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USING SIMULATION FOR COMPARING THE RESPONSE OF MATERIALS IN TERMINAL BALLISTICS

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ABSTRACT

This paper presents a simulation of a bullet impact on a plate, the materials being assigned to a bilinear isotropic hardening model, with a constant equivalent plastic strain for each involved material. The model takes into account the yield and fracture limits of both involved materials for the bullet and the plate one. The projectile has the dimensions of a 9 mm FMJ (full metal jacket). The model was developed with the help of Ansys 14.5. The authors presented the influence of the properties the plate is made of (steel or aluminium alloy). Also, they established a correlation between the evolution of the theoretical maximum von Mises stresses and the stages taking place during the impact. [1]

Keywords: Ballistic impact, model, bilinear isotropic hardening model, constant equivalent plastic strain

INTRODUCTION

The resistance of a target when been impacted by a projectile is a topic of interest in several important fields of human activity (military, aerospace, civil and nuclear applications) [1, 3, 4, 6, 17, 25].

Hamouda and Risby affirmed that the problem has not yet been fully understood or solved. Ballistic experiments are crucial to further understand the complexity of penetration mechanics in order to identify key parameters involved in the perforation and damage processes of armor materials. Numerical methods are based on finite element or finite difference codes. Since the relations governing the impact of solids are non-linear, numerical analysis of penetration mechanics allows a more accurate representation of the material response and a more realistic simulation of the process. The main advantage of

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this approach is the provided information, which enables a better understanding of the process and it is valuable for designing materials for protection against impact [4, 9].

Jankowiak, Rusinek and Wood [14] reported a simulation where parameters are varied in order to rank several steel grades. The simplified approach of the system involved in this study need further improved models because the projectile made of steel is described as rigid, a too simplified approach in the numerical simulation in order to obtain similarities with actual cases. The paper analyzes the perforation process of a steel target using a conical projectile over a wide range of impact velocities. Much of the work in this study is focused on the use of mild steel. To simulate the process of perforation and dynamic failure, a failure strain, which is constant, has been assumed for numerical analyses, and which is independent of strain rate and temperature in the range of interest. Rusinek et al. [19, 20] and Larour et al. [16] used a failure strain for a mild steel grade and to define the failure process, an element erosion method has been used. Thus, when the local equivalent strain reaches a failure strain level imposed by the user, the element is deleted from the analysis. A large value for failure strain will avoid disturbances that are related to plasticity during the perforation process, so that instability (mainly necking for thin sheet steel) may grow freely leading to full perforation of the projectile through the target [19, 25]. The effect of the element size (mesh density) in the target was investigated using the Johnson-Cook [15] model and an initial velocity of 300 m/s [4]. The numerical results appear relatively insensitive to mesh density for two levels of mesh refinement, with characteristic element lengths of 0.25 mm and 0.5 mm; this may be explained in the viscoplastic approach, which enhances regularization [25].

THE MODEL

This is a Lagrangian formulation and the authors considered it as being an appropriate approach for the impact of solid bodies since the surfaces of the bodies will always coincide with the discretization and are, therefore, well defined. The disadvantage is that the numerical mesh can become severely compressed and distorted in some problems, having an adverse effect on the integration time step and accuracy. These problems can be overcome, to a certain extent, through the use of eroding sliding interface and rezoning [4].

The model was developed with the help of ANSYS 14.5. The projectile and target plate configurations are given in Fig. 1. All cases are run for the projectile velocity of 400 m/s before the impact.

