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## METHODOLOGY TO OPTIMISE BALLISTIC PROTECTION SYSTEMS BASED ON AN EXPERIMENT/SIMULATION CORRELATION

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### ABSTRACT

This work presents a methodology aimed to optimise multi-layer and multi-material ballistic protection systems using an experiment/simulation correlation. This methodology is applied to minimise the mass of an armour steel-aluminium alloy protection system.

### INTRODUCTION

Ballistic protections usually result from an incremental and empirical approach and accordingly strongly depend on the experience and know-how of the manufacturer. Yet, in order to improve their specific ballistic resistance, current ballistic protections are more and more complex, based on multi-layer and multi-material systems, see Crouch (2017), and thus require the optimisation of a great number of parameters (e.g. layering order, thicknesses, number of layers, etc). In this context, numerical simulation-aided design has become indispensable, see for example Paman (2019). The methodology developed in the present work relies on a correlation between experiments and simulations following three steps: (i) calibration and verification of a numerical model, (ii) validation of the model and (iii) use of the model in an optimisation process.

Results of impact experiments involving simple configurations are used to feed an automatic calibration process based on numerical simulations performed with the explicit commercial finite element code Abaqus coupled to the Isight optimisation software. More specifically, the model parameters that depend on the strain rate and related to damage and rupture are identified at this stage (step (i)). Step (ii) validates the parameters of the previously calibrated model, comparing the experimental and numerical results obtained by impact tests on more complex configurations (not used in step (i)). If the correlation fails, a corrective loop is added between step (i) and step (ii) until the results match. As mentioned above, step (iii) aims to optimise a multi-component ballistic protection system (stacking order, layer thickness, etc.) for a given threat, in order to determine the best ballistic performance-mass ratio compromise.

### RESULTS AND CONCLUSIONS

This procedure has been applied to a bi-layered protection system, composed of an armour steel (MARS 380) plate and an aluminium alloy plate, impacted by a tungsten carbide projectile similar to a 7,62×51 AP8 ammunition core. Impact tests are carried out with a single stage gas launcher available in STIMPACT platform of Institut Clément Ader Lab. Model parameters were calibrated and verified in step (i) with a single plate (armour steel and aluminium alloy separately), and validated in step (ii) in a bi-layered configuration. Fig. 1 shows a good agreement between experimental and numerical results (8.8 mm MARS 380 armour steel (“MS8.8”) as front layer and 8.0 mm aluminium alloy (“AA8”) as rear layer, “MS8.8-AA8”). According to Fig.1, the ballistic limit velocity (BLV) is close to 720 m/s.

Finally, the position and thickness of each plate were optimised in step (iii). Table 1 reports some final optimised

designs for an arbitrary  $v_{BL}$  of 345 m/s

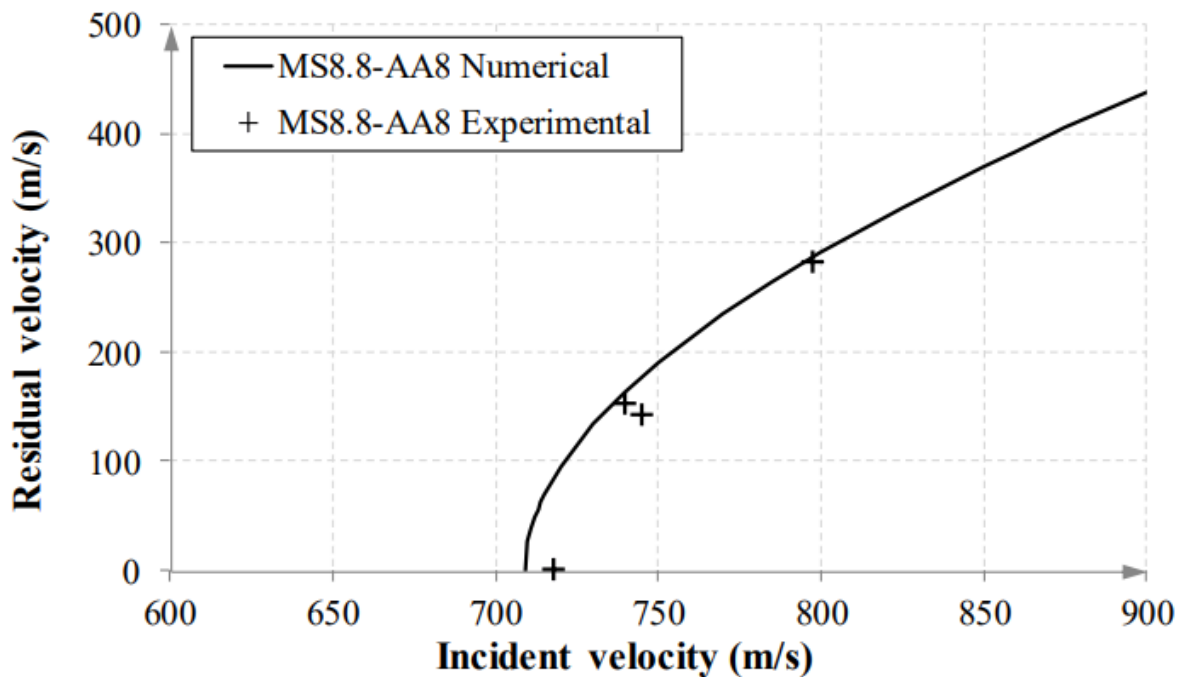


Fig.1 Comparison between experiments and simulations of a tungsten carbide projectile impacting a bi-layered protection system: 8.8 mm-thick MARS 380 armour steel as front layer and 8.0 mm-thick aluminium alloy as rear layer ("MS8.8-AA8")

Table 1 Optimisation results. Threat: tungsten carbide projectile at 345 m/s

Ballistic protection system	Front plate thickness (mm)	Rear plate thickness (mm)	Mass per unit area (kg/m <sup>2</sup> )
MS8.8-AA8	2.00	4.73	28.4
AA8-MS8.8	3.96	2.01	26.5

According to Table 1, a ballistic protection with an aluminium alloy as a front plate and an armour steel plate as a rear plate could be 7% lighter than the opposite configuration against the considered threat (tungsten carbide projectile at 345 m/s). This study allowed to optimise a ballistic protection system with a relatively low number of experiments, and paves the way to more complex optimisations (e.g. regarding materials, number of layers, air gaps, etc).

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