Universitatea *Transilvania* din Braşov

HABILIATION THESIS

CONTRIBUTIONS TO THE MECHANICS OF POLYMER MATRIX COMPOSITE MATERIALS

DOMAIN: MECHANICAL ENGINEERING

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BRAŞOV, 2015

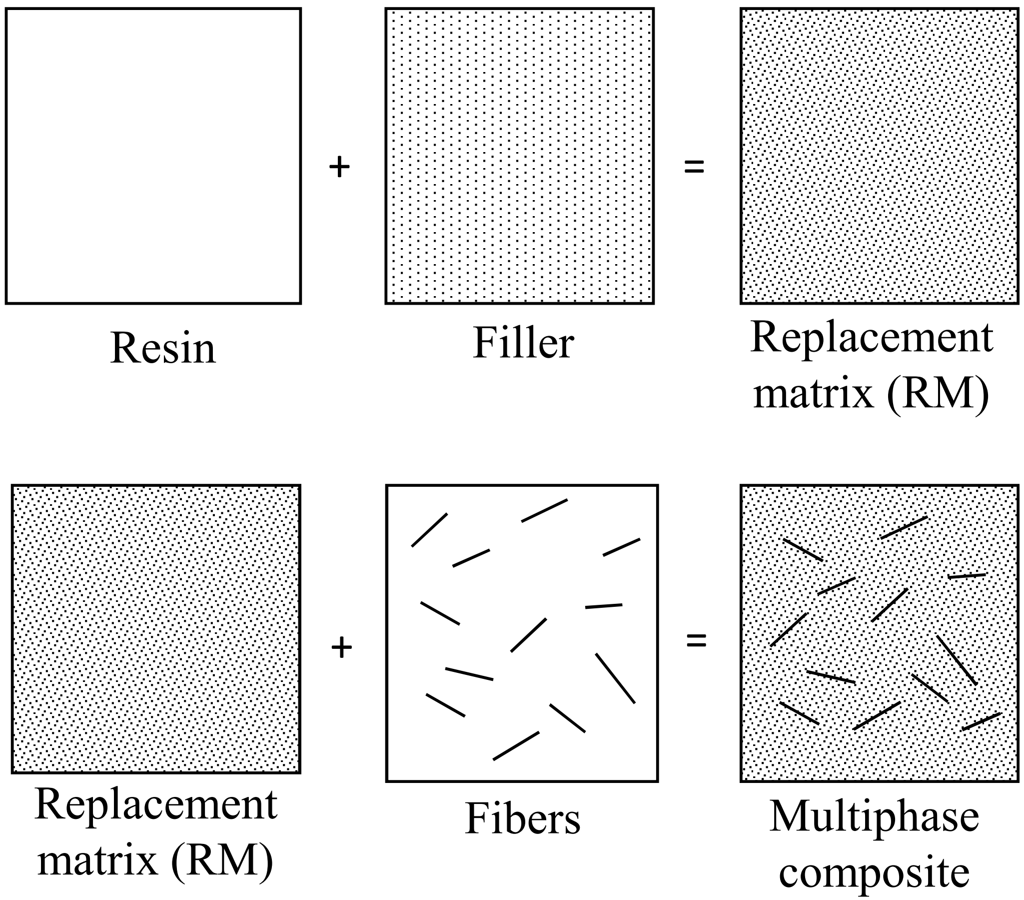
CONTENT

(B-i) Scientific professional and academic achievements

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials – Abstract of contributions

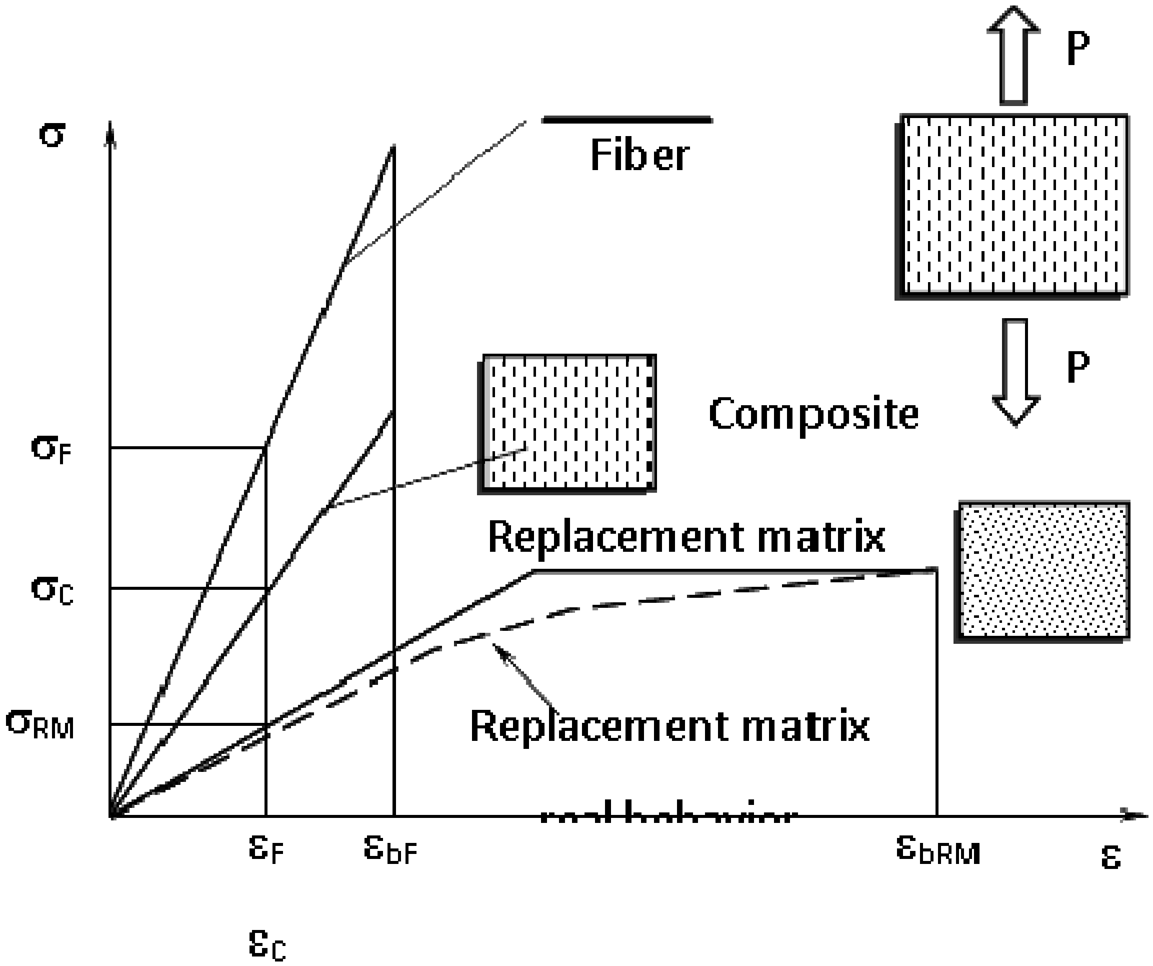
- One of my important contribution in the field of mechanics of polymer matrix composite materials has been published in *Computational Materials Science* in 2011 [45].
- My previous developments have been published in various proceedings [49], [51], [52], [55], [59], [60], [62], [67], [69], [70], [71], the last one being published in 2013 [43].
- The tensile strength computation of a multiphase Sheet Molding Compound (SMC) composite material takes into consideration the notion of substitute matrix formed by combination of resin and filler.
- I have computed the substitute matrix' Young's modulus as the harmonic mean between the elastic properties of the isotropic compounds.
- The determination of the upper and lower limits of the homogenized coefficients of a SMC composite material with 27% fibers volume fraction.
- I have used three averaging methods of the elastic properties of this material.
- The experimental results revealed close values to the arithmetic mean of the elastic properties of the isotropic compounds.

