The 4th International Conference
"Computational Mechanics
and Virtual Engineering"
COMEC 2011
20-22 OCTOBER 2011, Brasov, Romania

THE INFLUENCE OF CONCENTRATED LOADS ON COMPOSITES REINFORCED WITH WOVEN FIBER GLASS

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Abstract: *In order to assess the behavior of composite plates when subjected to concentrated loads, two types of specimens reinforced with glass fiber fabric were studied, with concentrated loads applied dynamically. Specimens were obtained by two different methods, casting. The tests were conducted on plate specimens with dimensions of* $150x100x2.5mm^3$.
During the impact (initial signal and smoothed) acceleration changes were followed, together with the variation of contact force, power curve - travel, travel time curve, and changes in energy absorbed by the plate. Research goal of this work is to determine the textile composite behavior when subjected to dynamical loadings and determine the optimal casting method that ensures superior mechanical properties for textile composite material.
Keywords: *composite material, woven, glass, experiment.*

1. INTRODUCTION

The behavior of composite material reinforced with E-glass in impact conditions with solid objects is the subject of many numerical, analytical and experimental research projects [1,2,3,6, 8, 9]. Nevertheless, the problem has yet to be solved or fully understood. Nowadays are three approaches are used to quantify the interaction of the penetrator and of the composite material: empirical, numerical and analytical methods [2]. The empirical methods seek to establish simple relations between some of the parameters which define the interaction between the projectile and the composite material including their properties, their geometry and its velocity [2, 9]. These parameters together with some others experimentally measured such as penetration depth, ballistic limit velocity etc, lead to parametric equations. This method is useful only when a very limited number of variables need to be correlated. The numerical methods are based on finite elements or finite differences codes[7, 8, 9, 11]. Since the equations governing the impact of solids are in general nonlinear, numerical analysis of penetration mechanics allows a more adequate representation and more precise simulations of the process. The disadvantages of this method arise from the high computer time required. The analytical methods enable the study of penetration mechanics from the general continuum mechanics equations. The goal is the development of models for approximating in the closest way the materials behavior.

This paper presents the results of an experimental method developed by the authors, which describes the analysis of concentrated loads on composites reinforced with woven fiber glass. To assess the behavior of composite plates when subjected to concentrated loads, two types of specimens reinforced with glass fiber fabric applied to concentrated loads applied dynamically were studied. These specimens were obtained by two different methods, casting [3,6].

The analytical analysis of the response is difficult to be conducted due to the fact that the plate transitory motion is coupled with a non-linear impact phenomenon. In the case of an elastic impact, for the composite plate leaned against the outline analytical solutions in Kirchhoff and Mindlin-Reissner plate theory can be found [9].

2. ANALYTICAL MODEL

The problem considered is as follows: a rigid projectile of mass m and velocity v impacts a woven composite material which is considered to be a plate made of n layers of fabric. All plies are assumed to possess the same wearing as well as basis weight. A complete model [1,2,3] is the one that takes into consideration the structure's dynamics, projectile's dynamics and the contact force. In the case of simple supported plates along the edges one can use the Navier's solution in order to obtain a closed-form solution for the transitory response. Subsequently, in this simple case one can be developed a complete model for impact problems. In accordance with the classic plate theory, for a symmetric laminated plate, without bending-twisting coupling ($D_{16}=D_{26}=0$), the displacement equation of the plate loaded by a concentrated force may be written under the form:

$$D_{11}\frac{\partial^4 w}{\partial x^4}+2\left(D_{12}+2D_{66}\right)\frac{\partial^4 w}{\partial x^2\partial y^2}+D_{22}\frac{\partial^4 w}{\partial y^4}+I_1\ddot{w}=F(t), \tag{1}$$

where D_{ij} is the bending stiffness, $I_1=\rho h$, w is the transversal displacement abd $F(t)$ is the external force. The eq. (1) and the outline conditions are satisfied when the displacements are developed in double series. The projectile's displacement, s, stands for: $s=\delta+w$. This verifies the equation:

