Researches on the behaviour of cellular antiballistic composites based on AlMg-SiC alloys

O Bălătescu 1, R M Florea 1, I Rusu 1 and I Carcea 1
1 Technical University “Gheorghe Asachi” of Iasi-Romania, Department of Materials Science and Engineering, Blvd. Mangeron, No. 59A, 700050, Iasi, Romania

E-mail: oana84rou@yahoo.com

Abstract. The researches presented in this paper refers basically to the impact of a small/medium caliber bullet shot on a light armor built on the base of a AlMg-SiC metallic composite cellular/foam. Thus, we study the antiballistic behavior and protection properties of the armor, based on the effects that occur at the impact zone of the bullet with the composite surface. We performed an antiballistic behavior modeling by means of a finite element analysis, based on a “multi grid” Fast Finite Element (FFE) system. We used for this purpose the DYNA 2D software package. The obtained samples show after the impact the occurrence of concentration / deformation pores effect and intercellular cracks development to the interior of the composite. Those effects, depending on speed, mass and length of the projectile ballistic trajectory, reduce zonal tensions due to the effect of cell walls deformation. It was obtained a good correlation between modeling results and the electron microscope analyse of the impact area. It is worth mentioning that almost all values for impact energy absorbed by the composite armor are in the protection active zone provided by it.

1. Introduction
Structural optimization, properties, impact resistance and ballistic behavior is a real need for application development especially in the military field. In practice occurred requirement to achieve optimization solutions for building and modeling of ballistic structures, or armor needed in areas such as military, naval and aeronautical programs made by dedicated packet type DYNA 2D. These are variants of calculation and solutions while providing a relatively safe with good quality results and descriptive, but not certainties in practical applications. Pair with a type DESIGNER ONE program that can incorporate solid modeling and structural analysis can lead to specific systems, which can quickly resolve issues related to the impact of bodies at high speeds, the energy absorbed and ballistic protection that some materials they can provide direct applications [1].

2. Presentation and general characterization of the modelling process
Till now it was not developed a unified theory that can fully describe the mechanical behavior of composites under ballistic and establish mechanisms dependence of mechanical parameters characterizing the impact:
- dependence of the mechanical properties of some geometrical and physical parameters of request: high speed impact, the time variation of pregnancy by fragmentation, temperature, etc.
- dependency on the conditions for obtaining the mechanical properties of the composite; depending on the technology used and the reinforcing elements of the matrix and the heat treatment, etc.

- dependence of the mechanical properties of nature and characteristics of the elements that have made reinforcement matrix cell density, total reinforced material, the nature of the interface and input materials introduced to modify the shape and size of the cells composite.

In the modeling activity is mandatory call micromechanics models and calculations to simulate the mechanical properties of materials with properties gradual. Sequential steps to be taken is in fact a classical procedure for FEA (Finite Element Analysis) evaluation:

- it is the mesh network with a suitable degree of surface geometry that occurs initiation impact (this area generally has the primary form of a grid network name consecrated by Mesh);

- development field area is represented by multiplying the impact of network elements in the mesh polygons representing elements associated clamping zone resulting from impact;

- developing a network with nodal elements around the impact area;

- representation of the composite elements subjected to impact cell were generated by a specific algorithm;

- detailed presentation of modified Mesh network around the impact area is done by increasing the number of dividers, with representation by leaps and play new network tense with a 2D representation may occur as a representation as small rectangles or polygons.

For statistical and comparative analysis in the case of a 9 mm caliber projectile it were generated features obtained from a series of polygon tests. Data are presented in summary in the following tables for which values were selected based on general data already published for 9mm weapons [2, 3].

| Feature ballistic protection | The thickness of armor (minimum value) |
|-----------------------------|---------------------------------------|
| Carbon steel plate          | 2 mm                                  |
| Concrete type B200          | 4,5 mm                                |
| Wall of bricks burned       | 50 cm                                 |
| Soft wood                   | 15 cm                                 |
| Hardwood                    | 12 cm                                 |
| Layer of earth              | 15 cm                                 |
| Snow                        | 50 cm                                 |

**Table 1.** Structural elements of antiballistic armor slightly (caliber projectile used in the study was 9 mm).

**Table 2.** Ballistic characteristics for the analytical study of projectile 9 mm.

| Feature caliber 9 mm, Projectile weigh [g], Speed [m/s], Energy* [J] | Maximum extension ballistic [mm] | Penetration ballistic gel [mm] |
|-----------------------------------------------------------------------|----------------------------------|-------------------------------|
| Automatic shooting type, 15, 300, 675                                  | 21                               | 410                           |

* The impact energy will be considered to be equal to the energy absorbed by the shield to which is added the residual energy.