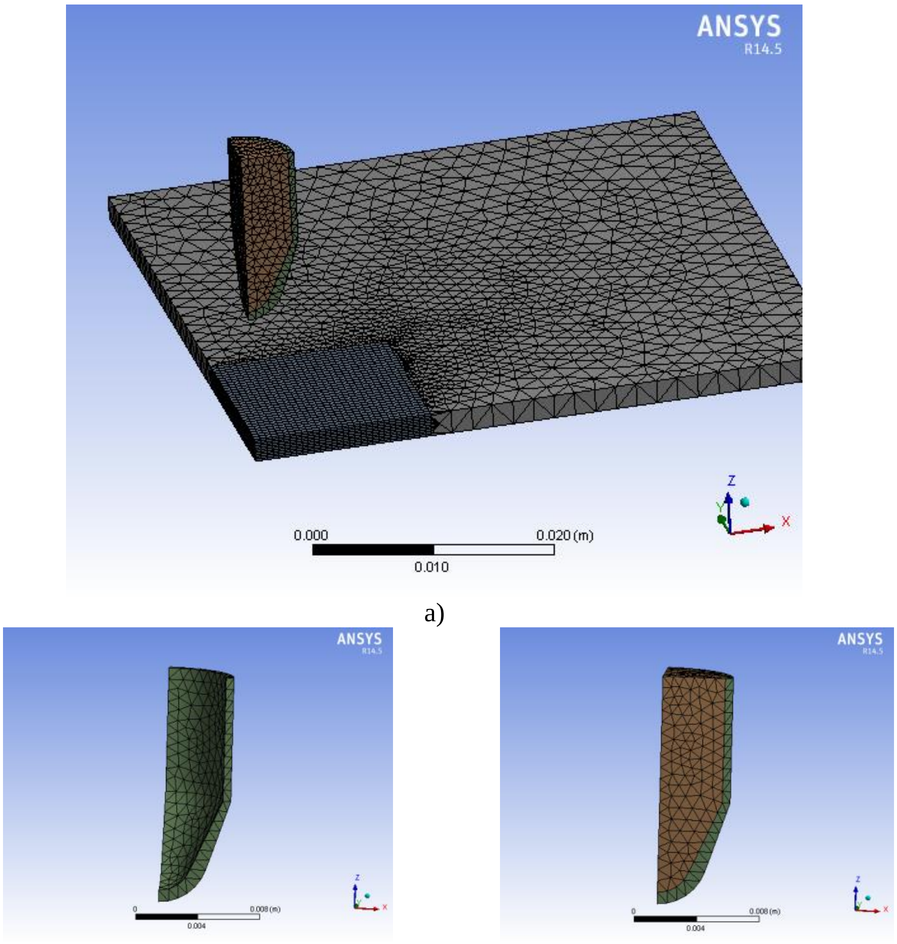
The projectile is considered as a two-material system, a jacket made of copper and a core made of lead. The properties of these materials are listed in Table 1.

Table 1. Material properties

Property	Materials			
	Plate		Bullet	
	Aluminium alloy	Steel NL	Copper Alloy NL (bullet jacket)	Lead (bullet core)
Density, kg.m^{-3}	2270	7850	8300	11340
Young modulus, Pa	7.1×10^{10}	2.0×10^{11}	1.1×10^{11}	1.6×10^{10}
Poisson ratio	0.33	0.3	0.34	0.44
Yield stress, Pa	2.8×10^{8}	2.5×10^{8}	2.8×10^{8}	3.0×10^{7}
Tangent modulus, Pa	5.0×10^{8}	1.45×10^{9}	1.15×10^{9}	1.1×10^{8}
Bulk modulus, Pa	6.96×10^{10}	1.6667×10^{11}	1.14×10^{11}	4.44×10^{10}
Shear modulus, Pa	2.6692×10^{10}	7.6923×10^{10}	4.1045×10^{10}	5.5×10^{10}
Equavalent plastic strain	0.75	0.60	0.75	0.75

The plate was virtually divided into two zones, the central zone and the peripheral one (Fig. 1a). The central zone has a finer mesh and the other one has tetrahedrons of larger size as the effect of penetration is concentrated in the central zone, as also reported by [1, 4, 6].

The plate has 13,915 nodes and 23,639 elements (including both peripheral and central zones) and the bullet has 970 nodes and 4,212 elements (Fig. 1b and c). The type of the connection between the jacket and the core of the bullet is "perfectly bonded". This model is isothermal and all cases were run for a temperature of 22ºC. The simulation was done for the elasto-plastic field.



a)

b) c)

Fig. 1. Mesh of the bodies involved in the impact: a) the system bullet-plate, b) the bullet jacket, c) the bullet core

The mesh of the bullet is an unstructured grid (or irregular) with tetrahedron element. Same grid was used for the peripheral zone of the plate. The central zone of the plate has a mesh with regular grid, the element being parallelepipedic, thus, the authors obtained a finer mesh of the zone of interest.