$$M_1\ddot{s}+P(t)=0, \tag{2}$$

with the initial conditions $s_0=0$, $\dot{s}_0=V$ out of which, through integration one can determine the projectile's displacement. By replacing the equation $s=\delta+w$, the non-linear integral equation that was solved interactively by using the trapezoid formula is obtained, which is used to calculate the integrals with the MATLAB program. In case of impacts in the plate's center, the result obtained is:

$$F(t)=\kappa_c\left(V\cdot t-\frac{1}{M_1}\int_0^t F(\tau)(t-\tau)d\tau-\frac{4}{\rho\cdot a\cdot b\cdot h}x-x\sum_{j=1,3,5}^{\infty}\sum_{k=1,3,5}^{\infty}\int_0^t\frac{1}{\omega_{jk}}F(\tau)\sin[\omega_{jk}(t-\tau)]d\tau\right)^{3/2}. \tag{3}$$

In order to model the contact the Hertz's contact law was used. It was supposed that the projectile has a spherical form and the Hertz's contact law is valid for the dynamic case as well where $\kappa_c=4/3E_3R^{0.5}$ [9].

2. EXPERIMENTAL PROCEDURE

Two types of specimens reinforced with glass fiber textile subjected to dynamically applied concentrated loads were studied in order to experimentally determine the behavior of the composite plates subjected to concentrated loads. The specimens were manufactured by reinforcing an epoxy resin with a EWR300 woven fabric. The EWR300 woven fabrics are made of continue *E*-glass fibers with cut margins which are consolidated by using a *Dreher* bond with filaments. Two different manufacturing strategies were used to obtain the specimens. The hand lay-up technology is used to prepare the specimens with two different pressures in the molding step: low (A) and high pressure (B). The first set of specimens is named A, numberd from 190-220; the second set is named B nd numbered from 30-50. Some characteristics of EWR300 woven fabric are known: weight $\gamma=315\pm5\%\,g/mm^2$, thickness $g=0.3\pm0.05\,mm$, tensile strength $\sigma=1750N/a\ narrowstrip\ of\ 50x0.3\ mm^2$ in case of the warp, tensile strength $\sigma=2500N/a\ narrowstrip\ of\ 50x0.3\ mm^2$ in case of the weft.

Figure 1 The device used to apply the load through free fall.

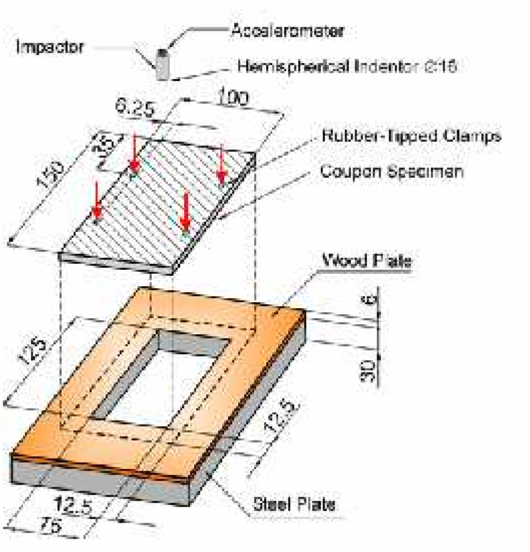

Figure 2. The geometry of the specimen and the fixture mode.

In order to apply the load a specially designed devise was used, as shown in figure 1. The size of the specimen was 150mm x100mm x 4mm and the fixing and loading positions used are as decribed in figure 2. The weight of the projectile is 1.9 kg and the loading was done with speeding of 1 to 5m/s. Two speciments were tested for each height used for loading.

The dall height and the impact acceleration was measured. By integration, the speed variation, the resulted displacement and the variation of the energy that was transmited tot he plate was determined. The impact test was conducted by making use of the device designed for this particular goal, having the energy capacity of 1-50J which was obtained by adjusting the height and/or the weight. Figure 3 presents the Lab View signal procession scheme. All graphics were obtained by using Matlab code.