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials



Schematic representation of a multiphase composite

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials



Stress-strain schematic behavior of a pre-impregnated composite material

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials – Important relations

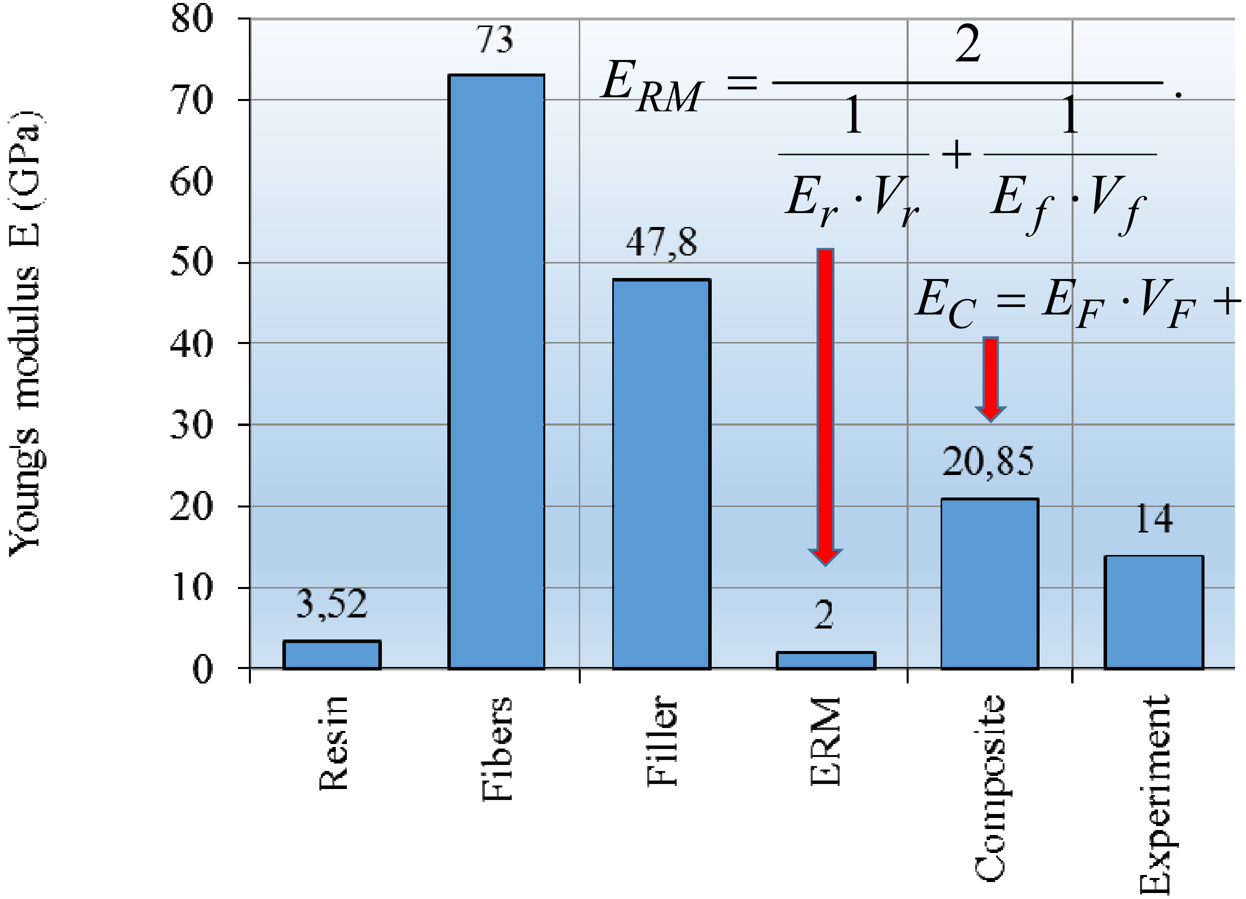
$$\sigma_C = \sigma_F \cdot V_F + \sigma_{RM} \cdot (1 - V_F). \qquad E_C = E_F \cdot V_F + E_{RM} \cdot (1 - V_F).$$

$$\sigma_{bC} = \sigma_{bF} \cdot V_F + \sigma_{RM'} \cdot (1 - V_F),$$

where σ_{bF} is the fibers break strength and $\sigma_{RM'}$ represents the replacement matrix stress at the moment when its strain reaches the fibers break strain ($\varepsilon_{RM} = \varepsilon_{bF}$).

$$\sigma_{bC} = \sigma_{bF} \cdot V_F + E_{RM} \cdot \varepsilon_{bF} \cdot (1 - V_F). \qquad E_{RM} = \frac{2}{\dfrac{1}{E_r \cdot V_r} + \dfrac{1}{E_f \cdot V_f}}.$$

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials - Results



$$E_{RM} = \frac{2}{\dfrac{1}{E_r \cdot V_r} + \dfrac{1}{E_f \cdot V_f}}.$$

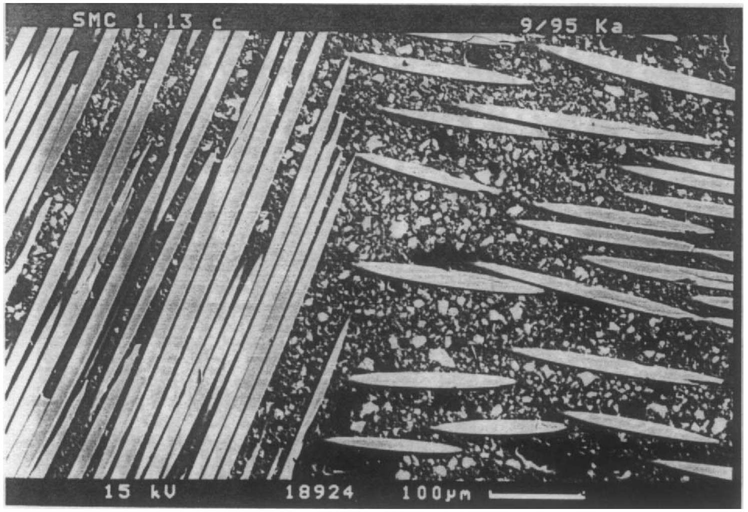
The inverse rule of mixture

$$E_C = E_F \cdot V_F + E_{RM} \cdot (1 - V_F).$$

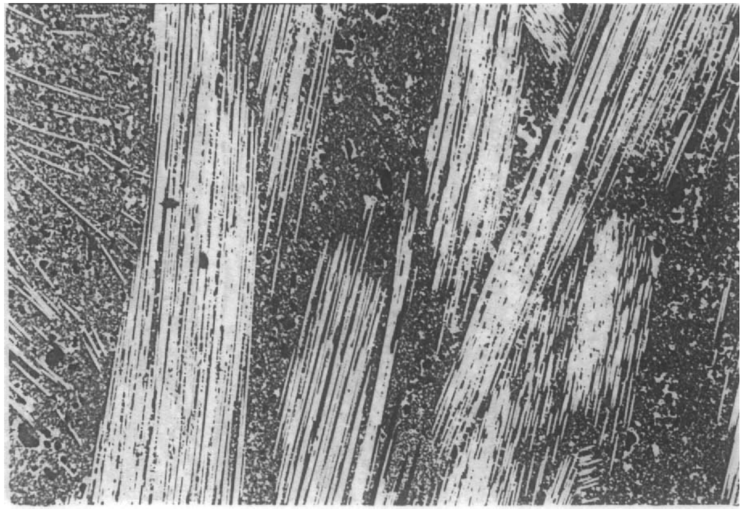
The rule of mixture

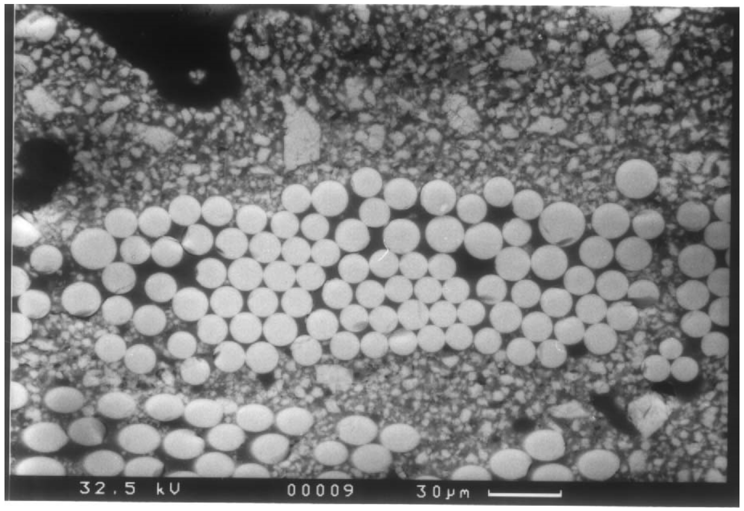
Young's moduli E_{RM} (replacement matrix) and E_C (composite) for a 27% fibers volume fraction SMC material