Taking into account the discussions in [7, 8, 10-13, 21, 24, 25], the authors considered that the central zone of the plate as being descretized using a unit square element and keeping a very similar size of elements in this zone, even if the thickness is varied (a cell hight in the central zone of 0.5 mm). The behaviour of steel is widely reported in the literature to include the effect of different loading paths, initial strain rates and temperatures [2, 5].

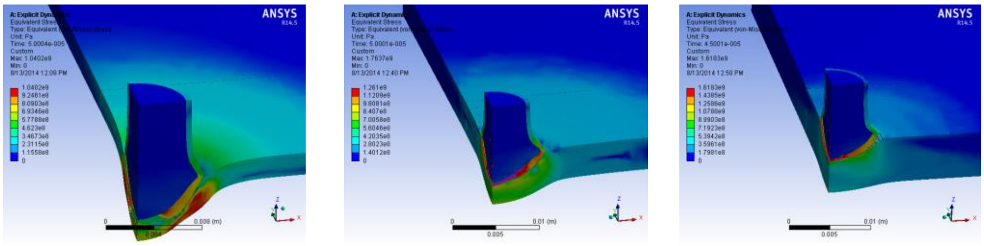
The friction coefficient between the bullet and the plate is considered to be 0.3 and constant, based on up-to-date literature [22], but further investigation could prove an influence of the stress state, strain rate and couple of the materials in direct contact and motion, during the impact, on the value of friction coefficient.

The cases are coded Ia, IIa and IIIa for the plate made of alluminium alloy and Is, IIs and IIIs for the plate made of steel. The thickness of the plate is 2 mm (case I), 4 mm (case II) and 6 mm (case III). All plate configurations have an initial surface of 200 mm x 200 mm. The support boundary condition of each target is encastred.

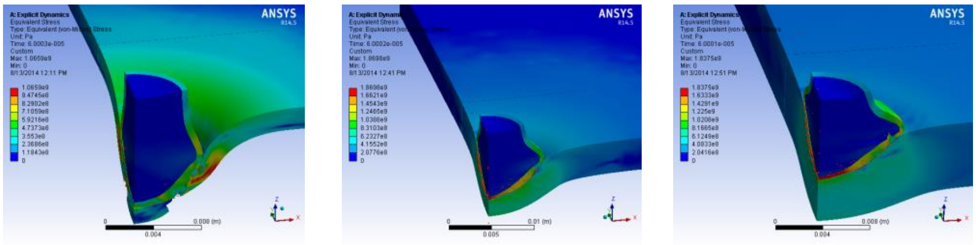
In order to analyze the failure process, the module Explicit Dynamic of the solver AutoDyne has been used.

RESULTS AND DISCUSSION

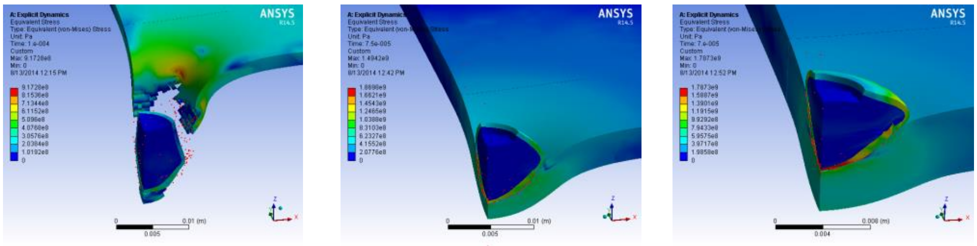
The influence of the plate thickness strongly depends on the material the plate is made of, as one may notice by comparing images in Fig. 2 and those in Fig. 3.