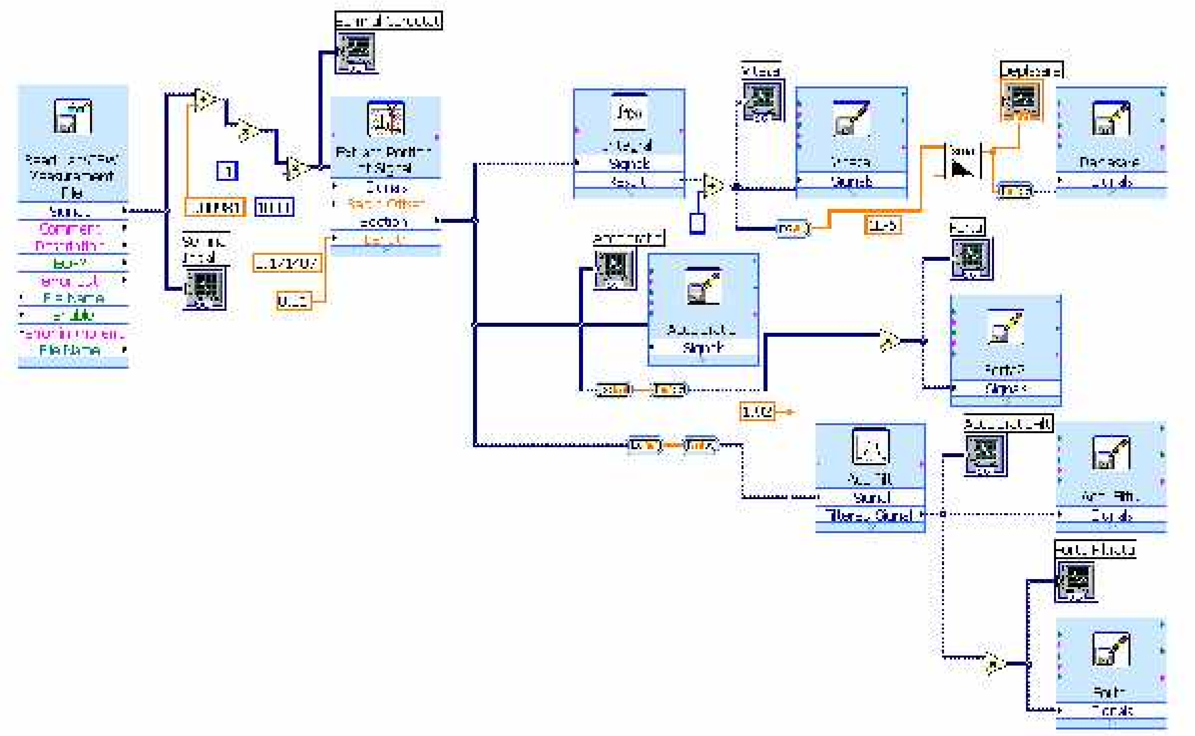

Figure 3. The bloc scheme used in Lab View for signal processing

The graphic results for some specimen are presented in this paper and include:

- The variation of acceleration at the time of impact (initial and averaged signal),
- The variation of the contact force (initial and averaged signal),
- The courve of force – displacemnet,
- The courve of time – displacemnet,
- The variation of energy absorbed by the specimen.

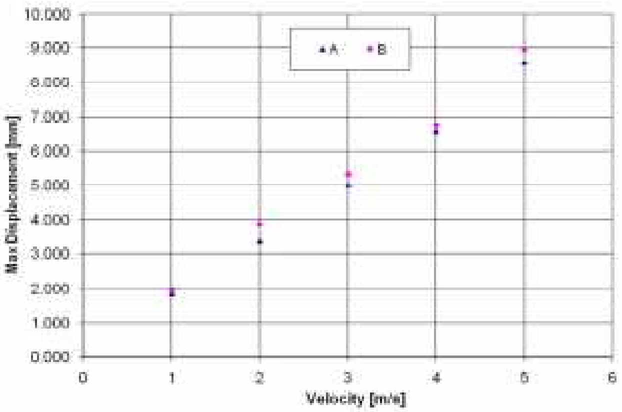

Figure 4. The average displacements recorded according to the initial velocity of the projectile for each specimen type.