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials – SMCs micrographs

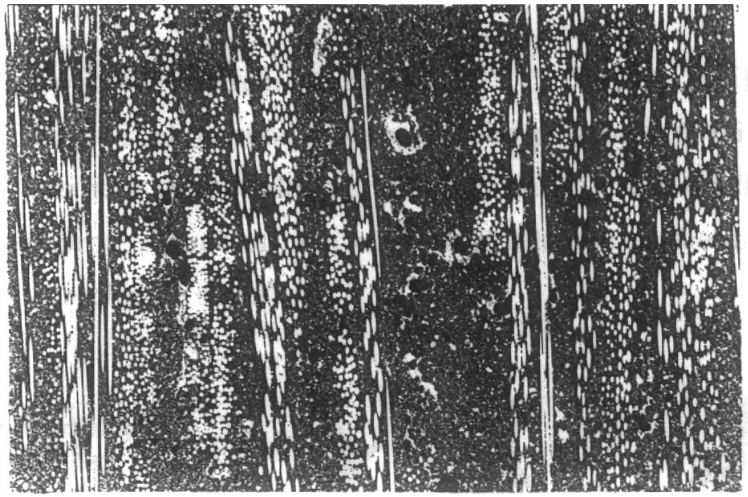


Micrographs of various SMC composite materials with various magnitudes taken in-plane

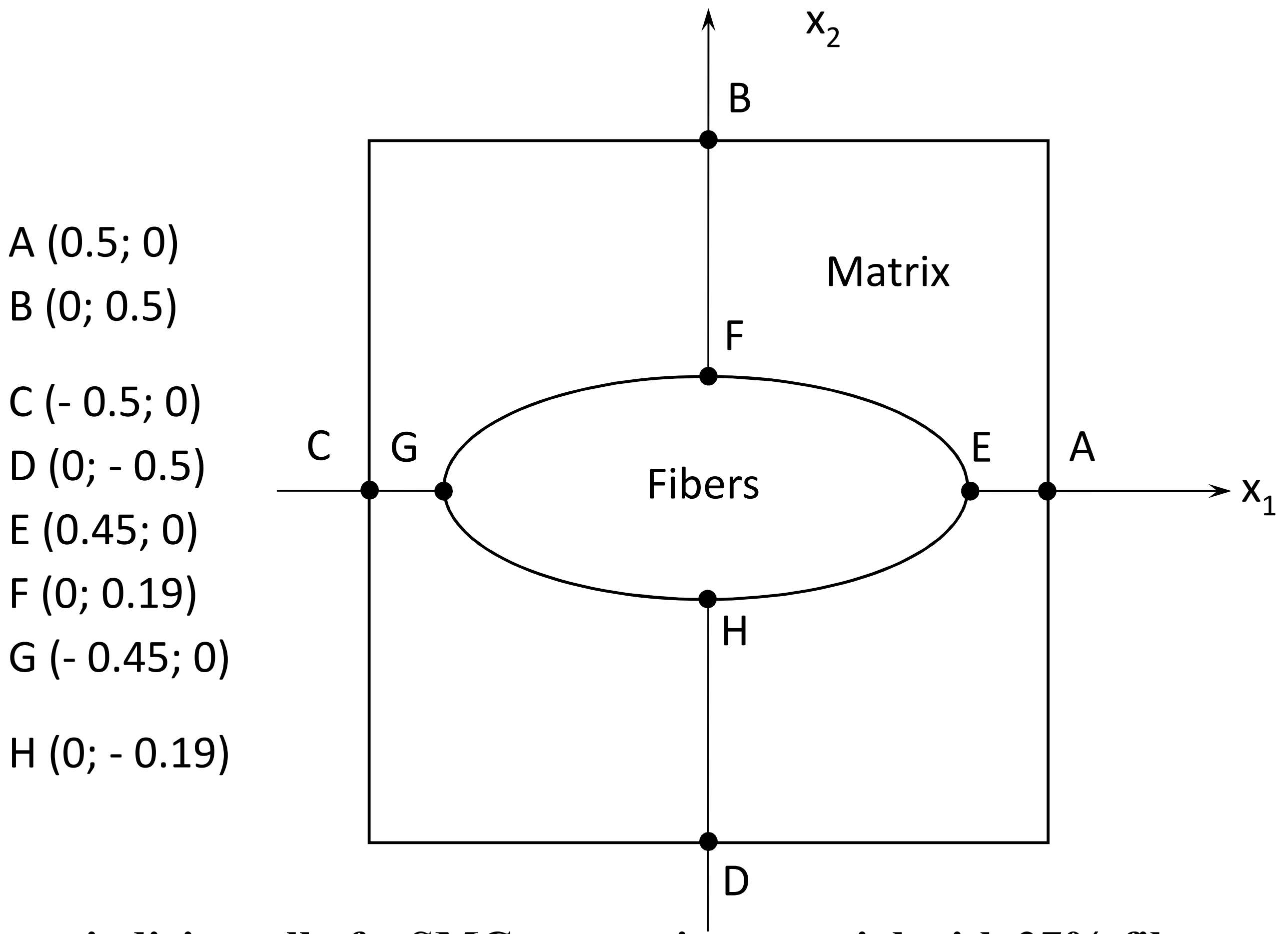




Micrographs of various SMC composite materials with various magnitudes taken perpendicular to their thickness



1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials – Prediction of elastic properties of a 27% fibers volume fraction SMC



Structure's periodicity cell of a SMC composite material with 27% fibers volume fraction

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials – Prediction of elastic properties of a 27% fibers volume fraction SMC. Upper and lower limits of the homogenized coefficients

- I have considered the function $f(x_1, x_2) = 10$ in inclusion and 1 in matrix. To determine the upper and lower limits of the homogenized coefficients, first the arithmetic mean as a function of x_2-axis followed by the harmonic mean as a function of x_1-axis must be computed.
- The lower limit is obtained computing first the harmonic mean as a function of x_1-axis and then the arithmetic mean as a function of x_2-axis. I have denoted with $\varphi(x_1)$ the arithmetic mean against x_2-axis of the function $f(x_1, x_2)$, so it follows:

$$\varphi(x_1) = \int_{-0,5}^{0,5} f(x_1, x_2)\,dx_2 = 1,\ for \quad x_1 \in (-0,5;\ -0,45) \cup (0,45;\ 0,5),$$

$$\varphi(x_1) = \int_{-0,5}^{0,5} f(x_1, x_2)\,dx_2 = 1 + 9,45\sqrt{0,2025 - x_1^2},\ for \quad x_1 \in (-0,45;\ 0,45).$$

- The upper limit is obtained computing the harmonic mean of the function $\varphi(x_1)$:

$$a^+ = \frac{1}{\int_{-0,5}^{0,5} \frac{1}{\varphi(x_1)}\,dx_1} = \frac{1}{\int_{-0,5}^{-0,45} dx_1 + \int_{-0,45}^{0,45} \frac{dx_1}{1 + 9,45\sqrt{0,2025 - x_1^2}} + \int_{0,45}^{0,5} dx_1}.$$

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials – Prediction of elastic properties of a 27% fibers volume fraction SMC. Upper and lower limits of the homogenized coefficients

- To compute the lower limit, I have considered $\psi(x_2)$ the harmonic mean of the function $f(x_1, x_2)$ against x_1:

$$\psi(x_2) = \frac{1}{\int_{-0,5}^{0,5} \frac{1}{f(x_1, x_2)} dx_1} = 1, \quad for \quad x_2 \in (-0,5; \ -0,19) \cup (0,19; \ 0,5),$$

$$\psi(x_2) = \frac{1}{\int_{-0,5}^{0,5} \frac{1}{f(x_1, x_2)} dx_1} = \frac{1}{1 - 3,42\sqrt{0,0361 - x_2^2}}, \quad for \quad x_2 \in (-0,19; \ 0,19).$$

- The lower limit will be given by the arithmetic mean of the function $\psi(x_2)$:

$$a_{-} = \int_{-0,5}^{0,5} \psi(x_2)\, dx_2 = \int_{-0,5}^{-0,19} dx_2 + \int_{-0,19}^{0,19} \frac{dx_2}{1 - 3,42\sqrt{0,0361 - x_2^2}} + \int_{0,19}^{0,5} dx_2 .$$

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials – Prediction of elastic properties of a 27% fibers volume fraction SMC. The material's coefficients estimation

- The material's coefficients estimation depends both on the basic elasticity properties of the isotropic compounds and the volume fraction of each compound.
- The upper limit of the homogenized coefficients can be estimated computing the arithmetic mean of these basic elasticity properties taking into account the volume fractions of the compounds:

$$A_a = \frac{P_M \cdot \varphi_M + P_F \cdot \varphi_F + P_f \cdot \varphi_f}{3}.$$

- The lower limit of the homogenized elastic coefficients can be estimated computing the harmonic mean of the basic elasticity properties of the isotropic compounds:

$$A_h = \frac{3}{\dfrac{1}{P_M \cdot \varphi_M} + \dfrac{1}{P_F \cdot \varphi_F} + \dfrac{1}{P_f \cdot \varphi_f}},$$

- An intermediate limit between the arithmetic and harmonic mean is given by the geometric mean written below:

$$A_g = \sqrt[3]{P_M \cdot \varphi_M \cdot P_F \cdot \varphi_F \cdot P_f \cdot \varphi_f},$$

where P and A can be the Young's modulus respective the shear modulus.

