponent <b>1.03</b>
Strength : <i>Johnson-Cook</i>	Melting temperature (K) <b>1793</b>
Shear modulus (kPa) <b>8.18E+07</b>	Failure model : <i>None</i>
<b>KEVLAR/EPOXY</b>	
Equation of states : <i>Orthotropic</i>	Tensile failure Stress 11 (kPa) <b>5.00E+04</b>
Sub-Equation of States : <i>Polynomial</i>	Maximum Shear Stress 12 (kPa) <b>1.00E+05</b>
Reference density (g/cm <sup>3</sup> ) <b>1.40</b>	Tensile Failure Strain 11 <b>0.01</b>
Young modulus 11 (kPa) <b>2.392E+05</b>	Tensile Failure Strain 22 <b>0.08</b>
Young modulus 22 (kPa) <b>6.311E+06</b>	Tensile Failure Strain 33 <b>0.08</b>
Young modulus 33 (kPa) <b>6.311E+06</b>	Post Failure Response <i>Orthotropic</i>
Poissons ratio 12 <b>0.115</b>	Fail 11 & 11 Only
Poissons ratio 23 <b>0.216</b>	Fail 22 & 22 Only
Poissons ratio 31 <b>3.034</b>	Fail 33 & 33 Only
Strength : <i>Elastic</i>	Fail 12 & 12 and 11 Only
Shear modulus (kPa) <b>1.54E+06</b>	Fail 23 & 23 and 11 Only
Failure : <i>Material Stress/Strain</i>	Fail 31 & 31 and 11 Only
	Residual shear Stiff. Frac. <b>0.20</b>

### C. NUMERICAL SIMULATION

Simulations of high velocity impact on the ceramic plate backed with Kevlar/Epoxy have been conducted using Autodyn-3D at 900 m/s. The Mohr-Coulomb strength model combined with cumulative damage model to represent the progressive crushing of the ceramic are used in the current study. Since compressive strength usually increases with increased hydrostatic pressure, yield stress is modelled by a piecewise linear variation with pressure (see table1).

In the simulations, the cumulative damage model with smoothed particle hydrodynamics (SPH) was used for the ceramic plate. A particle size of 0.5 mm was used and resulted in 20 SPH particles being placed inside the plate in the normal direction. The projectile and Kevlar/Epoxy backplate is modelled using Lagrange finite elements.

Figure 3 shows the simulated penetration process of the system by a steel projectile (4340 steel-bullet jacket, 1006 steel core and 2024T351 steel for lead core). The initial impact velocity is 900 m/s. Material location and material status during the impact is shown in the figure 3 and 4 respectively.

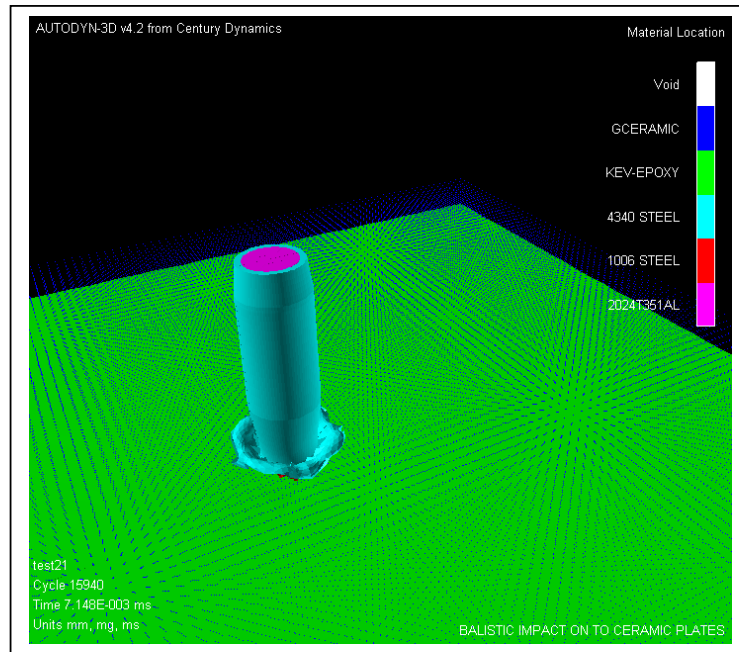


Figure 3. Material location

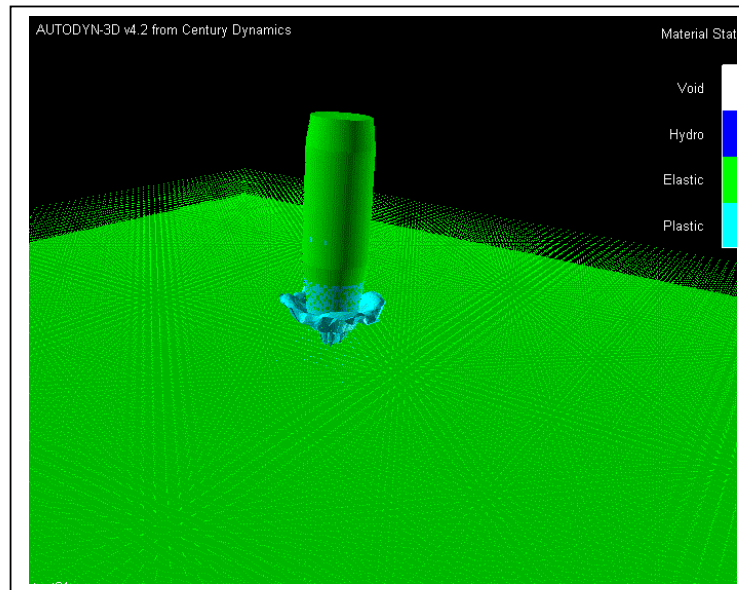


Figure 4. Material status