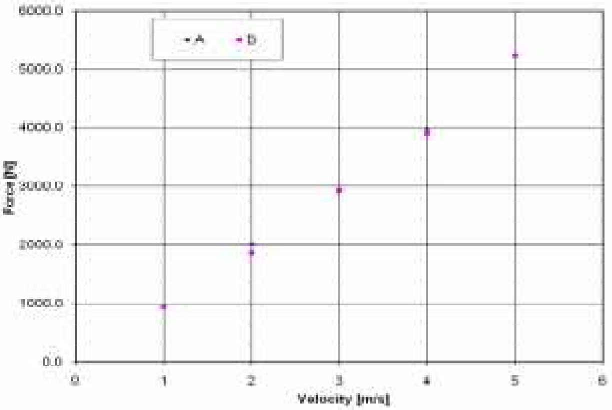

Figure 5. The average values of the maximal contact forces recorded at the time of impact as function of the initial speed for each specimen type.

In figures 4 and 5 are compared to the average values of displacements and contact forces recorded for each type of specimen.

Figure 6. The damage resulted for a type A specimen - number 209 – subjected to an impact with an initial speed of the projectile of 2m/s.

Figure 7. The damage resulted for a type B specimen – number 31) subjected to an impact with an initial speed of the projectile of 2m/s.

In figures 6 and 7 are given damage recorded specimens of type A and B, required the impact of the projectile at an initial rate of 2m / s. In figures 8 to 15 are some answers to the impact made when specimens A and B.

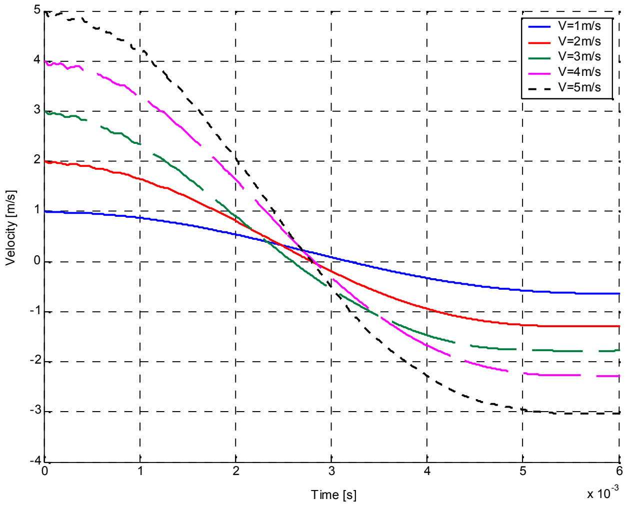

Figure 8. The speed variation recorded at the time of impact (type A).

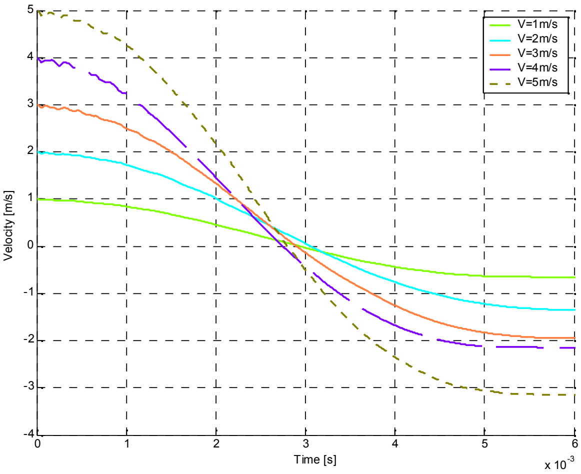

Figure 9. The speed variation recorded at the time of impact (type B).