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials – Prediction of elastic properties of a 27% fibers volume fraction SMC. Results

Table 1. Typical elasticity properties of the SMC isotropic compounds and composite structural features

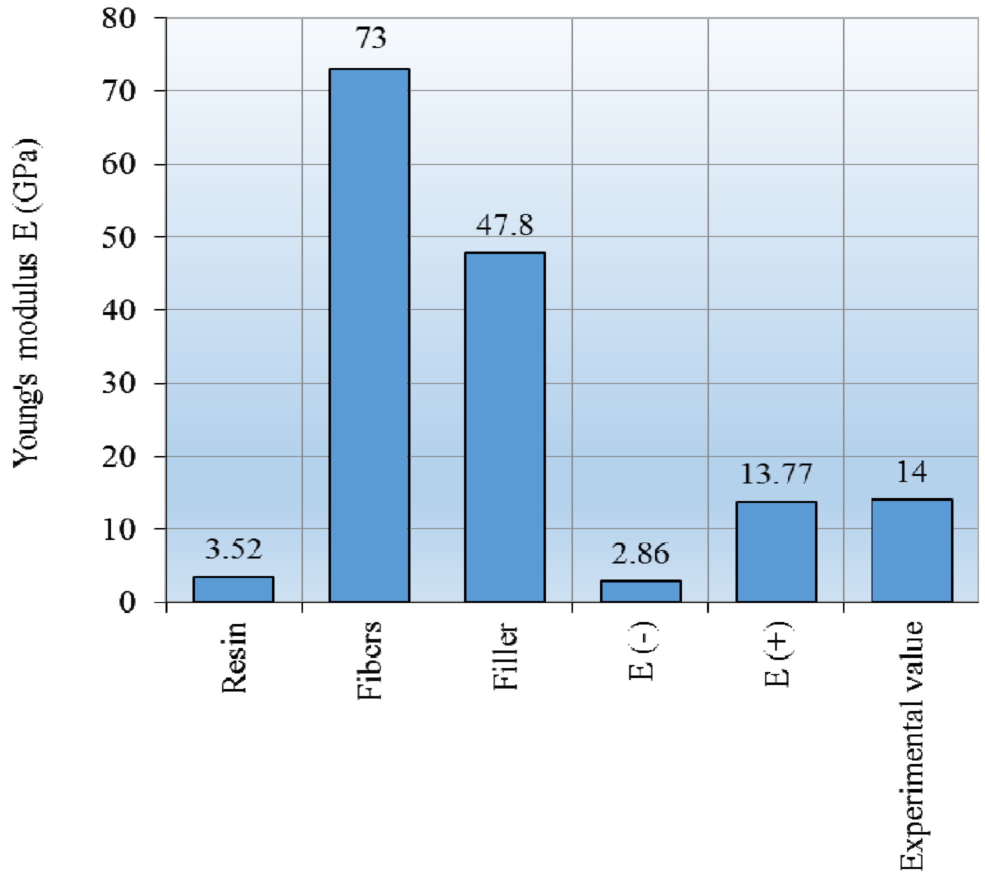
Property	UP resin	Fiber (E-glass)	Filler ($CaCO_3$)
Young's modulus E (GPa)	3.52	73	47.8
Shear modulus G (GPa)	1.38	27.8	18.1
Volume fraction (%)	30	27	43

Table 2. Upper and lower limits of the homogenized coefficients for a 27% fibers volume fraction SMC composite material

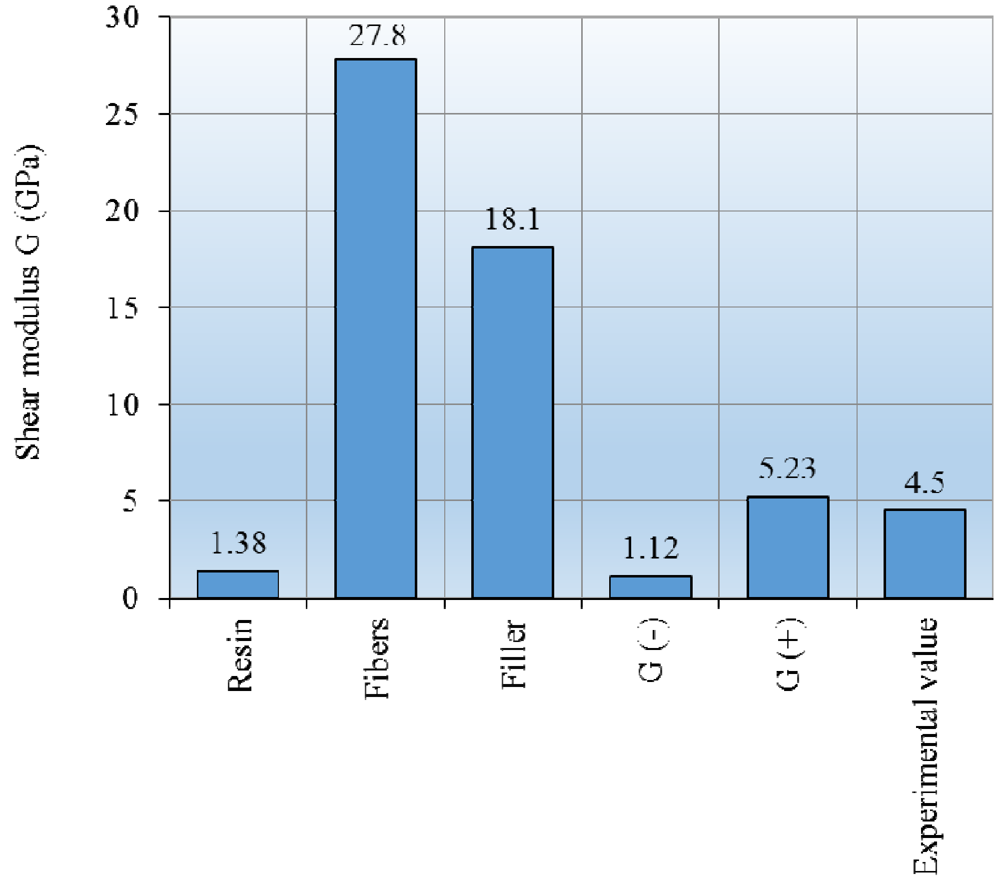
Angular variation of the ellipsoidal inclusion	Upper limit a^+	Lower limit a_-
0°	2.52	0.83
± 15°	2.37	0.851
± 30°	2.17	0.886

- The results presented in table 2, show that the upper limit of the homogenized coefficients decreases with the increase of angular variation of the ellipsoidal inclusion unlike the lower limit which increases with the increase of this angular variation.

