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INTERACTION BETWEEN A METALLIC REACTIVE ARMOR AND AN ARMORED FIGHTING VEHICLE (AFV) STRUCTURE: MODELLING SPALLATION

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When detonating, a metallic reactive armor can project high velocity plate towards the vehicle, eventually leading to spallation of the structure. A 2D spall numerical model is implanted in a finite element code, and validated towards laboratory and balistic experimental results. This model is then employed to assess protection capabilities of different intermediate shields.
Finally, a particularly polyvalent concept is proposed, and numerically evaluated.

1 – INTRODUCTION

Use of metallic Explosive Reactive Armor (ERA) allows a significant increase of the level of protection of an Armored Fighting Vehicle (AFV) against shaped charge threats. Yet, the detonation of ERA can project a high velocity plate towards the vehicle's structure. Pending the nature of the bearing structure, the impact can lead to a spall effect, including a risk of lethal fragments projection inside crew compartment. Numerical simulations of this phenomenon have been performed to analyze different protection concepts including a screen material between the outer hull of the vehicle and the ERA, prior testing.

2 – SPALLING MODEL

2.1 – Theoretical model

Klepaczko [1] has proposed a cumulative dynamic fracture criterion under short duration tensile stress pulse. Upon the mechanics of plane wave propagation analysis, this model describes cumulative damage generated by a tensile stress $\sigma_F(t)$ resulting from rarefaction waves. A critical loading time is described by:

$$t_{c0} = \int_0^t \left(\frac{\sigma_F(t)}{\sigma_{F0}} \right)^{\alpha} dt \qquad (1)$$

where, σ_{F0} is the threshold stress, and a is a material thermal activation energy parameter.

For an explicit resolution scheme, for very short time steps, the criterion can be rewritten as :

$$\frac{1}{t_{c0}} \sum_{\Delta t} \left(\frac{\sigma_F(t)}{\sigma_{F0}} \right)^{\alpha} \cdot \Delta t = 1 \qquad (2)$$

A damage parameter "*D*" is introduced (eq. 3), growing with time, from zero to one. This parameter is calculated each step with the constitutive law of the undamaged material. This parameter can lead to element erosion when completing full damage (D=1). Free surfaces are then created in the width of the wall, which are taken into account in contact algorithms.

$$D(t) = \frac{1}{t_{c0}} \sum_0^t \left[\left(\frac{\sigma_F(t)}{\sigma_{F0}} \right)^{\alpha} \cdot \Delta t \right] \qquad \text{if } \sigma_F(t) \geq \sigma_{F0} \qquad (3)$$

2.2 – Validation with laboratories experiments

Two classical AFV structural materials are considered in this study: classical steel armor (RHA) and aluminium alloy. The model's parameters for RHA were determined within a test campaign led by the university of Metz on behalf of Giat Industries [3]. Aluminium parameters are derived from [4].

Table 1: Material coefficients for spallation model

	σ_{F0} (GPa)	t_{C0} (µs)	α (-)	References
RHA steel	3.456	5	7.5	[3]
Aluminium alloy	1.2	2	1.35	[4]

These experiments consist in a plane impact of two 57 mm diameter disks, for different speeds and thicknesses. This experiment can provide a couple (pressure level, loading time) close to spall apparition. It permits to check out the criterion ability to express a spallation threshold.

Numerical simulation of those experiments are performed to validate the criterion implementation in LS-DYNA2D code, as an user subroutine. The axisymetric adiabatic model is based on a Johnson & Cook [5] constitutive law, a Mie-Grüneisen state equation, and the fracture criterion equation (2). The material parameters are taken from [6] for the constitutive law and from [7] for the equation of state.

Experimental results for an aluminium are presented in reference [4]. Several experimental configurations are represented and results are compared to experimental observations on a 7020 T6 alloy.

The correlation between experimental and numerical results allows to validate the parameters of the spallation model for a RHA steel (Fig. 1) and for an aluminium alloy, and it confirms the criterion ability to detect a spallation threshold.

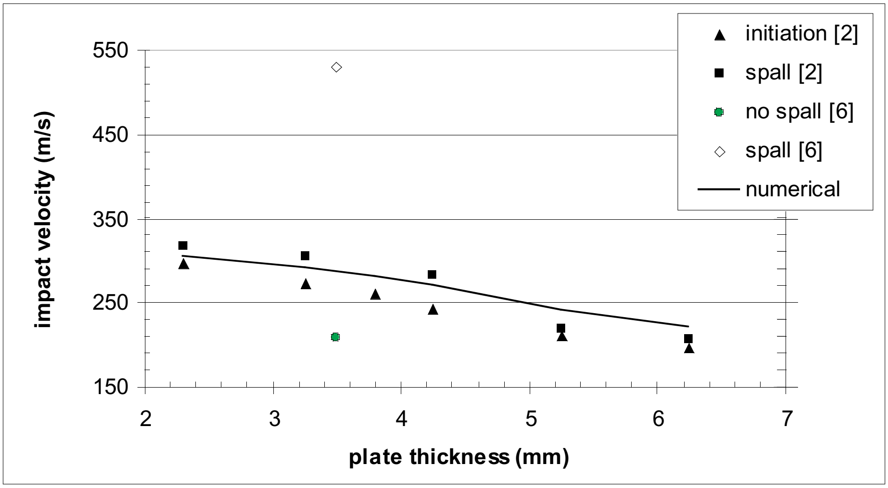

Figure 1: comparison of experimental and numerical results for a RHA steel.

