International Conference KNOWLEDGE-BASED ORGANIZATION
Vol. XXIII No 3 2017

NUMERICAL MODELING AND EXPERIMENTAL RESEARCH OF THE PERFORATION PHENOMENON OF CERTAIN MATERIALS USED FOR INDIVIDUAL PROTECTION BY BULLETS

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Abstract: *The paper captures two aspects related to the phenomenon of impact between bullets and different types of materials used for the individual protection of the militaries, for the same type of ammunition and for the same configuration of the ballistic protection system, both in the case of the activity of experimental shooting range testing, as well as in the case of the modeling and simulation of the impact between the bullet and the protection materials.*

Keywords: perforation, bullet, protection materials, armor.

1. Introduction

Recent analyses of the military specialists situate the place of military action in intensely inhabited areas. The isolated events associated to terrorist acts have already targeted urban centers due to the violent impact on society and of the media potential. Nevertheless, these situations represent individual actions and are not the result of an armed confrontation. They do not have the character of military conflict, first of all because they are aimed directly against civilians, without warning and without discernment. [9].

However, the era of classic military conflicts has come to an end, and fewer and fewer people imagine a possible new war in the form of the deployment of large forces, in unpopulated areas or evacuated in advance. The future wars will have a modular character and will take the form of local conflicts involved in an area or regional network. The objective of these conflicts will be the control over densely populated, possibly industrialized areas, so that their contribution to the logistical and media support of the conflict can be effectively exploited. The infrastructure of transport, communications, supply and camouflage of the forces becomes a key element in the development and support of conflicts. One can say that the future wars will be won in cities. Or they will be lost there.

Apparently, these combat scenarios have a less destructive character, the military actions being focused on the concept of keeping and using for one's own benefit the facilities and the infrastructure. Unfortunately, the other face of the medal shows us that moving the conflicts in urban areas leads to an unprecedented increase in the level of exposure of the population. Major cities are hard to evacuate, hard to defend and hard to control. It is inevitable that the fight for the control of an objective should not massively affect the population in the adjacent buildings that will either be destroyed or will become unsafe and incapable of providing adequate protection [9].

The phenomenon of perforation of the systems of individual protection of the militaries on the battlefield is a very complex phenomenon, which is essentially

DOI: 10.1515/kbo-2017-0173

reduced to the study of the effect of the bullet at the target. The conditions in which the bullet hits the target may vary greatly, depending on the impact velocity, the striking angle and the type of the projectile and of the target.
The actuality and the importance of this paper results from the perspective of using the results and the models that are offered, under different circumstances, such as the analysis of the protective capacity of a given piece of equipment, the analysis of the possibilities and of the solutions for increasing the protective capacity against a given type of ammunition, the comparative analysis of certain individual protection pieces of equipment given in order to obtain the best decisions regarding the endowment, the purchase or the use under certain imposed conditions.

2. The numerical calculus of the phenomenon of impact between projectile and armor

In order to solve the problems of non-linearity in the dynamics of continuous environments, especially when there appear strong deformations, the AUTODYN code has been developed. The differential equations that are at the basis of the code are derived from the laws of continuity of mass, impulse and energy. These laws are satisfied for each time gap, and, besides this, constitutive laws are needed to determine the manner in which materials behave, laws that allow for a link between the field of tensions and the deformations suffered by the material or the internal energy. The solution of this system of differential equations is obtained in AUTODYN by using finite element techniques, finite volumes or node network-free techniques [8]. The methodology of the solution is based on an explicit algorithm of integration in time.
The differential equations are solved through a set of algebraic equations obtained by discretization techniques, and the manner in which this discretization is performed leads us into the world of numerical methods of calculation. For the impact events between a ballistic penetrator and the protective armor, a unitary approach, using a single numerical method for all the elements of the model, does not provide a solution that meets the actual perforation conditions [7].
The techniques of coupling the solvers of different types into a single simulation allow for the use of the most appropriate solver for each domain of the problem. In order to achieve the simulation of the phenomenon of perforation of ballistic protection materials, the code uses the classical Lagrange and Euler solvers and the SPH solver. The Lagrange processor, for which the fixed network of nodes is deformed simultaneously with the material, has the advantages of a much higher calculation speed and of a good definition of the interfaces between the materials. The Euler processor, which uses a fixed network of nodes through which the material flows, needs a larger computational effort but is more suitable for large deformations and for the flow of materials [8].
The Lagrange processor can simulate the impact problems with large deformations, as it is our case of penetration by the bullet of the ballistic protection systems at high speeds, ability that can be improved by introducing an erosion algorithm [7]. The erosion algorithm eliminates the Lagrange areas that exceed the user-imposed deformation value, usually over 150%.
SPH is a Lagrange technique with potential in terms of accurately modeling the interfaces and flexible in terms of material models. Additionally, being a networkless method, it does not suffer from the same limitations observed in the case of the Lagrange techniques that do not withstand the strong deformations of the node network. The lack of a network also allows for the modeling and visualization of the fracturing of materials, thus the fragmentation process is solved in a natural way [8].
The analysis of the available options and their characteristics, in relation to the

studied impact phenomenon, led to the choice of the SPH solver for the ceramic material of the armor and the Lagrange solver for the rest of the materials [6].