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials – Prediction of elastic properties of a 27% fibers volume fraction SMC. Results

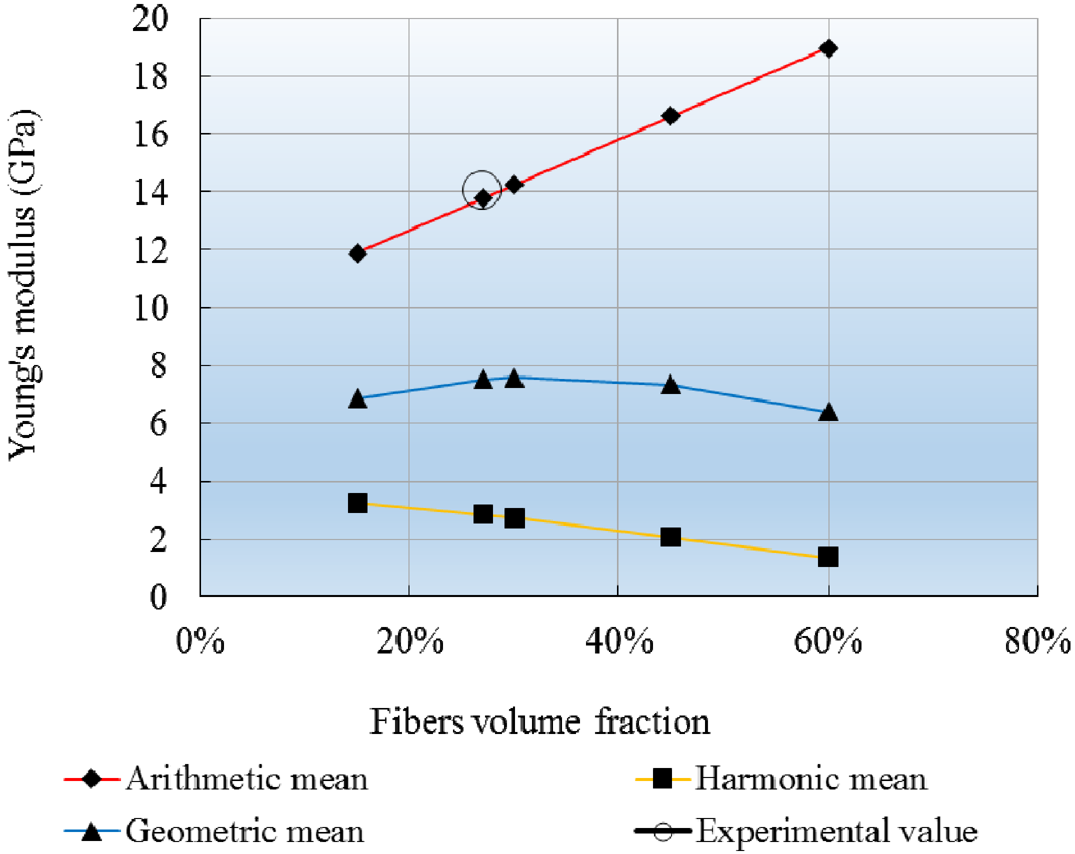


Young's moduli of the isotropic SMC compounds, the upper (E+) and lower limits (E-) of the homogenized elastic coefficients

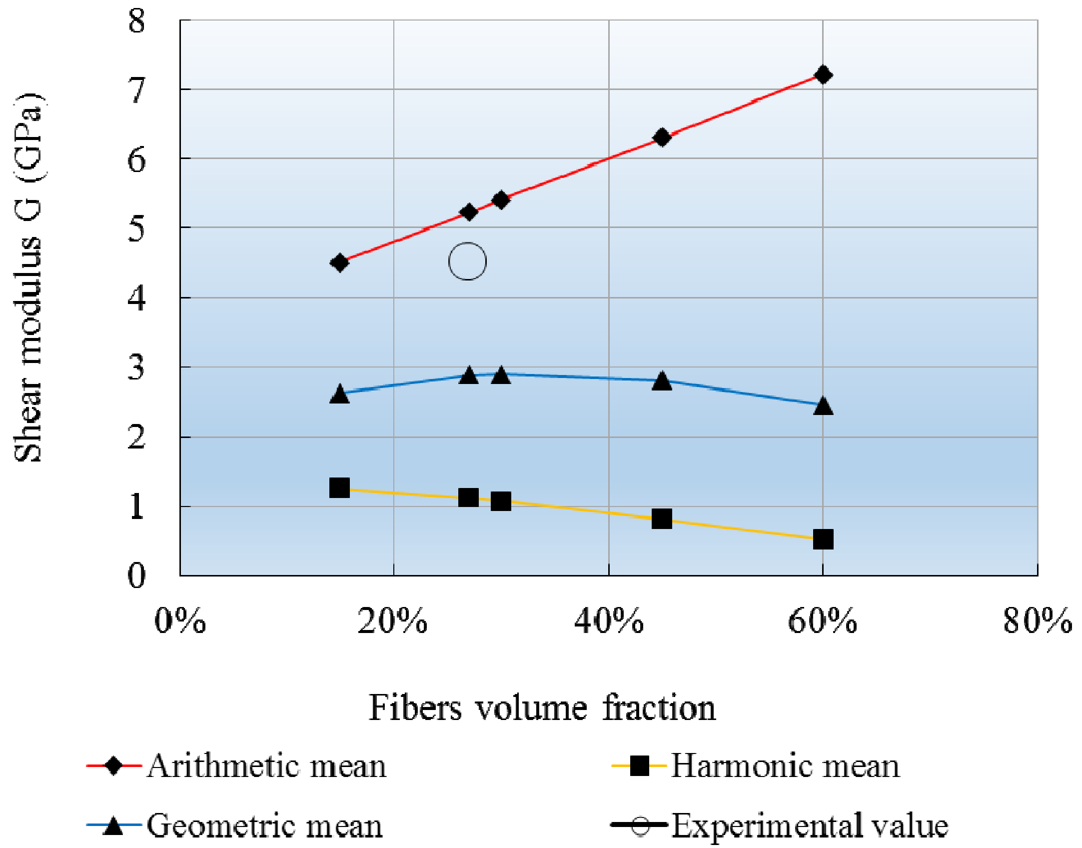


Shear moduli of the isotropic SMC compounds, the upper (G+) and lower limits (G-) of the homogenized elastic coefficients

1. Contributions to the tensile behavior and prediction of elastic properties of pre-impregnated composite materials – Prediction of elastic properties of a 27% fibers volume fraction SMC. Results



Arithmetic, geometric and harmonic averaging methods to compute the Young's moduli of various SMCs with different fibers volume fractions



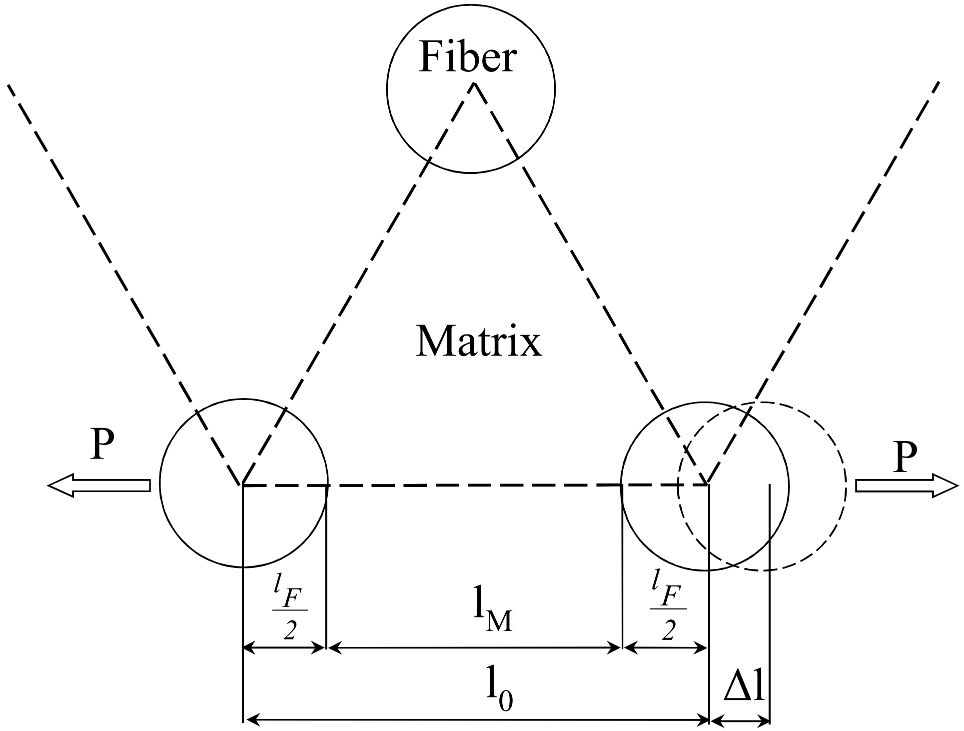
Arithmetic, geometric and harmonic averaging methods to compute the shear moduli of various SMCs with different fibers volume fractions

2. Contributions to the simulations of elastic properties of fibers-reinforced laminates under off-axis loading system – Abstract of contributions

- Personal simulations of elastic properties of some fibers-reinforced composite laminates under off-axis loading system, as well as the behavior of different polymer matrix composite laminates subjected to three and four-point bending using the finite element method have been published in two issues of *Optoelectronics and Advanced Materials – Rapid Communications (OPTOELECTRON ADV MAT)* in 2011 [46], [83].
- I have been taken into consideration various composite laminates to simulate their elastic properties using MAP_COMP_LAMSTR and MAP_COMP_LAMSTI programs developed by Hull and Clyne [17].
- These simulations have been published in different proceedings [29], [48], [54], [56], [57], [58], [64], [65], the last one being published in 2013 [44].
- I have computed the matrix strain increase factor in case of transverse lamina's loading for a hexagonal arrangement of fibers in matrix.
- Distributions of Young's moduli determined on two orthogonal directions, shear modulus as well as Poisson ratio of various composite laminates based especially on epoxy resin reinforced with different types of fibers, subjected to off-axis loading system are presented.
- Stresses in various composite laminates subjected to a general set of in-plane loads are also computed.