2.3 – Validation on ballistic trials

The fracture criterion used is a one-dimension model, dealing with plane impact. Yet, real plates projected by the explosive reactive armor are deformed by the detonation. We are going to check out the hypothesis that the criterion is still valid on the firing axis, where the flying plate stays nearly flat.

The reactive material model consists of a detonation speed and a Chapman-Jouget detonation pressure. The detonation products behave according to a JWL state equation.

The reactive armor time evolution is given in figure 2. The rear plate takes a curved form at the contact of the detonation shock wave. Yet, a large central zone of the flying plate keeps roughly a homogeneous speed field, and thus stays flat (Figure 2).

Comparison between simulation and ballistic tests results allows to validate the modeling hypothesis: cylindrical symmetry, criterion application on a nearly plane wave. Figure 3 presents the action of a reactive armour, applied to a 40 mm RHA steel bare structure, with a fracture occuring on the rear side [11]. The formation of the spalling plane was obtained with the numerical model.

Complete failure with fragment projection hazard includes dynamic propagation of the crack, which is not considered in this model. However, this risk can be empiricaly predicted through analysis of simulation's results, in terms of speed and kinetic energy of the spalling fragment.

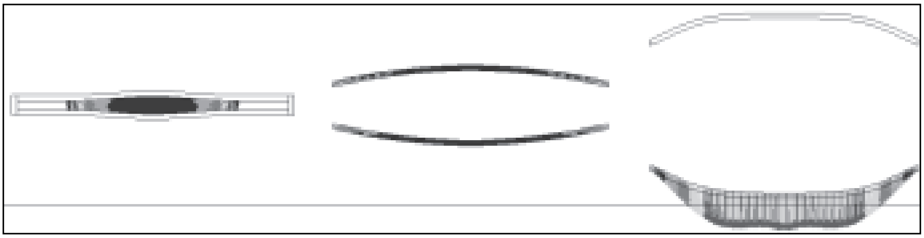

Figure 2: Model of ERA rear plate flight.

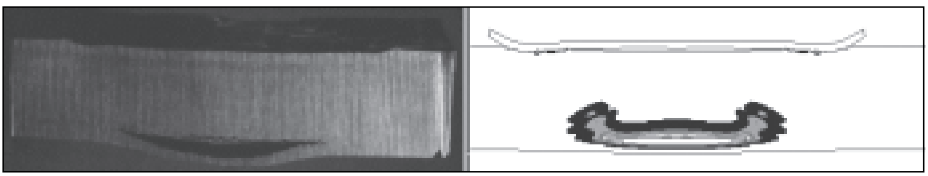

Figure 3: Comparison of experimental [11] and numerical spallation results.

3 – INDUSTRIAL APPLICATIONS

Experimental and numerical results obtained on bared structure (RHA steel and aluminium alloy) exhibit a real spallation risk in the AFV's structure. A way to protect the vehicle is to set a screen material between the reactive armor and the structure. Material shock behavior models are investigated for intermediate metallic or organic screens between the structure and the reactive armor.

3.1 – Screen material characterization under heavy shock

Shock behavior of different materials have been tested with an experimental set-up designed by Giat Industries [11], which generates representative high level shock, obtained in terminal ballistic (Fig. 4). Several parameters (deformation, position, time before projection, speeds, …) of the witness plate were measured by X-rays radiographies and by a rotating mirror streak camera. Thus, the absorbing potential of screen materials has been sorted out. This experimental device also gave the opportunity to validate the numerical constitutive models for impact velocities of the order of 1000 m/s.

For the case of a screen material composed of a GRP composite, a elastic perfectly plastic behaviour model was used [8], in conjunction with a Mie-Grüneisen state equation. Figure 5 shows the comparison between the simulation of the experimental set-up and the X-ray radiographies tracking the witness plate displacement.

The validity of the numerical model is confirmed under strong shock by the correlation between trial and simulation.

