COMPUTATIONAL ANALYSIS OF PROJECTILE IMPACT RESISTANCE ON ALUMINIUM (A356) CURVILINEAR SURFACE REINFORCED WITH CARBON NANOTUBES (CNTS) FOR APPLICATIONS IN SYSTEMS OF PROTECTION

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Abstract. Computational tests for ballistic impact energy absorption were developed on A356/CNTs composite material with the goal of estimating the improvement of the material's mechanical properties by the contribution of the CNTs [1]. For the implementation of computational tests on the material exposed to projectile impact, A356/CNTs was configured by means of generalized Hooke's model for anisotropic materials [1] and Johnson-Cook's model was used to determine material failure and propagation of energy [2]. A curvilinear surface (semi-spheres on a plaque) with an area of 23x23 cm and thickness of 12 mm was elaborated to represent the composite material. The impact on surface was done with a 9 mm projectile and the surface was developed with 4.5 mm radium semi-spheres. It was used a 0.3% of nanotube insertions on the composite total volume. The results indicated the plaque stopped the impact without drilling. Incidence of damage to wearer, as well as possibility of composite material improvement and the diffusion/dispersion analysis on the curvilinear surface was also done.

1 INTRODUCTION

A curvilinear plaque was elaborated in order to determine the behaviour of the surface when subjected to impact dynamic force. Semi-spheres of 4.5 mms de radium were designed on the surface since this geometric shape provides greater resistance to the material. The materials' properties values used during ballistic computational tests for A356/CNTs composite with a material type A356 and for CNTs were given a stiffness module of 1.81e12 Pa and a Poisson ratio of 0.45 [3, 4, 5]. During computational tests, finite elements analysis (FEA) was used to study the behavior of A356/CNTs composite.

A mesh was elaborated in order to determine the behavior of the surface when subjected to impact dynamic force. Solid elements were used to develop the mesh. NOM-166-SCFI-2005 was the main guideline for the development of simulations and the determination of ballistics-specific characteristics [13].

2 MATHEMATICAL MODELING

For the implementation of computational tests on the material exposed to projectile impact, A356/CNTs was configured by means of generalized Hooke's model for anisotropic materials [7, 8] and Johnson-Cook's model was used to determine material failure and propagation of energy [7, 8]. In Hooke's model, composite density was calculated from mass proportions [7, 8, 9, 10, 11]:

$$\rho_c = \frac{1}{\frac{m_{AL}}{\rho_{AL}} + \frac{m_{NTC}}{\rho_{NTC}} + \frac{V_V}{\rho_C}} \tag{1}$$

m_{NTC}, m_{AL} are the mass proportions of the constituent and Vc is the proportion in void volume. Johnson-Cook's Constitutive Model describes the relationship between stress, strain, strain rate and visco-elastic material temperature [8, 9, 10, 11].

This model is appropriate in a situation where strain rate varies between $10^2 s^{-1}$ and $10^6 s^{-1}$ and temperature varies according to plastic deformation caused by thermal softening. Stress flux model is represented as in (8) [8, 9]:

$$\sigma = (A + B\varepsilon^n)(1 + C\ln\dot{\varepsilon}^*)(1 - T^{*m}) \tag{2}$$

In (2) T is the system temperature, $\dot{\varepsilon}^*$ is the velocity of equivalent plastic deformation, ε is the equivalent plastic deformation, A is the initial cadence stress (MPa), B is the hardening module, n is the strain hardening exponent, C is the strain-rate dependent coefficient and m is the thermal softening coefficient.

The materials' properties values used during diffusion process and ballistic computational tests for A356/CNTs composite with a material type A356 and for CNTs were given a stiffness module of 1.8×1012 and a Poisson ratio of 0.45 [9,10,11].

The fracture model is combined with the criteria of Cockcroft and Latham where the element is eroded when $D = 1$, is described as [8, 9, 10, 11]:

$$D = \frac{1}{W_{cr}} \int_0^{\varepsilon eq} max(\sigma_1, 0) d_{\varepsilon eq} \tag{3}$$

Where: $\sigma_1$main maximum stress, W_{cr} total plastic work.

3 COMPUTATIONAL MODELING

A curvilinear plaque with an area of 23x23 cm and and thickness of 12 mm was elaborated to represent the composite material, fig.1.

