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Numerical evaluation of the behavior of a plate on impact with a rigid projectile using Smoothed-Particle Hydrodynamics method

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Abstract. Modern materials strength calculations, even if applied to classical problems of the theory of elasticity or plasticity, cannot be conceived without the use of numerical calculation methods and material models. This situation is a direct consequence of the progress made in the field of computers, both in the field of hardware and software. This article presents the numerical evaluation of the behavior of a plate on impact with a rigid projectile using Smoothed-Particle Hydrodynamics method and is shown the evolution of the impact with its effects (deformation with perforation of the plate). Also, an analize of the variation of the kinetic energy of the bullet and bullet velocity over time are presented.

1. Introduction

Modern materials strength calculations, even if applied to classical problems of the theory of elasticity or plasticity, cannot be conceived without the use of numerical calculation methods and material models. This situation is a direct consequence of the progress made in the field of computers, both in the field of hardware and software.

The inquisitive mind of man, the desire for the new, the desire to have a means of calculation dedicated to a certain analysis and others, considered together or individually, in order to bring reality closer to the description of phenomena, have led to the emergence of new methods of numerical analysis and simulation, known as meshfree particle method or particle-based methods. [1]

The SPH method is a relatively new method, used for the approximate integration of partial differential equations. It is also a meshless method, in a Lagrangian approach, which uses pseudoparticles (attached in nodes), on the basis of which an interpolation method is defined for the calculation of smoothed field variables.[2]

It is generally known that the formulation and application of a numerical method is difficult to achieve without a network (discretization). The mathematical formulation of the SPH method offers the solution to ensure the numerical stability of the solution for problems (equations) with Neumann type boundary conditions, in the conditions of an irregular distribution of nodes (particles) on the respective domain.

In the use of the SPH method, the state of the system is considered to be represented by a set of particles (placed in nodes), with individual material properties and which move according to the conservation equations to which they are subjected. Each particle is characterized by field variables, which can be mass (m), density (ρ), pressure (p), position (r), velocity (v), acceleration (a), temperature (T), and so on [3].

2. Fundamentals of the SPH method

The SPH method is a meshless method, which means that the examined domain is represented by a number of nodes that represent the domain's particles and their material properties. Each particle is an interpolation point for which the material properties have been determined [4].

The computed results on all the particles, using an interpolation function, provide the solution to the problem. The principles of SPH theory can be summarized as interpolation theory, in which all behavior laws are translated into integral equations [4]. The kernel function approximates the field variable (function) in a point with a weighted approximation (particle). The connection can thus be used to estimate a function *A(r)*:

$$A(r) = \int A(r')W(r - r', h)dr' \tag{1}$$

where the function $W(r - r', h)dr'$ is the kernel function, which has two main properties:

$$\text{a) } \int W(r - r', h)dr' = 1 \tag{2}$$

$$\text{b) } \lim_{h->0} W(r - r', h) = \delta(r - r') \tag{3}$$

δ is the Dirac delta function and h is the smoothing length. Figure 1[4] shows an intuitive illustration of this parameter.

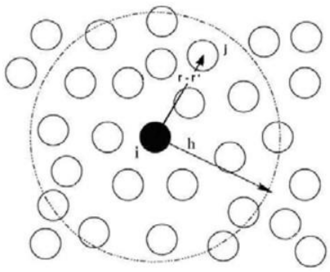
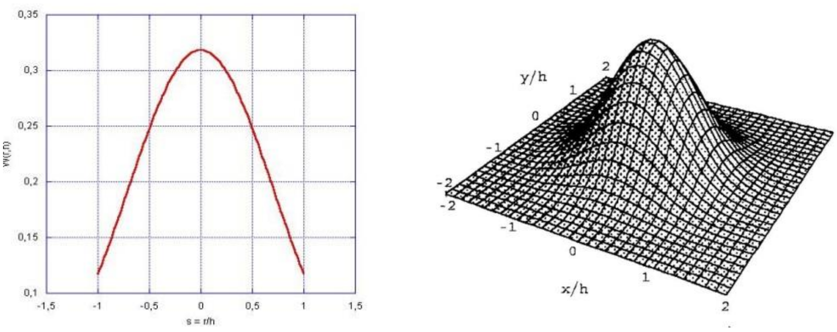


Figure 1. The smoothing lengh h

A domain comprising particles in interaction with particle i is defined by the smoothing length. Figures 2-a)[4] and 2-b)[4] show the smoothing function W(r,h) = W(r/h).



a) b)

Figure 2. Grafical representation of Kernel function

Different kernel functions, such as Gaussian, polynomial, and spline can be utilized. The cubic B-spline function is the most commonly utilized. The following is an example of such a function:

$$\text{a) } W(r,h) = \frac{\sigma}{h^n}\begin{cases}\left(1-\frac{3}{2}s^2+\frac{3}{4}s^3\right), & 0 \le s \le 1 \\ \frac{1}{4}(2-s)^3, & 1 \le s \le 2 \\ 0, & s > 2\end{cases} \tag{4}$$

where $s = r/h$, n is the number representing the spatial dimension (1, 2 or 3) and σ is a constant which can have the value: *2/3, 10/7π* or *1/π,* depending on the space with one, two or three dimensions. In fact, the kernel function is a delta or Dirac function with some specific requirements.