5×10^{-5} s 5×10^{-5} s 5×10^{-5} s



6×10^{-5} s 6×10^{-5} s 6×10^{-5} s



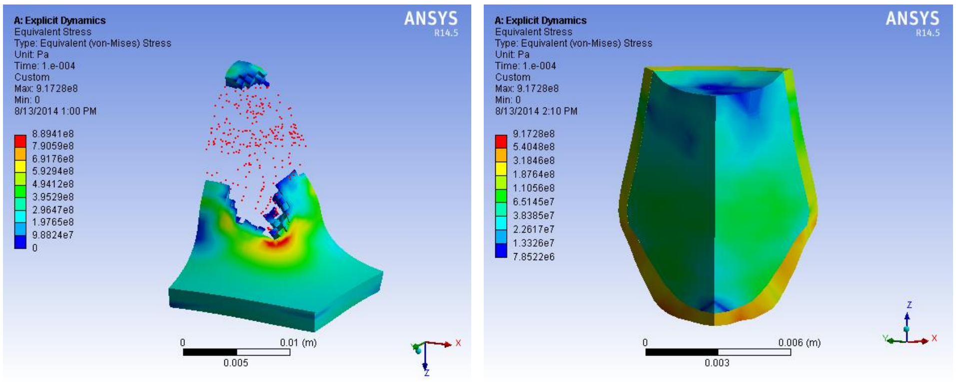
1×10^{-4} s 7.5×10^{-5} s 7.0×10^{-5} s

2 mm **4 mm** **6 mm**

(Case Is) **(Case IIs)** **(Case IIIs)**

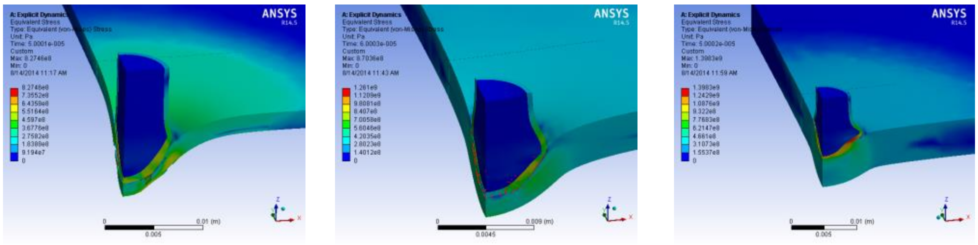
Fig. 2. Sequential images of the bullet impact with a plate made of steel

The material studied in these three cases shown in Fig. 2, is a mild steel, which is characterised by having a low yield stress and a large ductility [20].

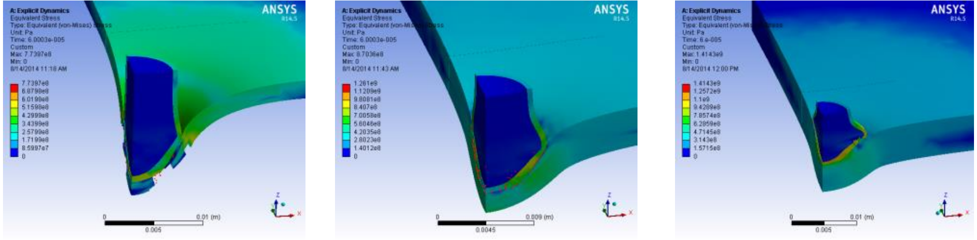


a) Petal aspect of the steel plate after impact b) Detail of von Misses stress distribution within the bullet

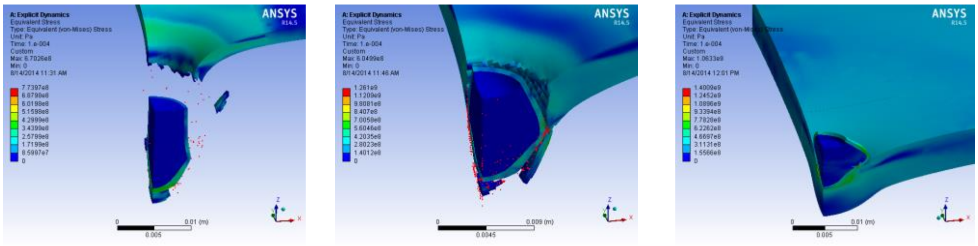
Fig. 3. Relevant details of the plate perforation (plate made of steel and having a thickness of 2 mm)



c) 5.0×10^{-5} s 5.0 x 10^{-5} s 5.0 x 10^{-5} s



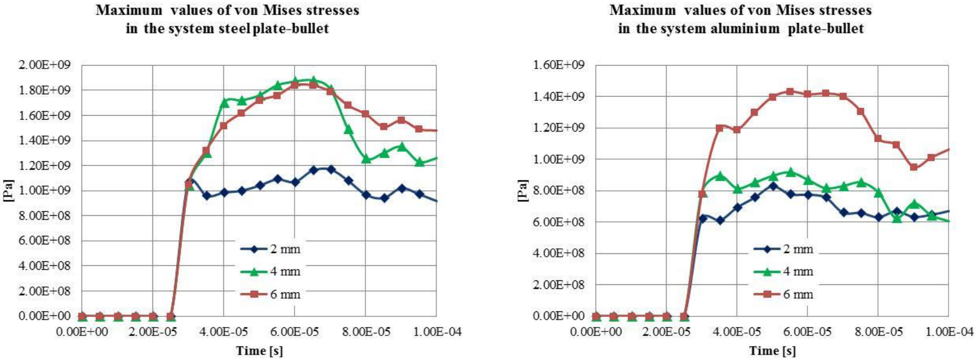
6.0 x 10^{-5} s 6.0 x 10^{-5} s 6.0 x 10^{-5} s