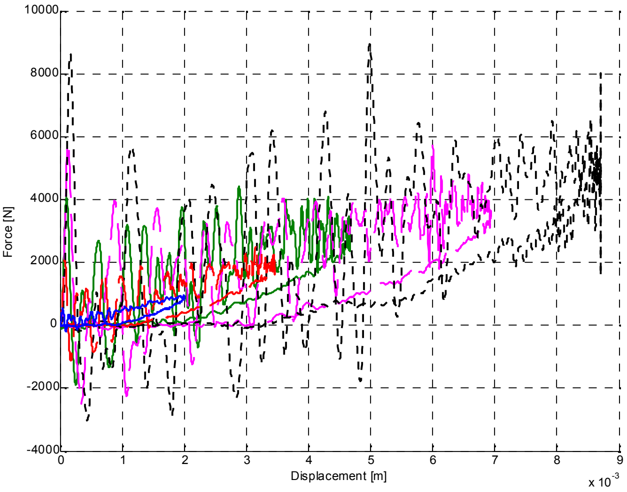

Figure 10. Force – displacement curves recorded at the time of impact (type A specimens).

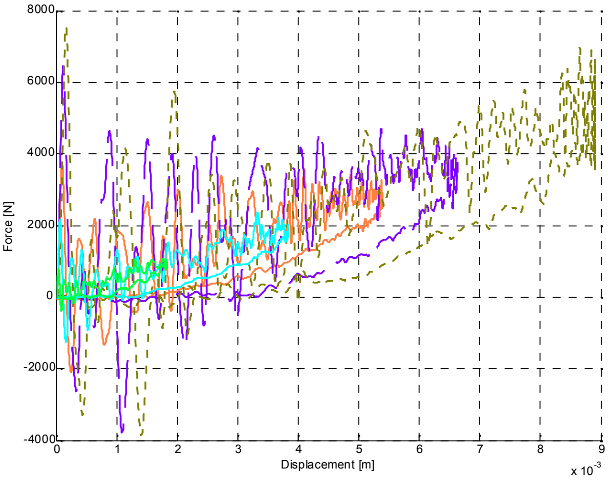

Figure 11. Force – displacement curves recorded at the time of impact (type B specimens).

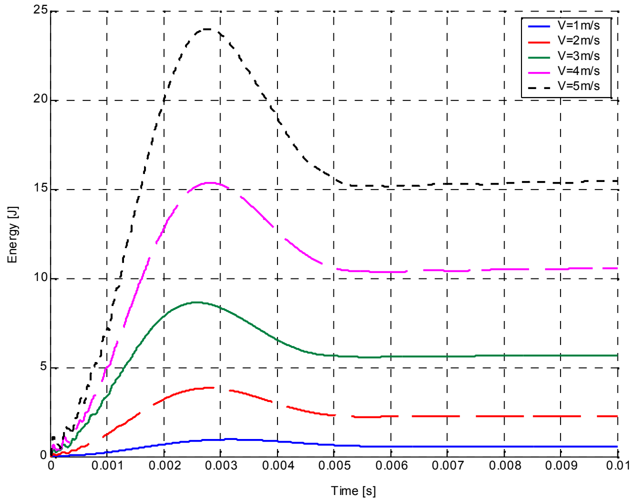

Figure 12. The transferred energy variation at the time of impact (specimens type A).

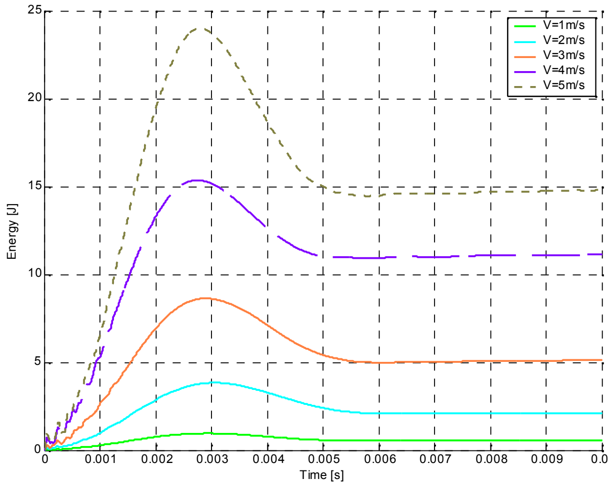

Figure 13. The transferred energy variation at the time of impact (specimens type B).