3. Experimental testing of the perforation phenomenon in the shooting range

The experimental activity is motivated by the study of the ballistic properties of composite armors with an external ceramic material and a metallic support plate. The ammunition used in the test is 7.62 mm in caliber (Figure 1).

Fig. 1 7.62 mm caliber ammunition

The test was performed on ceramic plates glued in front of steel structures (Figure 2). The ceramic plates on which the test was performed had a nominal thickness of 6 mm and lateral sizes of 40x40 mm.

Fig. 2 The structure proposed for testing

After each test (Figure 3), we showed the manner in which the armor fastening system (composite structure with an outer layer of ceramic material and a steel support plate) is presented. The results were the expected ones for all the tests, in the sense that the fastening and fixing systems worked and the support plate remained fixed.

Fig. 3 The tested system (before the shooting)

The ceramic plates were destroyed and detached from the metal support plates (Figure 4).

Fig. 4 The destruction of the ceramic plates

We used behind this firing system a kevlar vest by means of which we wanted to recuperate the ballistic penetrators, which enabled us to make an assessment of the state of each 7.62 mm bullet.

We noticed several degrees of damage of the bullets. A first finding is the bullets that suffered from the erosion of the tip to a greater or lesser extent. Another category of bullets are those which, alongside the strong erosion of the tip of the core, presented one or more transversal fractures. We could not confirm a relationship between the armor configurations and the presence of the fractures because for the same armor configuration and impact velocity, the phenomenon of transversal fracturing of the core may or may not be present.

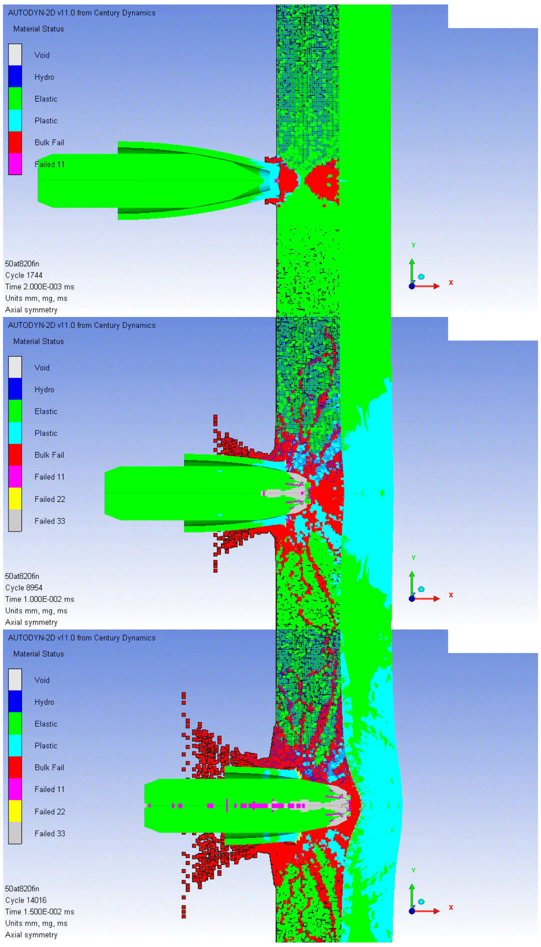
The erosion of the tip of the penetrator is caused by the ceramic particles generated by the impact that have an abrasive action on the tip due to the relative motion [2].

The transversal fractures are caused either by the bending stress due to the oblique impact or by the stretching stress due to the interference of the expansion waves that are due to the reflections of the waves of compression at the convergence of the clear surfaces such as the bottom of the projectile or the clear surface of the support plate [3].

4. Results and discussions

For numerical simulations, two-dimensional elements with four nodes were used, keeping the dimensions and the mechanical properties of the materials used within the experimental testing. The ceramic plates on which the test was performed had a nominal thickness of 6 mm and the metallic ones of 4 mm. In order to model the ceramic plates, the SPH technique was used [1], [7], [8].