To determine the effects of the damage produced by projectile bullet-type small and medium arms, shall be carried out in general a ballistics test. Ballistic test standard is firing a projectile from a distance of 10 m in a target containing a special substance called ballistic gel or paste; range experiments being carried out with different types of weapon [4].
Table 3. Performances range ballistic projectile 9 mm depending on the type of firearm [4].

**Ballistic performance**

| Firearm-type projectile 9 mm/mass | Speed [m/s] | Energy [J] |
|----------------------------------|-------------|------------|
| Bonded Defense/12g               | 373         | 835        |
| Speer Gold Dot JHP/12g           | 320         | 614        |
| Speer Gold Dot JHP +P/13         | 330         | 702        |
| Federal Hydra-Shok/15g           | 270         | 561        |
| US Army Ball FMJ/15g             | 250         | 477        |

As a behaviour mode, the pores of a composite cell to be subjected to the effect of the concentration/deformation and cracking within the composite intercellular for reducing the tension zone by the effect of deformation of the cell walls, thereby reducing the total fracture energy. Neglecting the effects of deformation occurring at a force F it can be considered the total energy absorbed will depend on the number of cells and the structure/geometry composite alveolar cells; but will depend on the relative density and the volume/size of the cell.

Determinations are experimentally assessing fracture and deformation energy as it occurs. The values obtained are dependent on the composite matrix, the shape, cell size, and density of the composite. Ceramic components placed in metal cellular materials have major influences on the matrix plasticity and thermal and mechanical energies of nature that can be absorbed by the matrix. At the same time they influence the composite brittle deformation process, which can be considered as an advantage in terms of load transfer when speaking of the protection can be provided at the time of impact components.

To implement a mathematical model simulating ballistic impact phenomena, we need a network computing discrete set around the two bodies (ie projectile and armor). The mathematical model is transformed into a numerical model equations by approximating the laws governing the movement of bodies and determine the amounts of energy values bodies in motion. This makes the numerical model to work exclusively on a discretized grid computing (mesh), unlike the analytical model which is valid for any field, including the discretized. The transformation is necessary because its structure is made to work with computer programs (numerical models) [5, 6].

3. **Experiment and comparison of data obtained with the results of modeling**

In the experiment a 9 mm caliber bullet was directed on an armored area-based on composite cellular AlMg-SiC. In order to study the surface deformation armor, composite initial target surface was covered with an epoxy resin stabilization (retain small microparticles that appear at the impact). After impact is obtained as one image shown like in figure 2 and reversed in a FEA modeling in figure 3.

![Figure 1. Initial situation of the experiment with the composite and projectile presentation.](image-url)
Figure 2. Armor surface deformation that resulted from the impact of projectiles.

Figure 3. Generating FEA analysis grid with mesh grid representation of the composite surface area of impact projectiles.

For example we have chosen a two-dimensional rendering of the antiballistic experiment for the armor with low section of 20 mm (armor that can be used against small caliber weapons). The pictures show the key steps in ballistic behavior play three distinct ways in which you can assign sequential grid-simplified representation of the armor structure (figure 4).

The figures below show the updated image projectile in three phases with modification and composite structural deformation due to ballistic impact.

Figure 4. Application modeling to present sequential volume changes that occur as a result of the projectile impact with the composite surface; a. initial geometry of the assembly projectile- ballistic protection surface, b - representation of quasi-ballistic impact initial presentation of deformation and perforation armor, c - the final state of play time blocking projectile impact and occurrence of major geometric deformation; deformations occur in projectile by its bulging with shortening and deformation of cells that makes up the composite armor structure.

For modeling and numerical simulation parameters were used with minimum values determined experimentally or calculated from the table 4.

Table 4. Maximum values for modeling and numerical simulation.

| Characteristics of material | Unit of measurement | Values       |
|----------------------------|---------------------|--------------|
| Young’s modulus - E        | N/mm²               | 42780        |
| Poisons coefficient - ν     | -                   | 0,27         |
| Tensile strength – σ       | N/mm²               | 125          |
| Density - ρ                | kg/m³               | 2000         |
| Projectile speed - vp      | m/s                 | 300          |
| Projectile mass -mp        | kg/s                | 0,015        |
| Friction coefficient - μ    | -                   | 0,22         |
| Average hardness - HB      | -                   | 90           |
| Von Mises criterion – maximum value | Pa | 4,4x108 |
On electron microscopy SEM analysis of the impact zone, we can see that a crater formed by deformation, just as a result of laminar flow-plastic composite after ballistic impact (figure 5). We also observed small loose particles composite wall and a major deformation type ductile matrix composite flow especially in the tilt angle under which hit ballistic projectile.

**Figure 5.** Image of the impact area resulting from the penetration of the tip projectile in composite volume. Small fragments results are deposited in the impact crater.