3. Materials and methods

The purpose of this paper is to evaluate the performance of an aluminum plate on impact with a 7.62 mm rigid projectile using Smoothed-Particle Hydrodynamics method. A normal impact was considered, with an impact velocity of 500 m/s and the analyses time of $9*10^{-5}$ seconds.

Numerical simulations were carried out using the LS-DYNA software [5].

For the theoretical study, the aluminum homogeneous and isotropic plate, presented in Figure 3, has the following characteristics:

- Density: $\rho = 2710$ [kg/m^3]
- Young's modulus: $E = 0.690*10^{11}$ [Pa]
- Poisson's ratio: $\upsilon = 0.33$
- Yield stress: $\sigma_c = 315e6$ [Pa]
- Dimensions: 0.1 m x 0.1 m x 0.005 m
- Node number = 50000
- Element number (SOLID164) = 50000
- Inter-nodal distance = 0.001 [m]

The material model used for the plate was plastic kinematic hardening and a rigid material was considered for the bullet. From my own experience, the plastic kinematic hardening material model describes very well the behavior of Aluminum plate and I trust the material constants (the Cowper Symonds coefficients). Using thin plates, high impact velocity, short execution time and unreliable thermal effect, this material model is the most suitable in our case.

The interest was focused on the plate, that's why it was considered a rigid material for the bullet. The using of these assumptions covers the calculation results and save computer time.

The plate was simulated by Smoothed-Particle Hydrodynamics method and the nodes belonging to the four sides have all degrees of freedom blocked (DOF=0).

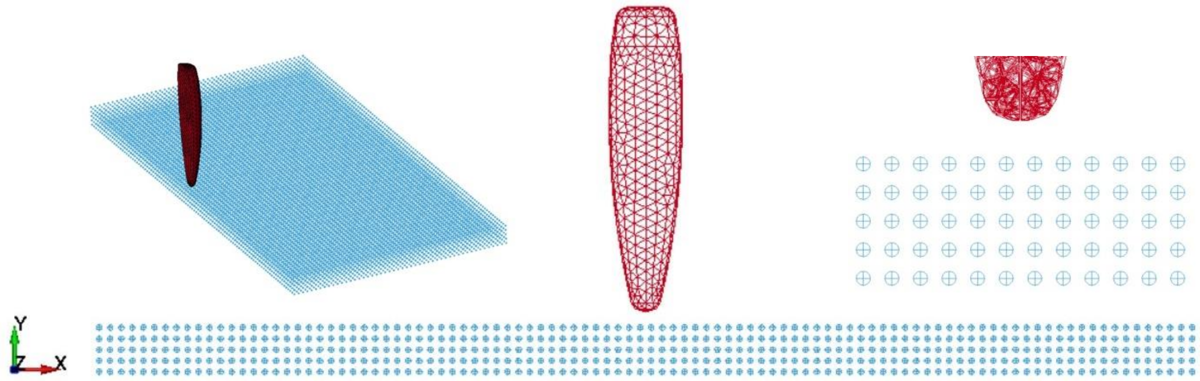


Figure 3. Smoothed-Particle Hydrodynamics model

The characteristics of the bullet, presented in Figure 4, are the following:

- Caliber = 7.62 [mm]
- Density: ρ = 7850 [kg/m^3]
- Impact velocity = 500 [m/s]
- Volume = 6,8587e-7 [m^3]
- Mass = 0.00538 [kg]
- Element number (SOLID168) = 3860
- Node number = 6046
- Average element finit dimension = 0.001 [m]

