Analytical and numerical simulations of ballistic impact on composite lightweight armours

V. S. Gálvez

Department of Materials Science,
Universidad Politécnica de Madrid, Spain

Abstract

This paper summarizes the utilization of analytical and numerical computation as valuable tools for lightweight armour design optimisation. Some examples of ceramic/metal and ceramic/composite lightweight add-on armours are presented to withstand ballistic impact of armour piercing projectiles.

Keywords: ballistic impact, armour piercing projectiles, lightweight armours, analytical simulation, numerical simulation.

1 Introduction

The last decades have seen a dramatic improvement in the perforation capability of modern weapons. Kinetic energy projectiles, shape charges and explosively formed projectiles (EFP) have increased its performance so that nowadays any lightweight armour with traditional materials can be defeated [1]. In parallel, vehicle protection has been also improved by using new materials, like ceramics and composites, by using composite armours and by utilization of reactive armours [2].

The optimisation of lightweight vehicle armour design against a definite threat is thus a difficult task due to the high number of parameters involved: material selection, thicknesses of different materials, impact obliquity, etc. A design based exclusively on experimental tests is therefore expensive in money and time.

Analytical and numerical simulations are valuable tools for such lightweight armour design, enabling an important reduction on the number of fire tests required to check the performance of the solution. This paper summarizes some
contributions to lightweight vehicle armour design with advanced materials produced at the Materials Science Department of the Universidad Politécnica de Madrid (UPM) by means of analytical and numerical simulations of ballistic impact [3-7].

2 Armour design

Armour design can be achieved by three approaches: empirical, analytical and numerical. The empirical approach is based simply on firing tests. Vehicle armours with traditional materials such as high strength steel can be easily designed by using this approach. Empirical design with advanced materials such as ceramics and composites is however very time consuming due to the high number of parameters involved. In these circumstances it is worthwhile the utilisation of any or both of the two other approaches.

Analytical simulation is based on the development of expressions derived from continuum mechanics equations able to describe the penetration process and to obtain valid data concerning perforation, crater depth and width, residual velocity and mass of the projectile, etc. Often equations governing the process are quite involved requiring the use of the computer to solve the unknowns, but computations may be carried out in a few seconds, thus a very high number of parameters can be analyzed very rapidly.

On the other hand, numerical simulations are carried out by discretizing projectile and target by using a finite element method or a finite different method and computing the penetration process step by step with the use of a numerical computation code (hydrocode). The whole process may last from a few minutes up to several hours. Therefore, the number of parameters that can be analyzed is much smaller than those in the analytical approach. Also the cost can be similar
to that of the empirical approach. However, the information obtained from a numerical computation is much more important than that obtained with the two other approaches.

Thus, we can conclude that the best way for armour design with advanced materials is a clever combination of the three abovementioned methods.

Figure 1 is a sketch of the methodology proposed. After defining the threat and the requirements of the protection, the analytical tool may be used for rough computations to discriminate the preliminary solutions. After that, numerical simulation is a valuable tool to tune the solution and to validate the analytical tool. Finally, firing tests are always required to check the performance of the solution.

Figure 2.

3 Ceramic/metal armours

Infantry Fighting Vehicles (IFV) are lightweight vehicles usually protected only against low calibre projectiles. The improvement of its protection to be able to
withstand impact of medium calibre projectiles (20 APDS, 25 APDS, 30 APDS) while keeping a moderate increase of armour weight lead to the utilization of ceramic/metal armours, either joined to the main armour or spaced from it (add-on armour concept) [8].

For ceramic, metal add-on armour design, a new analytical model was developed at the Materials Science Department of the UPM. The code, named SCARE is able to compute residual velocity and residual mass of the projectile after perforation of the add-on armour for different materials, projectiles, impact speeds and obliquities. Figure 2 illustrates the perforation process for ceramic/metal armour defeated by medium calibre projectiles. A cone of comminuted ceramic is produced distributing the pressure on the ductile metal plate. Finally the backing is bulged and it fails in tension along a spread surface.

For example, figure 3 illustrates the results obtained with SCARE code for optimal design of alumina-aluminium armour against the 25 mm APDS projectile at different impact obliquities.

![Figure 3](image1.png)

![Figure 4](image2.png)
Also, figure 4 summarizes the results of residual velocity after perforation of 25 mm APDS projectile impacting ceramic/aluminium armour at normal impact. The figure includes results obtained with the analytical programme SCARE as well as those achieved with the numerical code AUTODYN. As can be seen there is a good agreement between the two computation methods.

Analytical and numerical codes have been validated by experimental tests. For instance, figure 5 shows the perforation of ceramic/aluminium add-on armour by 20 mm APDS projectile at 30° obliquity. The figure depicts the perforation of the armour at two different times by the numerical hydrocode AUTODYN as well as the shadowgraphs taken at the same times by X-rays during actual firing test. As can be seen, the agreement between the numerical simulation and the experimental results is excellent. It is interesting to point out that the projectile after perforation of the add-on armour is eroded and destabilized, being unable to perforate the main armour.

Figure 5.

4 Ceramic/composite armours

Composites are an alternative solution for ductile backing of ceramic armours when the weight is the most important requirement. That is the case for instance of the protection of airplane cockpits or helicopters seats.

For lightweight ceramic/composite armour design a new analytical model has been developed at the Materials Science Department of the UPM. The model has been validated for ceramic/composite armour impacted by armour piercing (AP) projectiles by numerical simulation and experimental tests [5].
Figure 6.
For example, figure 6 summarizes the analytical predictions of residual velocity vs. impact velocity for 95 percent purity alumina backed by Kevlar29 with different thicknesses impacted by 7.62, 12.70 and 14.5 AP projectiles at normal impact.

Finally, figure 7 includes the results of ballistic limit vs. areal density obtained with the analytical programme and the numerical hydrocode AUTODYN as well as some experimental data for the three armour piercing projectiles analyzed. As can be seen, the agreement is good, showing that both the analytical model and the numerical code are valuable tools for the optimal design of lightweight ceramic/composite armours against armour piercing projectiles.

5 Conclusions

Analytical and numerical simulations are valuable tools for lightweight armour design optimisation with advanced materials. Although firing tests are always required for validation of the solution, the number of shots can be dramatically reduced by previous screening with numerical simulation. This paper shows some examples of actual designs with ceramic/metal and ceramic/composite lightweight armours.

References