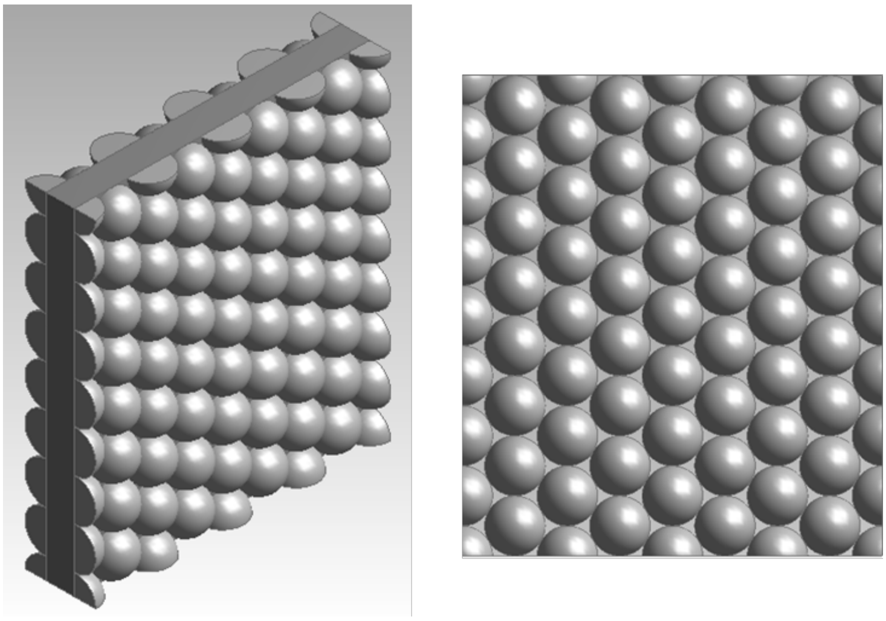

Figure 1. Three-dimensional plate with semi-spheres and core (test panel).

A Parabellum 9mm caliber projectile was selected to perform the tests. Based on international standards for shielding and ballistic testing [13, 14, 15], criteria and reference data for computational tests were determined. Projectile velocity of 436 m/s ± 9.1 m/s, dimensions and geometric characteristics were selected as show the fig. 2.

Figure 2. Parabellum 9mm-caliber projectile.

The system of the plate and the projectile is presented, fig. 3.

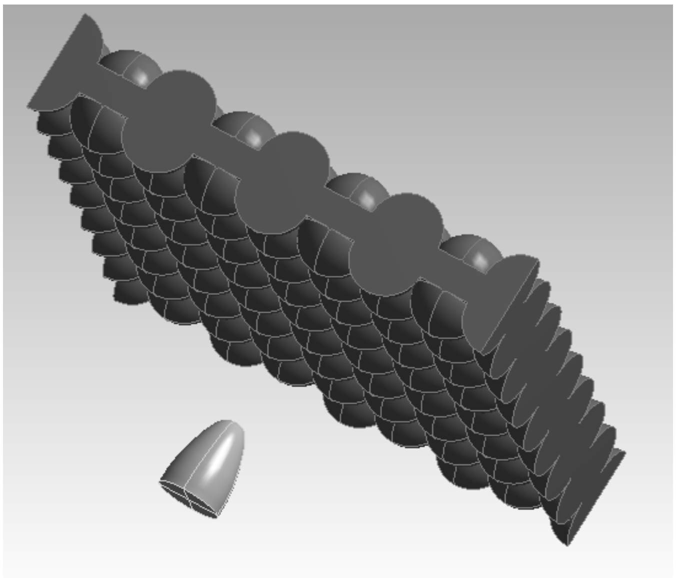

Figure 3. Plate-projectile system for the development of impact tests

4 NUMERICAL MODELING

During computational tests, finite elements analysis (FEA) was used to study the behavior of A356/CNTs composite. A mesh was elaborated in order to determine the behavior of the plaque when subjected to dynamic impact energy. 3D elements of 20 nodes were used to develop the mesh, fig. 4.

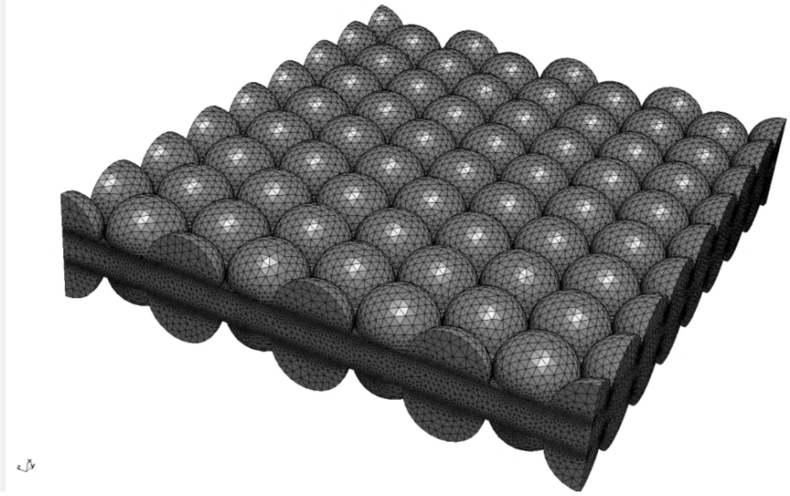

Figure 4. Meshed of the 3D curvilinear plate by means of solid elements.