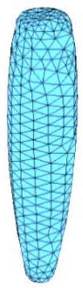
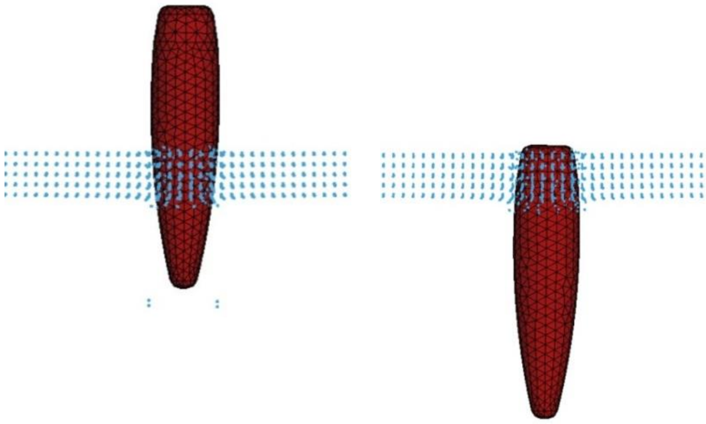


Figure 4. Model of the bullet

4. Numerical simulation

In Figure 5 can be observed the phenomenon of penetration of the aluminum plate, but also the phenomenon of yielding the material by fragmentation and displacement of particles both in the direction of perforation and in the opposite direction.

t = 10 μs *t = 20 μs*



t = 30 µs *t = 60 µs*

Figure 5. Time evolution of the impact

From the analysis of the field of von Mises equivalent stresses or of the pressure on the impact direction from Figure 6, it can be seen both the strong local character of the impact and the symmetry of the stresses that appear on the plate.

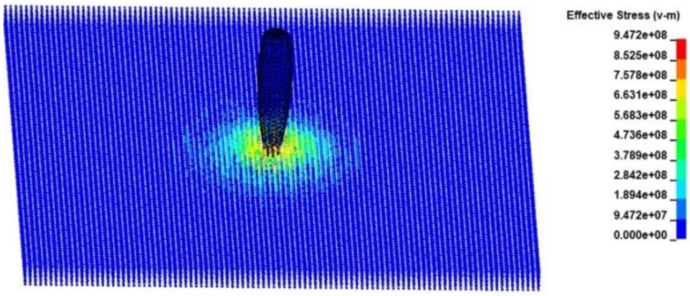


Figure 6. von Mises equivalent stresses over time

From the graphical representation of the bullet kinetic energy variation, presented in Figure 7, results a variation between the limits of 543-673 Nm, meaning that there is a falling of the kinetic energy of the bullet by 19%. At time t = 60 µs, the total energy of the bullet enters a level, which means the completion of the perforating process, the bullet following a constant velocity, without encountering resistance.

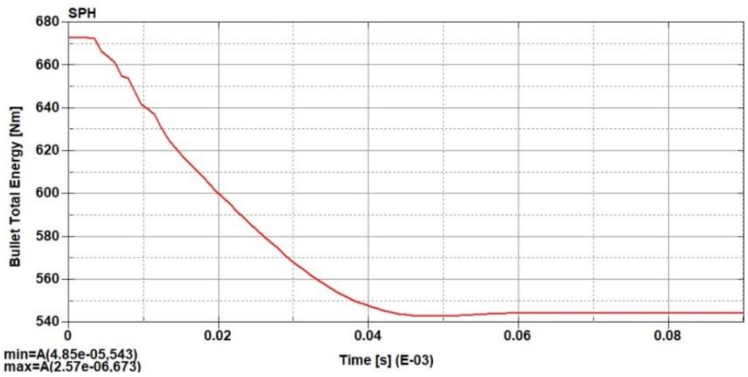


Figure 7. Time evolution of the bullet total energy

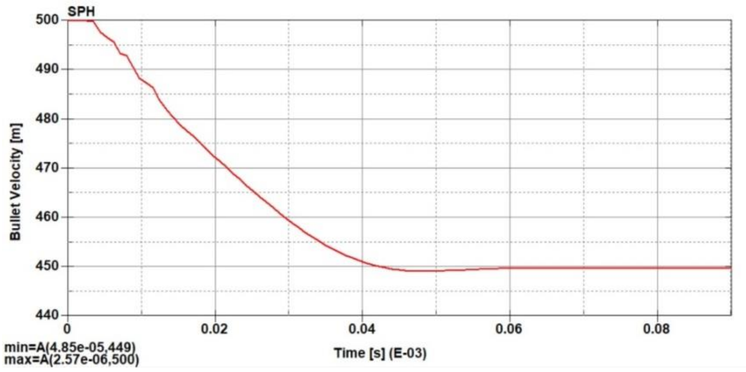
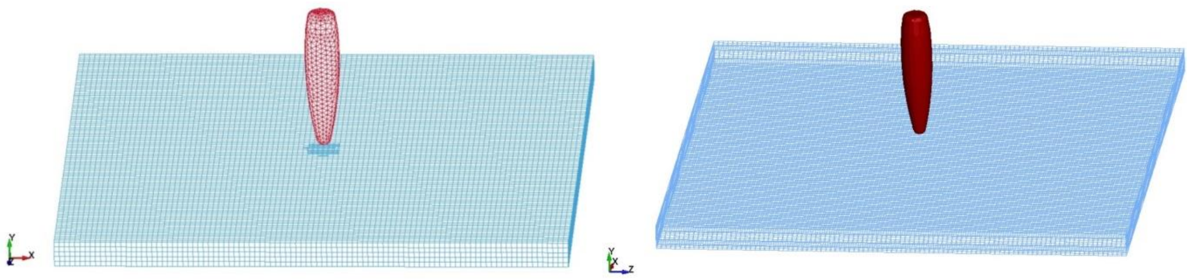


