SIMULATIONS OF THE PENETRATION OF 6061-T6511 ALUMINUM ALLOY TARGETS BY SEMI SPHERICAL-NOSED RIGID PROJECTILES

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ABSTRACT

An axisymmetric simulation model for penetration of rigid body to 6061-T6511 aluminum targets has been developed subjected to various impact velocities between 490m/s and 1000m/s. In this model, penetration resistance pressure of the target structure is provided by functions derived from principles of dynamic cavity expansion has been applied in front of projectile nose for replacing target structure. Final penetration depth results were then compared with experimental data. It's shown that an axisymmetric simulation model is encouraging for prediction.

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1. Introduction

Traditionally, penetration modeling in numerical simulation usually used the fully coupled analysis, i.e, both projectile and target are discrete in computational code. However, there are weaknesses in the fully coupled analysis simulation, which certain categories have to be considering in order to performing simulation analysis, i.e., failure criterion [Anderson and Bodner (1988)], contact problem [Li et. al. (2004)], mesh distortion for the large deformation [Chen (1990,1995), Peric et al. (1996, 1999)] and reliable material model [Li et. al. (2004)].

Since the deformation and kinetics of projectile influences the trajectory of projectile. Warren and Tabbara (2000) developed alternative approach for predicting projectile's trajectory, which it is so call "uncoupled analysis". In their approach, target structures are modeled by arbitrary layers of materials and the projectile is modeled by standard finite elements. The interaction between projectile and target model is made by applying resistances loads (provided from dynamic cavity function) to the elements on the outer surface of the projectile mesh, as shown in Figure 1.

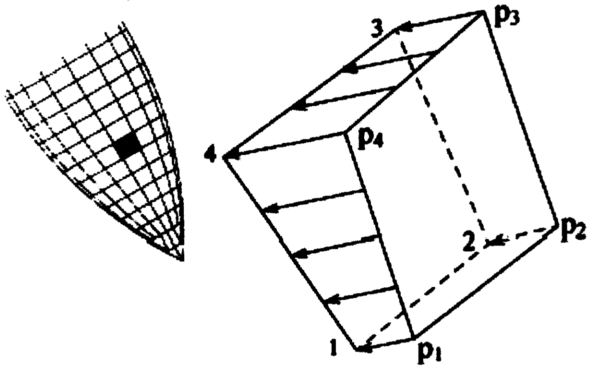

Figure 0 : Definition of a pressure boundary condition that acts on an element side [Warren and Tabbara (2000)]

In this paper the concepts implemented by Warren and Tabbara (2000) is applied in the ABAQUS finite element code for modeling penetration event. Simulation model is validated by comparing final penetration depth with experimental data obtained by Forrestal et. al.(2000). In Forrestal et. al.(2000) experiments, 0.023 kg weight, 7.11-mm-diameter, 74.7-mm-long, spherical-nose, VAR 4340 steel projectiles were launched into 250-mm-diameter, 6061-T6511 aluminum targets which were thick enough so the projectile would not perforate the target. The projectile strikes the target at the normal incidence. For validation purpose, the target materials and the dimensions of the projectile in experimental used in the following numerical simulation, as shown in Table 1 and Figure 2.

Table 1 : Material properties [Forrestal et. al.(2000)]

	Material	Y (Mpa)	A	B	$\rho(Kg/m^3)$	ν
Projectile	Rigid	-	-	-	-	-
Target	Al Alloy	276	5.0394	0.9830	2710	1/3

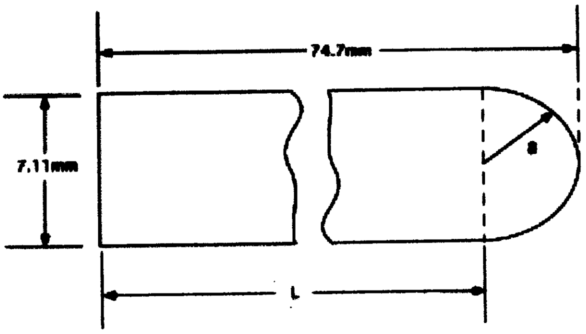

Figure 2 : Projectile geometry [Forrestal et. al.(2000)]

2. Numerical Simulation Model

In this method, there is no need to discrete target structures. The target is replaced by a resistance pressure applied on the surface of the projectile. The projectile is modeled by standard finite element using ABAQUS 6.3 software and treated as a discrete rigid body with element type RAX2. Penetration resistances of the target are influenced by the material properties of the target and the kinematics of projectile. The resistance loads which is provided by sub routine program (using FORTRAN 95), then applied to the elements of surface projectile contact as shows in Figure 3.