In the same way, another numerical mesh for the 9 mm-caliber projectile was elaborated. This projectile impacted the curvilinear plaque, fig. 5.

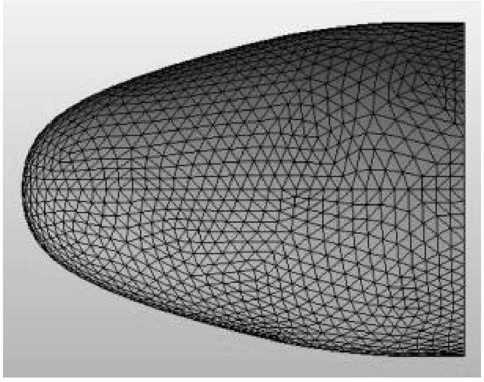

Figure 5. Meshed of the 9 mm-caliber brass projectile.

5 RESULTS

Mechanical tests performed on the impact-subjected A356/CNTs composites indicated that reinforcement material favor the composite's mechanical properties, achieving energy dissipation-absorption and effectively stopping the projectile trajectory.

Results were validated by means experimental tests where the surface was impacted by a Parabellum projectile. Results of the simulations and of the experiments tests were similaires. In general, the results showed the composite exhibited kinetic energy dissipation modes and a capacity to diminish impact damage, fig 6 and fig. 7.

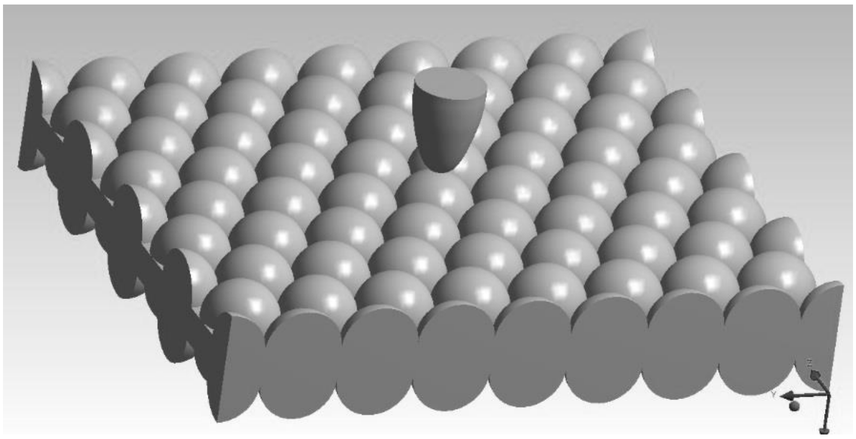

Figura 6. Initial position of projectile and panel A356 before impact.

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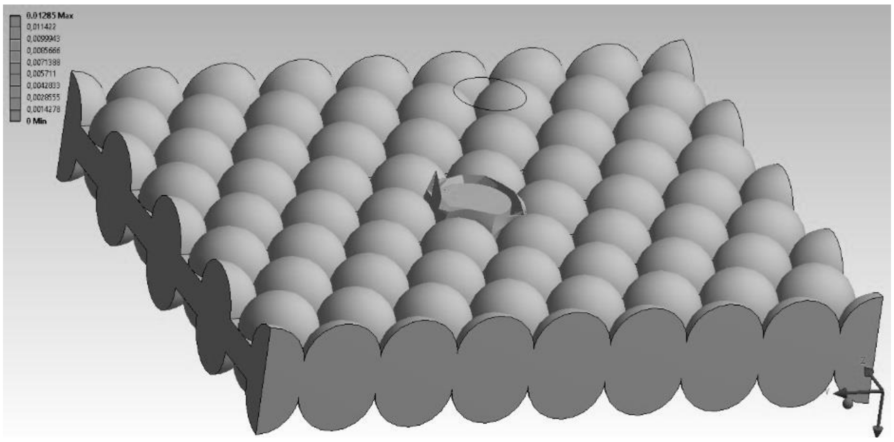

Figure 7. Penetration of the projectile in the impact without perforation.

6 CONCLUSIONS

- Several simulations were executed on an A356/CNTs plaque subjected to dynamic impact load until the perforated surface didn't pass the security limit defined by NOM-166-SCFI-2005 guidelines. Simulations considered a solid projectile in order to grant the design a higher safety factor.
- The most favorable result was achieved using a plaque made of semi-spheres.
- This research offers insight on how perforation of composite materials subjected to ballistic impact is generated. Incidence of damage to wearer, as well as possibility of reinforcement improvement and diffusion/dispersion of CNTS in A356 is also discussed.

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