Numerical modelling of aramid composite combat helmet under impact threat

I. Rubio[1*], M- Rodriguez-Millán[1], J.A. Loya[2]

[1]Department of Mechanical Engineering
[2]Department of Continuum Mechanics and Structural Analysis
*igrubiod@pa.uc3m.es

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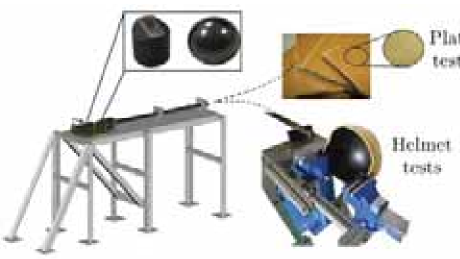
Motivation

Aramid composites have become increasingly important in defence due to their high stiffness, lightweight and high energy absorption capacity. The use of personal protections has been increased because of the recent rise terrorism, civil and international conflicts since it enables to minimise the morbidity and mortality resulting from ballistic head injuries. Continuum efforts are being dedicated made to reduce further the helmet weight without diminishing ballistic resistance. The design of helmets to achieve strictest requirements combining impact resistance and reasonable weight is currently one of the primary concerns of military and security industry. The development of an excellent quality combat helmet involves an expensive and long-time experimental campaign. For this reasons FEM has an important role in protection development. The principal goal of this work is develop a realistic and validated model of combat helmet to use like a optimize tool for manufacturers. As main contribution, a multilayer model that contains more than twenty layers that combat helmet are composed is presented. This particularity allowed calculating the damage extension and back-face deformation, validated with computed tomography (CT) scan.

Experimental procedure



Aramid/PVB (V_{arx} =18%) ρ_a = 8,86 kg/m²

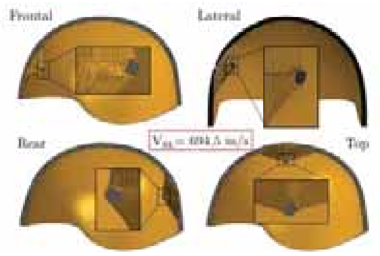
FSP and Sphere projectiles V_{imp} = 600-850 m/s. Impact recorded sequence with high speed camera

Experimental test was performance on plates and combat helmets using diferent geometries and masses projectiles, in order to **calibrate and validate a FEM.**

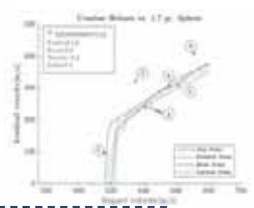
Validation

Validation onto helmet model → **Ballistically:** ballistic limit and curve; **Damage**: Damage area

Combat helmet ballistic validation

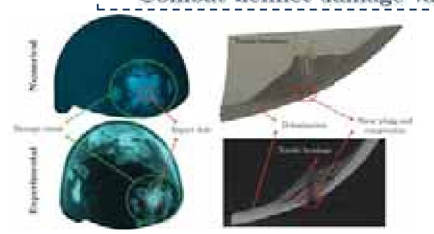


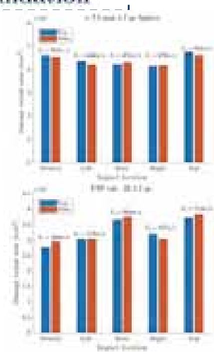
The model replies the diferent locations that helmet were impacted: frontal, rear, lateral (both) and top



The model provides good correlation with experimental ballistic limit V_{expBL}=696 m/s

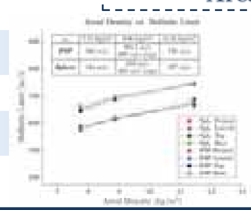
Combat helmet damage validation





An analysis of the internal helmet damage after impacts is carried out through CT scan tomography and compared with numerical simulations.

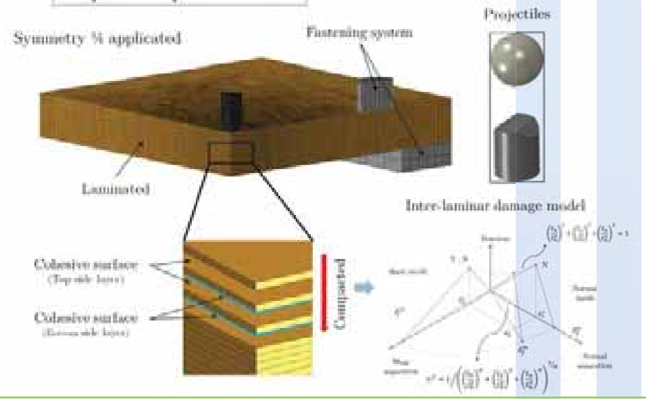
Areal density influence



The ballistic limit increase with the areal density and depends of the location of the impact, being lower in lateral impact situations due to the proximity of boundary conditions. This is a very good tool to optimize the number of layers

Numerical Model

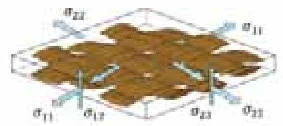
Impact on plates model

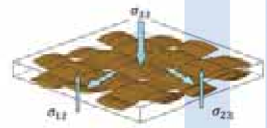


The FEM proposed consists of a **multilayer definition** where it is possible to observe with good accuracy the different failure modes that appear on composite.

Intra-laminar material model behaviour

In-plane damage | Out of plane damage





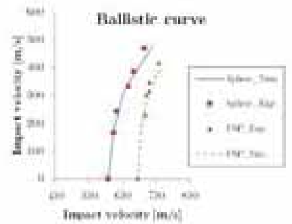
$$d_{f1} = \left(\frac{\sigma_{11}}{X_{1T}}\right)^2 + \left(\frac{\sigma_{12}}{S_{12}}\right)^2 + \left(\frac{\sigma_{13}}{S_{13}}\right)^2$$

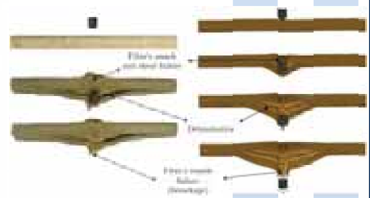
$$d_{f2} = \left(\frac{\sigma_{22}}{X_{2T}}\right)^2 + \left(\frac{\sigma_{12}}{S_{12}}\right)^2 + \left(\frac{\sigma_{23}}{S_{23}}\right)^2$$

$$d_3 = \left(\frac{\sigma_{33}}{Z_c}\right)^2 + \left(\frac{\sigma_{13}}{S_{13}}\right)^2 + \left(\frac{\sigma_{23}}{S_{23}}\right)^2$$

Intra-laminar mechanical model behaviour of Aramid/PVB composite was implemented through a **VUMAT user subroutine** that consider linear elastic behaviour until failure.

Calibration step





Damage induced to plate

Good accuracy between numerical results and experiental test

Conclusions

- In this work, a numerical model for combat helmets of aramid composites against two kinds of ballistic projectiles (1.1g FSP and 1.7g steel sphere) has been developed for designing purposes.
- The numerical model proposed has been calibrated with experimental results on flat plates and then validated ballistically onto real combat helmets .
- The FEM of combat helmet shows very good accuracy on terms of damage variable qualitativelly and quantitativelly. This is possible to multilayer model proposed in this work.
- Kinetic energy transference from the projectile produces global deformations/delamination close to the ballistic limit. Far the ballistic limit, damage is more localized.
- An analysis of areal density influence on ballistic limit has been realized. This is a very interesting study because it possible to use this multilayer model like a tool to optimize the number of layers, depending of threat that will be exposed according to different standards.

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