**Figure 6.** Laminar flow deformation and destruction of composite walls adjacent at the impact area. High composite compressions due to kinetic energy and armor matrix deformation.

After the projectile impact occurs practically most of the times a major deformity especially the bullet tip. The areas most affected are those little grooves on printed and formed projectile due to existing rifling print a ballistic trajectory correct (a procedural motion to maintain the most accurate trajectory of the bullet). Composite near the impact zone it is suffer important deformation in the volume structure; deformation being a function of speed, projectile mass and length of the ballistic trajectory [7].

Figure 8 shows when it is considered that over 95% of the kinetic energy of the projectile has already been transmitted to the cellular composite armor. Playing network at this time is difficult because the network can no longer represented faithfully take two bodies deformations due to the impact. FEA (Finite Element Analisys) details are very hard to find and even in the FFE (Fast Finite Element) system, but it can be also performed a presentation of the ballistic behavior in FFE network representation. Modeling system generates a detailed representation of volumetric deformation around the projectile in the final stage to unlock the armor. Modeling highlights some of the features of plastic deformation that we presented above electron microscopy analysis which identifies the matrix plasticity around the projectile.

**Figure 7.** Finite element analysis that highlights of maximum impact stress areas for a projectile with conical tip which penetrates the composite. Maximum tension recorded on the basis of von Mises criterion involves maximum deformation of the composite.

**Figure 8.** Finite element analysis that highlights the areas that suffered major destruction effects both for surface impact armor and for the projectile that penetrated the armor.
Figure 9. The correlation obtained based on the study for a projectile weighing 15 g and composite armor AlMg15 cell density of 2 kg/dm$^3$ with 15% SiC particles added.

There is a good modeling correlation made based on finite element analysis, with the results that analyzes the impact zone microscopy. It is noteworthy that almost all values for impact energy absorbed are in the active area of protection provided by the composite armor. From the chart below it can be easily seen that the 20 mm armor made from cellular composite presents sufficient efficiency for a 9 mm projectile (figure 9).

4. Conclusions
The study of this paper is reduced in principle to present only the effect of the impact that it has a small or medium caliber bullet on a lightly armored being constructed of a metal composite cellular/foam from AlMg-SiC. We could thus define based on FEA analysis and electron microscopy, which were the elements of antiballistic behavior, qualities of the cellular composite armor and some effects that occur with the bullet impact with the armor surface.

After the impact in the case of the projectile is practically most often a major deformation and in particular the tip of the bullet. The composite it’s suffer important deformation at the volume structure near the impact area, deformation being function of speed, projectile mass and ballistic trajectory length.

There are practical for these type of composites a wide range of applications and combinations to achieve ballistic armor for military vehicles in particular.

References
[1] S Nimmala 2014 A comparison of DYNA3D, NIKE3D and LS-DYNA (Oregon State University) http://www.llnl.gov/str/Raboin.html
[2] http://simage1.sportsmansguide.com/adimgs/l/1/186220i_ts.jpg
[3] MSC Nastran for Accurate, Efficient & Affordable Finite Element Analysis http://www.mscsoftware.com/Contents/Products/CAE-Tools/MSC-Nastran.aspx
[4] Bullet Body Armour – Anti-Ballistic http://www.anti-ballistic.com/shop/
[5] Zohdi T I 2002 Modeling and Simulation of Progressive Penetration of Multilayered Ballistic Fabric Shielding Comput. Mech. 29(1) pp 61-67
[6] Lim C T, Shim V P W and Ng Y H 2003 Finite-element Modeling of the Ballistic Impact of Fabric Armor Int. J. Impact Eng. 28 pp 13-31
[7] Grujicic M, Pandurangan B, Zecevic U, Koudela K L, B A and Cheeseeman B A 2007 Ballistic Performance of Alumina/ S-2 Glass-Reinforced Polymer-Matrix Composite Hybrid Lightweight Armor Against Projectiles Multidiscipline Modeling in Materials and Structures 3 pp 287-312
[8] Wong A K and Connors M L 1971 A Literature Survey on Correlation of Laboratory Tests and the Ballistic Resistance of Rolled Homogeneous Steel and Aluminum Armors. Technical Report AMMRC SP 72-10 (Watertown MA: Army Materials and Mechanics Research Center)
[9] Mamalis A G et al. 1997 Crashworthy capability of composite material structures Composite structures 37 pp 109-134
[10] Jones N 2010 Energy-absorbing effectiveness factor Int. J. Impact Eng. 37 pp 754-765
[11] Maine E M A and Ashby M F 2002 Applying the investment methodology for materials (IMM) to aluminium foams Materials & Design 23 pp 307-319