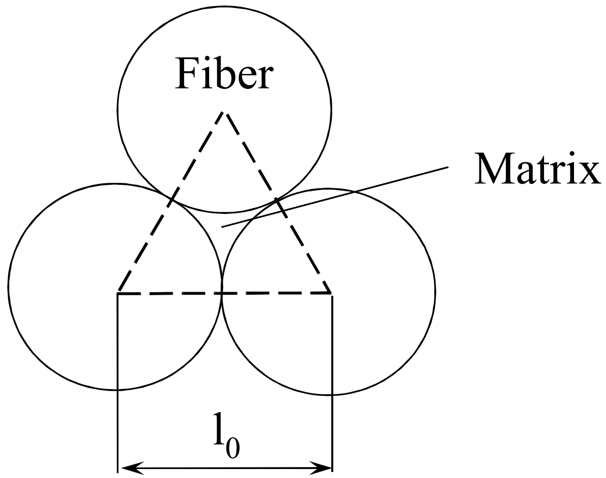
2. Contributions to the simulations of elastic properties of fibers-reinforced laminates under off-axis loading system – The matrix strain increase factor

- To compute the matrix strain increase factor in case of parallel "hexagonal shape" disposed fibers in a unidirectional fibers-reinforced lamina, I have developed a scheme presented below.



Parallel "hexagonal shape" disposed fibers in a composite lamina subjected to transverse tensile loads

$$\varphi_{max\ theoretic} = \frac{\pi}{2\sqrt{3}} = 0.906$$



Maximum fibers volume fraction in case of parallel "hexagonal shape" disposed fibers

2. Contributions to the simulations of elastic properties of fibers-reinforced laminates under off-axis loading system – The matrix strain increase factor

- The ratio between matrix length and the length between fibers can be computed using following relation:

$$\frac{l_M}{l_0} = 1 - \frac{d}{l_0} = 1 - \sqrt{\frac{2\varphi\sqrt{3}}{\pi}}.$$

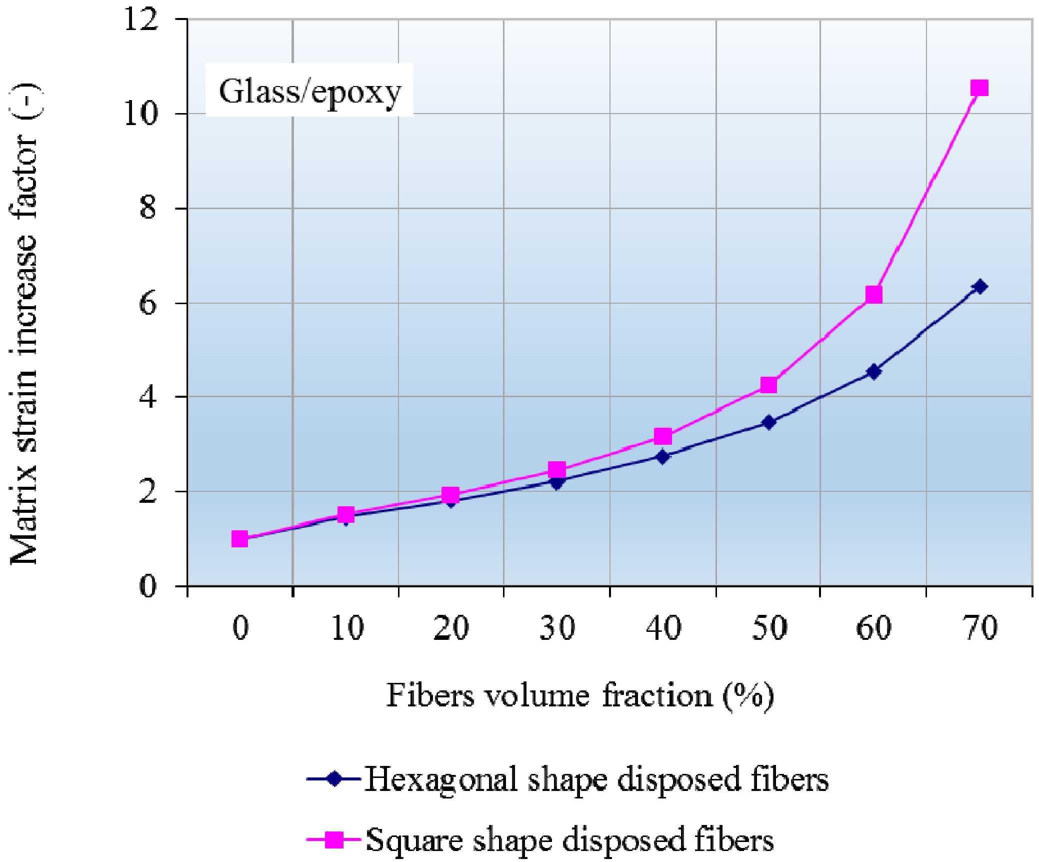
- The matrix strain increase factor in case of parallel „hexagonal shape" disposed glass fibers in a composite lamina subjected to transverse tensile loads, will be:

$$f_\varepsilon = \frac{\varepsilon_M}{\varepsilon_\perp} = \frac{1}{\frac{l_M}{l_0} + \frac{E_M}{E_F}\left(1 - \frac{l_M}{l_0}\right)} = \frac{1}{\frac{l_M}{l_0}\left(1 - \frac{E_M}{E_F}\right) + \frac{E_M}{E_F}} = \frac{1}{\left(1 - \sqrt{\frac{2\varphi\sqrt{3}}{\pi}}\right)\left(1 - \frac{E_M}{E_F}\right) + \frac{E_M}{E_F}}.$$

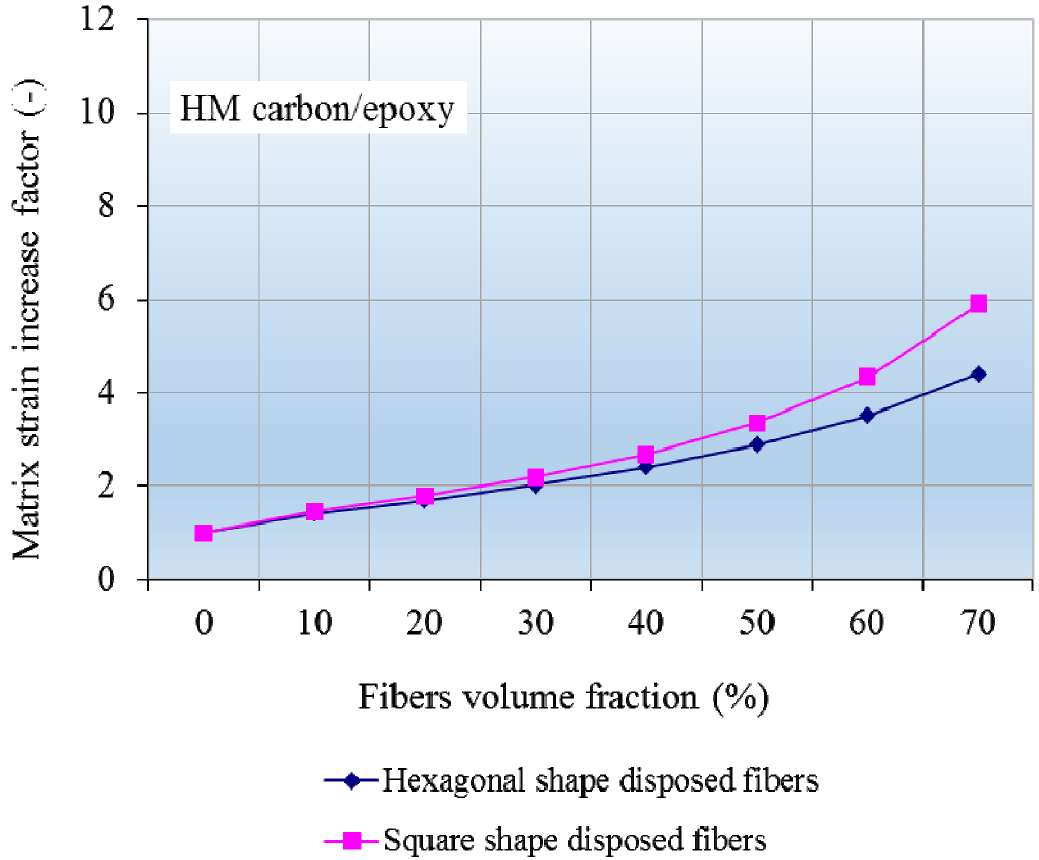
- The matrix strain increase factor in case of parallel „hexagonal shape" disposed carbon fibers in a composite lamina subjected to transverse tensile loads, will be:

$$f_{\varepsilon\, hex.} = \frac{\varepsilon_M}{\varepsilon_\perp} = \frac{1}{\frac{l_M}{l_0} + \frac{E_M}{E_{F\perp}}\left(1 - \frac{l_M}{l_0}\right)} = \frac{1}{\frac{l_M}{l_0}\left(1 - \frac{E_M}{E_{F\perp}}\right) + \frac{E_M}{E_{F\perp}}} = \frac{1}{\left(1 - \sqrt{\frac{2\varphi\sqrt{3}}{\pi}}\right)\left(1 - \frac{E_M}{E_{F\perp}}\right) + \frac{E_M}{E_{F\perp}}}.$$

2. Contributions to the simulations of elastic properties of fibers-reinforced laminates under off-axis loading system – Results

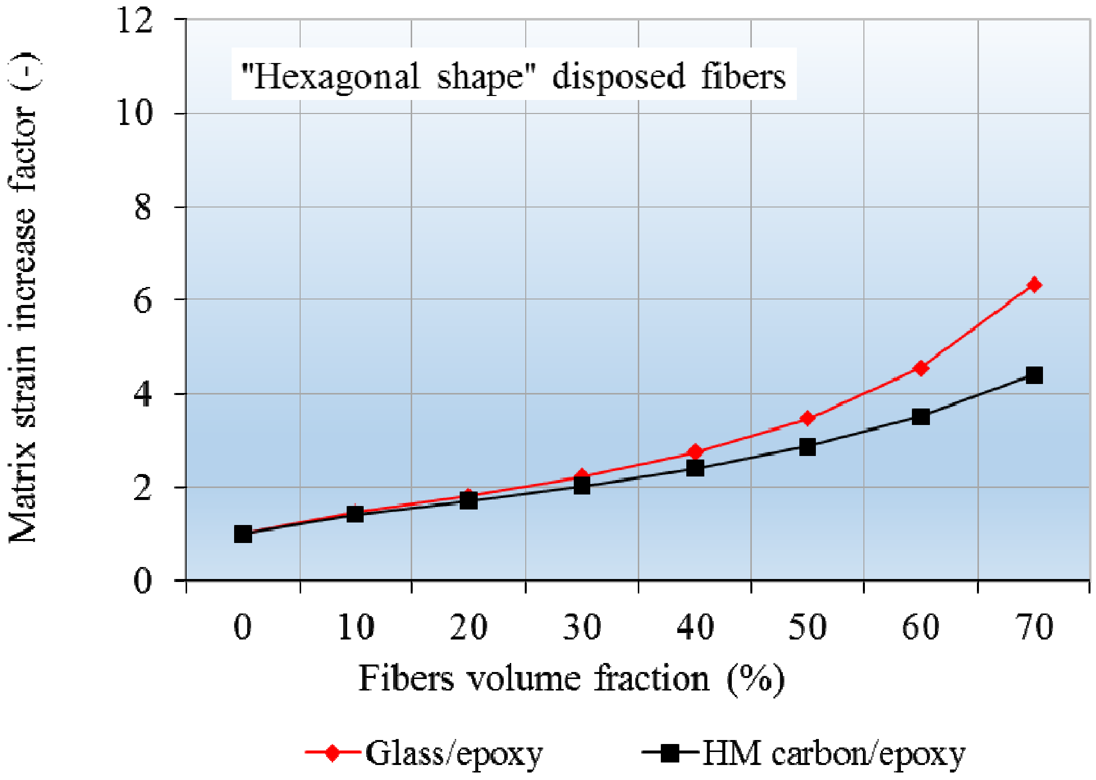


Matrix strain increase factors for hexagonal and square shape disposed fibers in a glass fibers-reinforced epoxy resin lamina

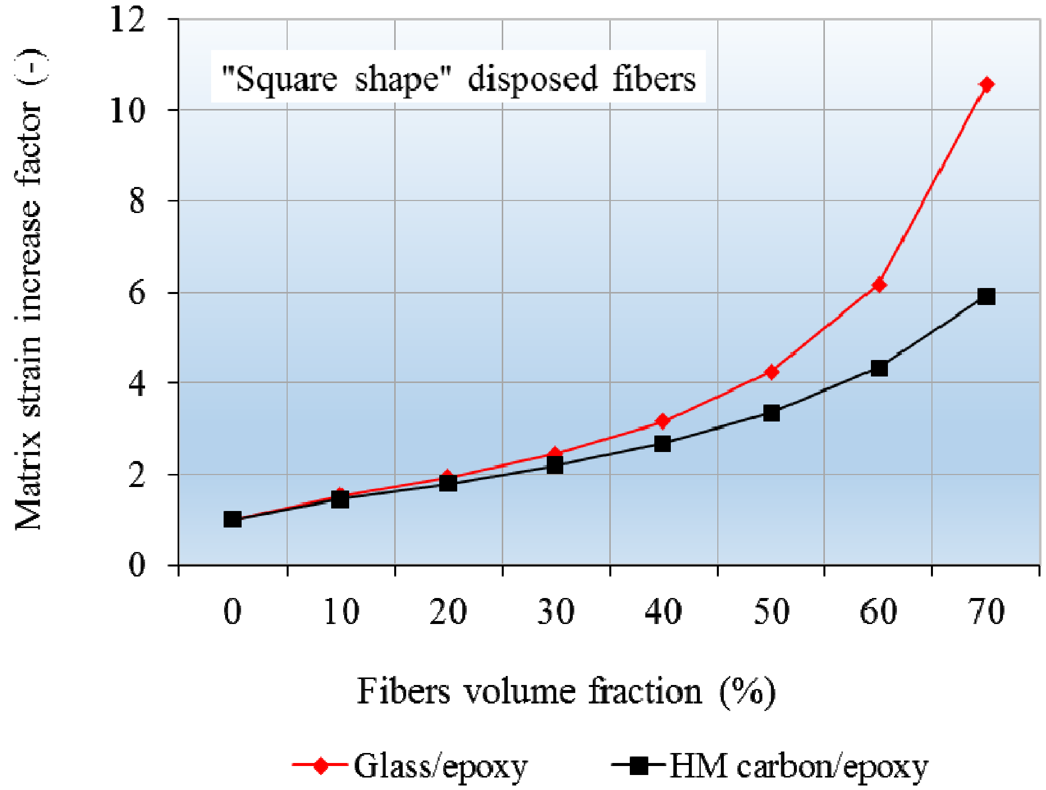


Matrix strain increase factors for hexagonal and square shape disposed fibers in a HM carbon fibers-reinforced epoxy resin lamina

2. Contributions to the simulations of elastic properties of fibers-reinforced laminates under off-axis loading system – Results