d) 1.0 x 10^{-4} s	1.0 x 10^{-4} s	1.0 x 10^{-4} s
2 mm	**4 mm**	**6 mm**
(Case Ia)	**(Case IIa)**	**(Case IIIa)**

Fig. 4. Sequential images of the bullet impact with a plate made of aluminum

This simulation points out both plate and bullet deformations (see Figures 1-4) and gives information on stress concentrations and, with high probability, “describes” the failure process. These data are useful in designing the testing methodology with actual materials.



a) b)

Fig. 5. Maximum values of von Misses stress in the model

Figure 5 presents typical curves of the maximum values of von Misses stress, for the analyzed system (made of bullet and plate). For plates with integral penetration, these values are lower as compared to values obtained in the system bullet-plate without total penetration. These maximum values could be obtained on or near the interface of the two bodies in contact (plate and bullet).

Tests made at Scientific Research Center for CBRN Defense and Ecology qualitatively validate the shape of the impacted zone into plates made of steel (Fig. 6).

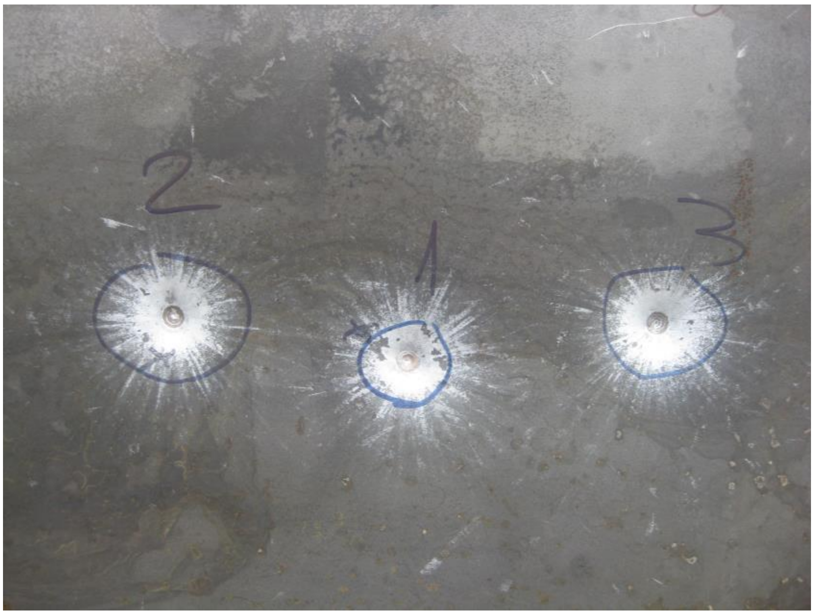


Fig. 6. Ballistic impact of a steel plate without penetration [from Scientific Research Center for CBRN Defense and Ecology]

CONCLUSIONS

The phenomena discussed in this paper improves the understanding of the perforation process, in particular the effect of the material behaviour on estimating the ballistic limit.

Simulation could be useful for evaluating armor safety, evidencing the particularities of the bullet damages into a plate. The aluminum alloy is penetrated by the bullet for a thickness of 2 mm and 4 mm and for the other value (h=6 mm), the bullet is trapped into the plate at a certain height, but for the other material (steel), the bullet is stopped into the plate, even a the smaller plate thickness of 4 mm (see Fig. 2).

The effect of the material behavior when imposing a constitutive relation has been shown to be important in accurately predicting the perforation behavior and energy dissipated at high impact velocity.

However, this model is expected to be adapted to particular impact situations and some simulation parameters, as equivalent plastic strain and friction coefficient during the impact need further investigation, based on a statistical analysis on laboratory tests in order to validate the use of this model for reducing time and costs of actual tests.

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