Figure 8. Time evolution of the bullet velocity

Figure 8 shows the time variation of the bullet velocity during the penetration and perforation processes and it is observed that the bullet velocity is reduced from the initial value of 500 m/s to the minimum value of 449 m/s, then he enters a bearing, which means the completion of the perforation process, which follows a constant speed of 450 m/s, without encountering resistance.

5. Results and discussions

This paper is part of a large and complex study in which was analyzed the impact between a rigid projectile and a homogeneous and isotropic aluminum plate, measuring 100 x 100 x 5 mm, with a bullet velocity of 500 m/s.



a) b)

Figure 9. Finite Element model and Element Free Galerkin model

This impact was simulated by Finite Element method (Figure 9, a), by Element Free Galerkin method (Figure 9, b) and by Smoothed-Particle Hydrodynamics method (Figure 3), and the results obtained by these three methods were compared in Table 1. During the study, were used the same boundary conditions, the same material properties and the same bullet velocity.

The Element-Free Galerkin (EFG) method is a very promising method for the treatment of partial differential equations. Because of the absence of element connectivity, nodal points can be added easily to the part of the domain where the solution is (expected to be) steep. This makes the EFG method more flexible than the Finite Element method. The method looks very promising for computations in fracture mechanics, since nodal points can be arranged around crack tips in order to obtain accurate stress intensity factors [6].

Table 1. Comparison between three numerical methods

	SPH	MEF	EFG	Error EFG/MEF	Error SPH/MEF
Plate total energy [Nm]	10.9	9.89	10.5	6.17%	9.27%
Bullet total energy - max [Nm]	673	673	673	0.00%	0.00%
Bullet total energy - min [Nm]	543	604	594	-1.66%	-8.59%
Bullet velocity - min [m/s]	449	474	470	-0.84%	-4.47%
Bullet residual velocity [m/s]	450	476	470	-1.26%	-4.26%
processing time [s]	20	76	233		

It can be seen that the values obtained are close and the errors are relatively small, below 10%, which is a very good match of the values obtained, implicitly a proper analysis

6. Conclusions

A numerical analysis of the ballistic performance of an aluminum plate on impact with 7.62 mm projectile was conducted, using the SPH method, for the bullet velocity of 500 m/s.

The results obtained by SPH method were compared with the results obtained in the numerical simulation of the same impact, analyzed with the Finite Element method and the Element Free Galerkin method and the errors are slightly lower, below 10%, this representing a very good concordance of the values obtained, implicitly an appropriate analysis.

References

[1] Năstăsescu, V., Bârsan, G., Metoda SPH (Smoothed Particle Hydrodynamics) Editura Academiei Forţelor Terestre „Nicolae Bălcescu“, Sibiu, 2012;

[2] *Năstăsescu, V.,* FEM or SPH ?, Journal of Engineering Sciences and Innovation**,** Technical Science Academy of Romania, Vol. I, Issue 1/2016, pag. 34-48;

[3] *Năstăsescu, V., Bârsan, G.,* Metoda particulelor libere în analiza numerică a mediilor continue, Editura AGIR, Bucureşti, 2015;

[4] *Năstăsescu, V.,* SPH method in applied mechanics, U.P.B. Sci. Bull., Series D, Vol. 72, Iss. 4, 2010;

[5] LS-DYNA Keyword User's Manual, Vol. I, Livermore Software Technology Corporation, May 2007;

[6] *D. Hegen,* Element-free Galerkin methods in combination with finite element approaches, Comput. Methods Appl. Mech. Engrg. 135 (1996) 143-166;

[7] *Hadăr, A.,* Structuri din compozite stratificate, Editura Academiei şi Editura AGIR, Bucureşti, 2002;

[8] *Hadăr, A., Marin, C., Petre, C., Voicu, A.,* Metode numerice în inginerie, Editura Politehnica Press, București, 2005;

[9] *Hou, W., Zhu, F., Lu, G., Fang, D-N.,* Ballistic impact experiments of metallic sandwich panels with aluminium foam core. Int J Impact Eng 2010;37:1045–55;