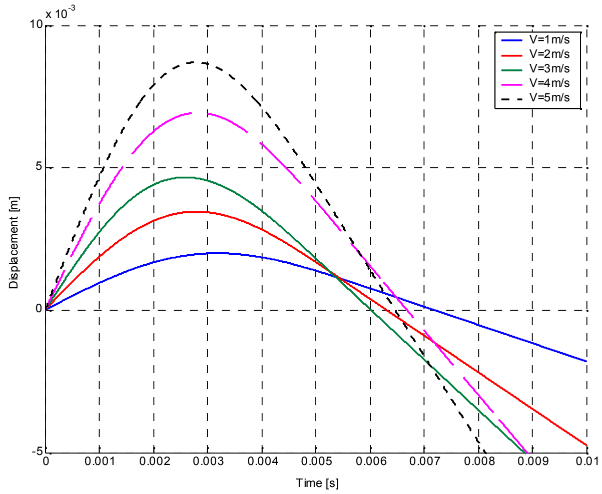

Figure 14. The displacement – time curves recorded at the time of impact (specimens type A).

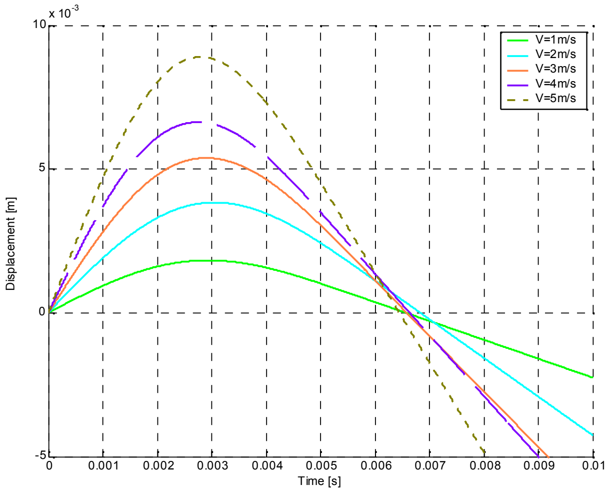

Figure 15. The displacement – time curves recorded at the time of impact (specimens type B).

3. CONCLUSION

The figures 13-15 present the results recorded at the time of impact for the specimens A and B. By taking into account the results presented in figures 4 and 5 the following conclusions emerge:

- The projectile's displacement and velocity after impact were obtained by successive integration of projectile's acceleration.
- The energy absorbed by the plate represents a small part of the initial kinetic energy for the low velocity impact and, in case of perforation; the whole energy of the projectile is to be transferred to the plate.
- One can notice that at low velocity impact, the maximum energy absorbed by the plate is reached simultaneously with the maximum values of the contact force and displacement - low velocity impact; consequently for these cases the method of energy conservation for response assessment can be applied;
- The type B specimens present small displacements for approximately the same maximal contact force values recorded at the time of impact;
- Visible damage was noted for initial speed of the projectile of 2m/s; For the type A specimens, a mate area were the matrix was deteriorated was noted. The load determined delamination and radial fissures that start in the contact area. For type B specimens, the mate area that corresponds to the damaged matrix and the induced delamination is visible at the level of the load application, with overall small radial fissures.
- The displacements introduced larger for the type A specimens. The mate area on the opposite surface is larger when compared to type B specimens.
- In order to increase the composite resistance and exterior sacrifice layer could be used in order to determine the spread of the concentrated applied load, thus leading to reduced deterioration.

ACKNOWLEDGEMENT

This work is supported by CNCSIS –UEFISCSU, project number PNII – IDEI 733 / 2008.

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