Ballistic impact on ceramic/composite armours
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Abstract

Ceramic/composite armours are being increasingly utilised as protective structures against medium calibre projectiles due to its high efficiency compared to monolithic steel armours.

Armour design optimisation use to be helped by the utilisation of different design tools, either analytical models that simulate the penetration process by one-dimensional simple equations or numerical hydrocodes that simulate the process by finite element or finite difference methods.

An accurate description of the ballistic impact of a medium calibre projectile onto a ceramic/composite armour is far from being fully solved neither by existing analytical models nor by commercial hydrocodes, due to the lack of data of the mechanical behaviour of materials involved, and specially of failure criteria at high strain rates.

The paper presents some advances on the simulation of the penetration process of medium calibre projectiles on ceramic/composite armours, both by analytical and numerical approaches, that agree well with empirical data, thus providing design tools that permit optimum armour design with a reduced number of actual firing tests.

1. Introduction

Weight is a key factor in the armour design for the ballistic protection of moving systems such as vehicles, aircrafts and personnel of security and defence corps. Nowadays, the state of the art lightweight armour to
defeat armour piercing (AP) projectiles is a ceramic/composite one, usually a boron carbide tile backed by aramid or polyethylene panels.

Design optimisation of ceramic/composite armours is a complex task due to the high number of variables controlling the penetration process of projectiles into the target. Therefore, the traditional method of armour designing based exclusively on firing tests is expensive when used with composite armours. It has the added disadvantage that the results are hardly extrapolated to configurations other than those tested.

An alternative method is the simulation of the ballistic impact by numerical or analytical models. Numerical simulation is performed by means of hydrocodes that integrate the differential equations of the mechanics of continuous media using finite differences or finite elements. Analytical models simulate the impact process by assuming simplifying hypotheses to derive the projectile equations of motion. Analytical simulation is fast, although less accurate than numerical simulation. Armour design optimisation is better accomplished by a clever utilisation of both ways. Anyway, experimental validation of the solution achieved must be carried out by actual firing tests.

In the last decade, the Department of Materials Science of the Polytechnic University of Madrid has developed both numerical subroutines for dynamic behaviour of ceramic/composite targets implemented in commercial hydrocodes [1] as well as analytical models of ballistic impact onto ceramic-composite armours [2,3].

This paper shows the possibilities of both approaches to obtain an optimal design of ceramic/composite armours to defeat armour piercing projectiles.

2. Models

Numerical simulations of normal ballistic impact on ceramic/composite targets is carried out by using the commercial AUTODYN 2D hydrocode, where special subroutines for modelling the dynamic behaviour of ceramic and composite materials have been implemented.

The basic hypotheses of the dynamic constitutive equations utilised to model ceramic materials have been published before and they will not be repeated here [1]. On the other hand, composites dynamic behaviour is modelled by assuming orthotropic elastic behaviour and the well known Tsai-Wu failure criterion [4]. The steel of the projectile core is modelled by the Johnson-Cook constitutive model [5].
Analytical simulation of the penetration process on ceramic/composite targets is done by using the Chocron and Sánchez-Gálvez analytical model. A detailed description of the model can be found in ref. 2. The model was previously validated by comparing the analytical predictions with experimental data of impact of small and medium calibre projectiles onto ceramic/composite targets. See for instance fig. 1, were ballistic limits of 12.70 mm projectiles impacting 6.35 mm thick alumina 85% purity backed by Kevlar 29 panels have been plotted. The figure shows both the analytical predictions as well as the experimental data published by Mayseless et al. [6].

Figure 1: Ballistic limits of 12.70 mm projectiles impacting 6.35 mm thick alumina 85% purity backed by Kevlar 29.

3. Impact simulations.

Published experimental results of ballistic impact of projectiles on ceramic/composite targets are scarce. Therefore, fine tuning of model parameters to achieve a good agreement to experimental behaviour is difficult. The Department of Materials Science of the Polytechnic University of Madrid has been involved in a European Cooperative Research Project named RTP 3.2 in the frameworks of the EUCLID programme [7]. Although the majority of the experimental results
obtained within that project are classified, they have been very useful for tuning the above mentioned models. After that, both the numerical hydrocode and the analytical model have become useful tools for ceramic/composite armour designing. For instance, in this paper the models are used to simulate normal ballistic impact of three projectiles, 7.62 AP, 12.70 AP and 14.5 API on alumina 95% purity backed by Kevlar 29 panels, for which some experimental data are available [8].

Figures 2, 3 and 4 illustrate the analytical predictions of projectile residual velocity after perforation of the target vs. impact velocity for different areal density values of the armour for the three projectiles analysed respectively. From those figures, the analytical prediction of ballistic limits (minimum speed for perforating the target) is easily derived. Figure 5 shows the ballistic limit vs. areal density for the three projectiles analysed as well as some experimental results [8]. As can be seen, the agreement between analytical results and experimental data is excellent, specially taking into account the simplicity of the analytical model that allows a very fast computation. For instance, all the computations required to draw figures 2, 3 and 4 have been performed in a few minutes in a PC.

![Figure 2: Analytical predictions of 7.62 mm projectiles impacting alumina 95% purity backed by Kevlar 29.](image-url)
Figure 3: Analytical predictions of 12.70 mm projectile impacting alumina 95% purity backed by Kevlar 29.

Figure 4: Analytical predictions of 14.5 mm projectile impacting alumina 95% purity backed by Kevlar 29.
On the other hand, a few numerical simulations have been carried out to compare the results with the analytical ones. In figure 5 the numerical results of ballistic limits have also been included showing a good agreement to the experimental data and the analytical predictions. Since experimental data of residual velocity after perforation of the target are not available, it is not possible to check the accuracy of the analytical and numerical simulations. Nevertheless, a plot of analytical and numerical histories can be carried out, to compare one to another. For instance, figures 6, 7 and 8 show three velocity histories. As can be seen, some discrepancies between analytical and numerical histories are observed, although a good agreement is achieved on the final residual velocity after perforation of the target.

Figure 5: Ballistic limits of the three projectiles impacting alumina 95% purity backed by Kevlar 29.
Figure 6: Velocity history of 7.62 mm projectile impacting at 900 m/s on 30 Kg/m² alumina/Kevlar armour.

Figure 7: Velocity history of 7.62 mm projectile impacting at 900 m/s on 40 Kg/m² alumina/Kevlar armour.
Figure 8: Velocity history of 12.70mm projectile impacting at 1000 m/s on 100 Kg/m2 alumina/Kevlar armour.

4. Conclusions

Ceramic/composite armours have shown higher efficacy than monolithic steel armours to defeat modern kinetic energy projectiles. Composite armour design is a complex task due the high number of variables controlling the ballistic impact phenomenon. This paper has demonstrated the validity of analytical models and numerical hydrocodes to simulate accurately the penetration process of medium calibre projectiles onto ceramic/composite targets, thus enabling an optimal design of lightweight composite armours.

References