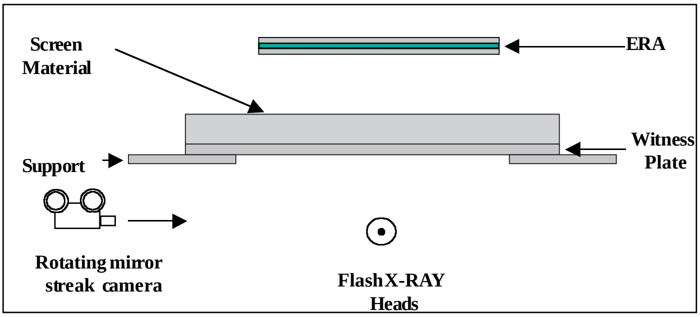

Figure 4: Description of the experimental device for screen materials.

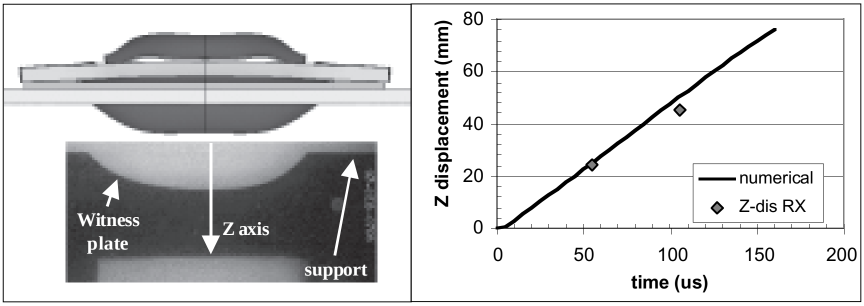

Figure 5: Comparison between numerical and experimental [11] results for GRP.

3.2 – Structure protected by an absorbing material

The GRP validated model was applied to an aluminium structure. A CVR plate is located between the target and the reactive armor. The minimal thickness preventing the formation of a spalling plane is given by calculation for various thicknesses of the structure (Fig. 6).

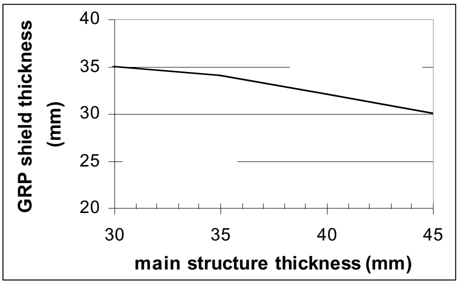

Figure 6: Preliminary data for the design of a GRP shield on an aluminium alloy structure.

3.3 – Examination of a multipurpose protection concept

The evolution of fighting environment for armies leads to protect a vehicle from multiple threats with increasing efficiency. In particular, new levels of protection against medium calibre APDS, APDS-FS and warheads like rocket and missile appear. The association of a reactive and a passive armor is a response to such requirement.

TA6V titanium alloy represents a good armor material against tungsten alloy kinetic projectiles, but also against shaped charge threats [9], [10]. This multipurpose ability suggests a potential benefit in terms of efficiency and reduction of mass, on the vehicle coupling this armor material and reactive technologies. We shall yet make sure that such a concept does not lead to spallation in the structure. The numerical model developped can then validate the feasability of the concept before experimentation.

Numerical results shown in Figure 7 reveal that a 16 mm thick TA6V plate is able to protect a 40 mm aluminium structure, against spallation induced by the reactive armor rear plate.

Therefore, TA6V alloy plates brings three main functions in this concept :

- an improvement of the ballistic protection against medium caliber and shaped charge,
- a protection against spalling effect on the vehicle,
- and, finally, a mechanical support for the reactive tiles or blocks.

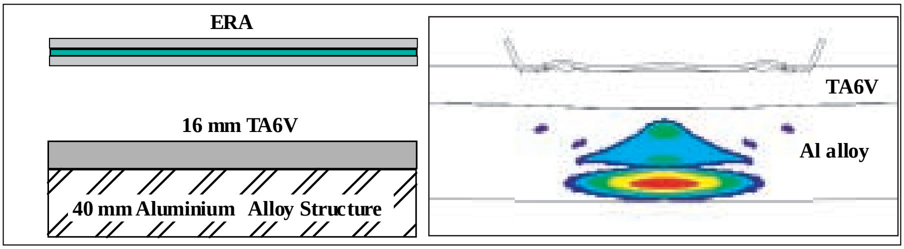

Figure 7: Simulation of a multipurpose protection concept KE medium caliber / shaped charge.

4 – CONCLUSION

An empirical spallation criterion is implanted in an industrial finite element simulation code LS-DYNA2D. The whole simulation capabilities and criterion validation domain were evaluated, compared to laboratories plane impact tests and ballistic experiments.

This numerical model was found to provide a large validity range, allowing analysis of several key conception parameters of the armor: structure thickness, nature and thickness of intermediate material, configuration of the explosive reactive armor.

A particular case of TA6V multipurpose protection concept against medium caliber and shaped charge, was evaluated by simulation. It was found that the inherent ballistic efficiency of titanium alloys improve the protection level of armored fighting vehicle, and can play a significant role in preventing spallation.

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