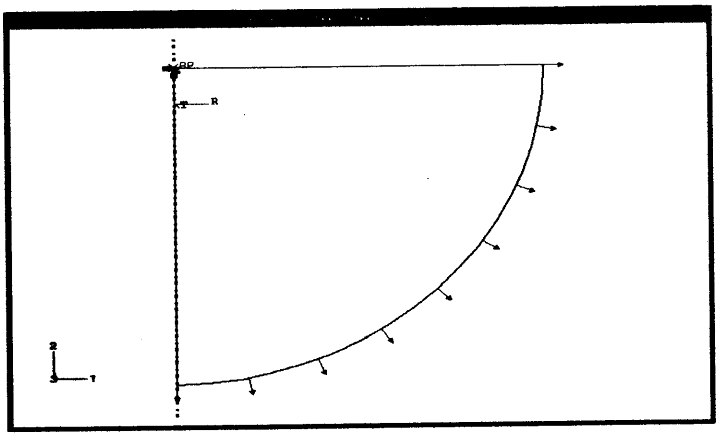

Figure 3 : Resistance pressure applied to semi spherical projectile.

A function derived from principles of dynamic cavity expansion has been applied in sub routine program as a resistance pressure for projectile. The dynamic cavity expansion yields the following relation between the normal compressive stress σ_n on the projectile nose and the normal expansion velocity V_n [Chen and Li (2002)]:

$$\sigma_n = AY + B\rho V_n^2 \qquad [1.0]$$

Where by Y and ρ are yielding stress and density of target material, correspondingly. A and B are dimensionless material constants. Those values were shown in Table 1.

2.1 Basic Explicit Dynamic Finite Element Algorithm

The explicit dynamics analysis procedure is based upon the implementation of an explicit integration rule together with the use of diagonal or "lumped" element mass matrices. The equations of motion for the body (projectile) are integrated using the explicit central difference integration rule.

$$V^{(i+1/2)} = V^{(i-1/2)} + [(\Delta t^{(i+1)} + \Delta t^{(i)})/2]a^{(i)} \qquad [1.1]$$

$$U^{(i+1)} = U^{(i)} + \Delta t^{(i+1)} V^{(i+1/2)} \qquad [1.2]$$

where U is displacement, V is velocity and a is acceleration. The superscript (i) refers to the increment number and $(i-1/2)$ and $(i+1/2)$ refer to midincrement values. The central difference integration operator is explicit in that the kinematic state can be advanced using known values of $V^{(i-1/2)}$ and $a^{(i)}$ from previous increment. The computational efficiency of the explicit procedure is depend on using the diagonal element mass matrices because of the inversion of the mass matrix that is used in the computation for the accelerations at the beginning of the increment is triaxial ;

$$a^{(i)} = M^{-1} \Delta F \qquad [1.3]$$

where are;

$$\Delta F = \left(F^{(i)} - I^{(i)}\right) \qquad [1.4]$$

$$\left(F^{(i)} - I^{(i)}\right) = \frac{\sigma^{(i)}}{Area} \qquad [1.5]$$

M is the diagonal lumped mass matrix, A is the front nose's projectile surface, F is the applied force vector, I is the internal force vector and $\sigma^{(i)}$ is determined by constitutive equation (Equation [1.0]).

3. Results

In this section, results from simulations model are compared with experimental data [Forrestal et. al (2000)].

Table 0-1 : Comparison penetration depth data of Aluminum Alloy 6061-T6511.

Velocity (m/s)	Experimental (mm)	Simulation (mm)
496	37.6	41.9
572	48.1	52.8
781	72.7	83.9
821	84.3	89.9

841	91.4	92.9
932	96.5	106.2
967	94.4	111.3

4. Discussion and conclusions

Tables in results section summaries the final penetration depths of projectiles obtained from simulation models and compared with experimental data by Forrestal et al.(2000). Because of there was no angle of obliquity (i.e. velocity vector normal to the target), the projectile model in simulations are constrained in the x and z directions allowing it to move only in the y direction. The simulation's prediction shows encouraging predictions.

5. References

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