At the initial moment, the speed of the projectile nodes was 710 m/s. The analysis duration was 170μs with the increment for data recording of 10 ... 20 ns and the one for recording images of 4 μs. The dynamic analysis program that was used provides at the outut data, images and graphs related to the deformed state, the velocity field, the deformation field, kinetic energy data, etc. [6], [7], [8] (Figure 5).



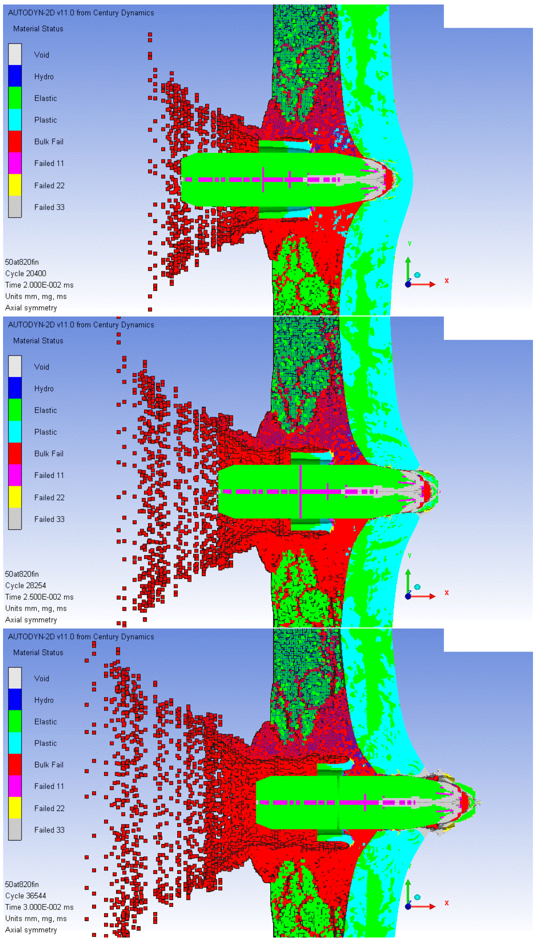


Fig. 5 Results of the numerical analysis regarding the perforation of the system proposed by the bullet

After running the analysis program, with the initial conditions specified, the following results were obtained:

- the perforation of both plates (the ceramic plate and the steel one);
- the accelerated deceleration of the projectile during the initial phase accompanied by oscillations indicating the appearance of shock waves in the material;
- the complete destruction of the ceramic plate in the impact area;
- signs of pronounced erosion of the tip of the penetrator [4], [7], [8].

We found that the results obtained after running the numerical simulation program are in direct agreement with those found within the experimental testing in the shooting range (Figure 6).

Fig. 6 Aspects of the perforation of the metal plate

The quality of the mechanical properties can also be the cause of the different degrees of erosion that are noticed at the tip of the projectile [4].

We can conclude that the deterioration (even the fragmentation) of the bullets is largely due to the intensity of the shock generated by the impact when the impact occurred in an area of the plate with good mechanical properties and it is not due to the bending efforts caused by the existencce of a nonperpendicular impact [5].

5. Conclusions

The main component of this paper is represented by the analysis of the terminal ballistic parameters and by the configuration of the solution of appropriate protection for a given ammunition (7.62 mm caliber for the submachine gun md. 1963) and a composite armor made of a ceramic plate and a metallic one.

The testing activity was complemented by the development of certain numerical models designed for the simulation of the impact phenomena studied experimentally, in which the behavior of the ceramic plates was modeled by means of the SPH technique, and the conclusions of both studies led to the same results.

The paper aims at analyzing the impact phenomenon between the projectile and types of composite armor, both from the point of view of the practical results obtained following the experimental firings in the shooting range as well as following the numerical simulation for the most accurate description of the dynamic penetration process and of the the behavior of the materials in the case of a dynamic regime respectvely. The numerical solving of the impact phenomena can follow different paths (Lagrange, Euler or SPH) each with its own advantages and disadvantages.

The results of the simulations were in good agreement with the experimental tests.

The processing of the experimental results obtained following the combat shootings, corroborated with the numerical simulations presented in this paper has enabled the highlighting of certain specific phenomena that appear from the interaction between the bullet and the composite (ceramic-metal) armor system which can open new research directions:

- the extention of the numerical method to a broader range of backing materials (especially those that correspond to real solutions);
- increasing the individual protection performance by introducing certain resistant and low-weight ceramic materials;
- improving the performance of the perforating ammunition by increasing the tenacity of the perforating core in order to avoid fracturing in the early stages of the impact, as well as analyzing the possibility of covering the surface of the penetrating tip with various materials in order to reduce the erosion phenomenon produced at the impact with the ceramic plates.

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