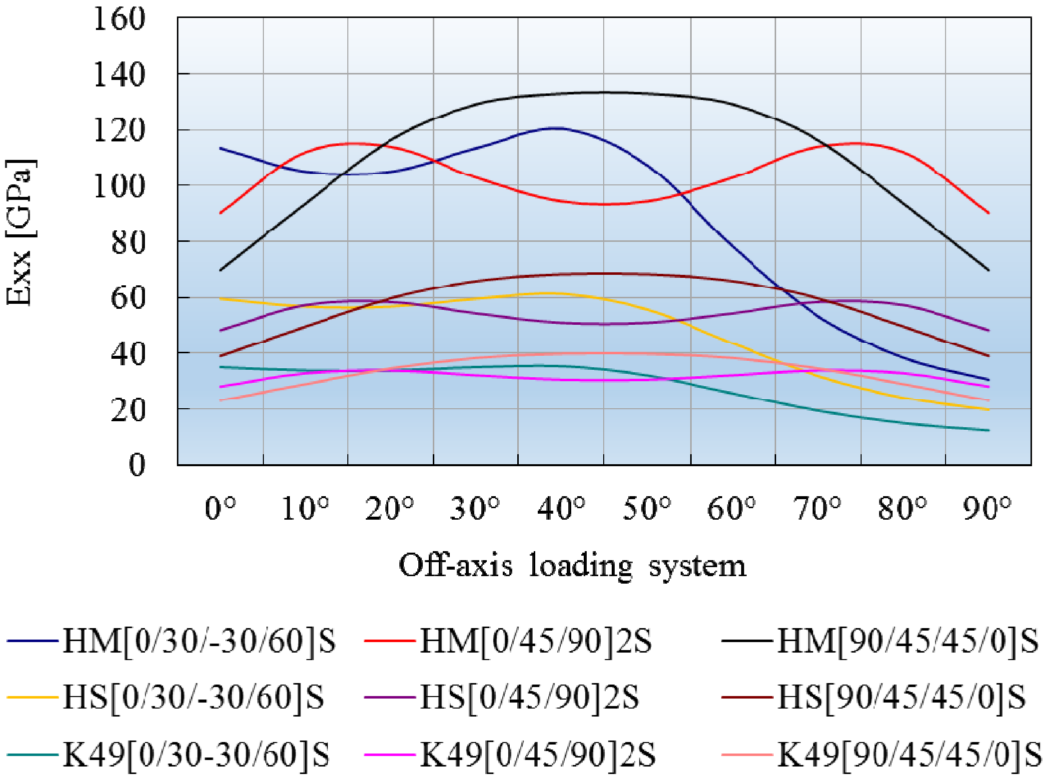
Matrix strain increase factors in HM carbon and glass fibers-reinforced epoxy resin laminae for "hexagonal shape" disposed fibers



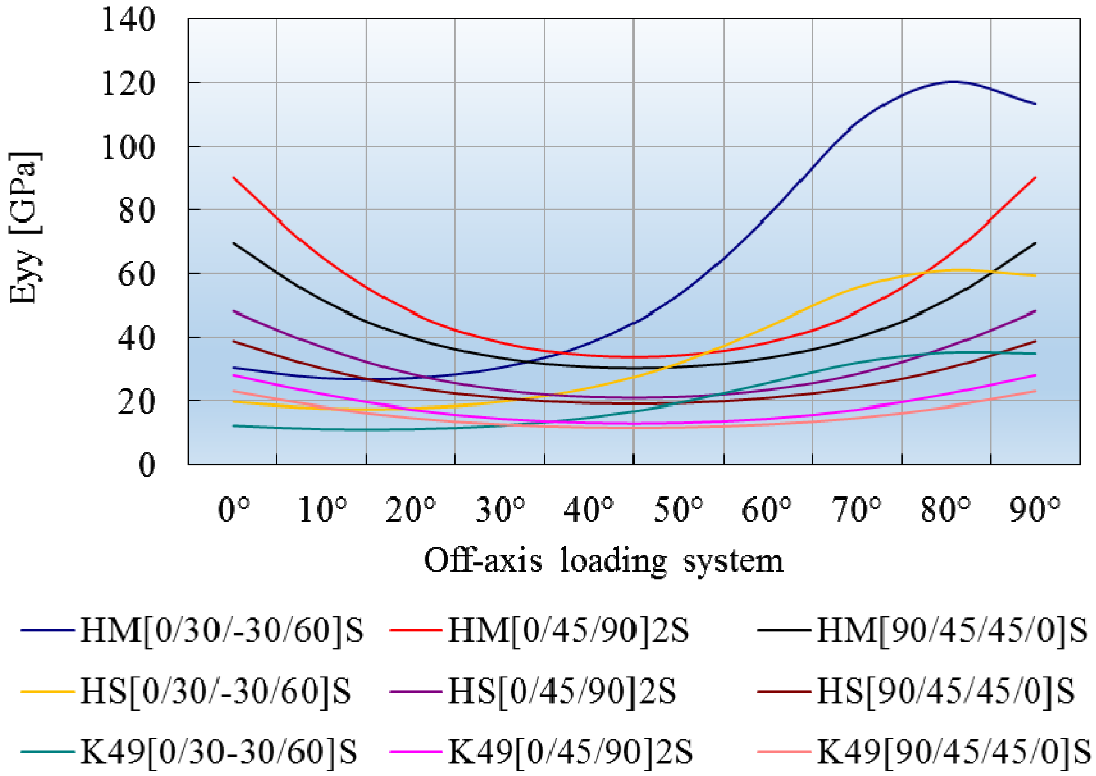
Matrix strain increase factors in HM carbon and glass fibers-reinforced epoxy resin laminae for "square shape" disposed fibers

2. Contributions to the simulations of elastic properties of fibers-reinforced laminates under off-axis loading system – Symmetric laminates

- Case of HM-carbon, HS-carbon, Kevlar49 $[0/30/-30/60]_S$, $[0/45/90]_{2S}$ and $[90/45_2/0]_S$ laminates

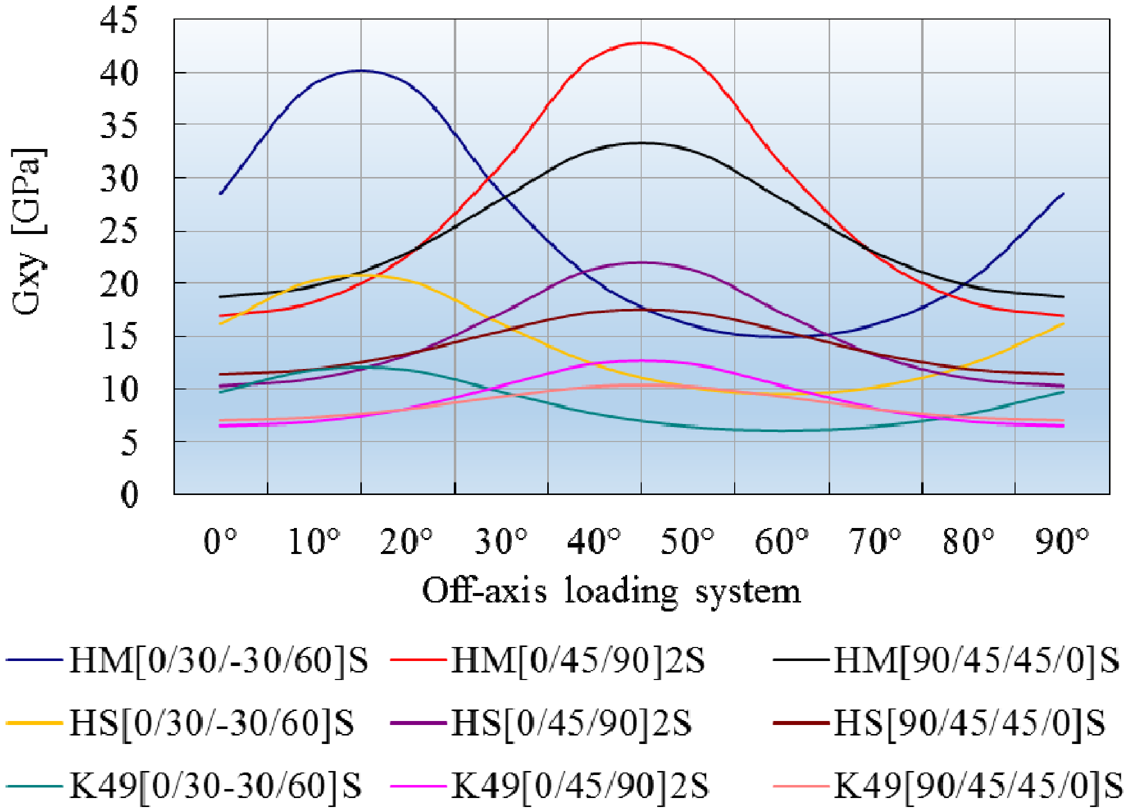


E_{xx} distribution of some carbon and aramid fibers-reinforced epoxy based symmetric laminates

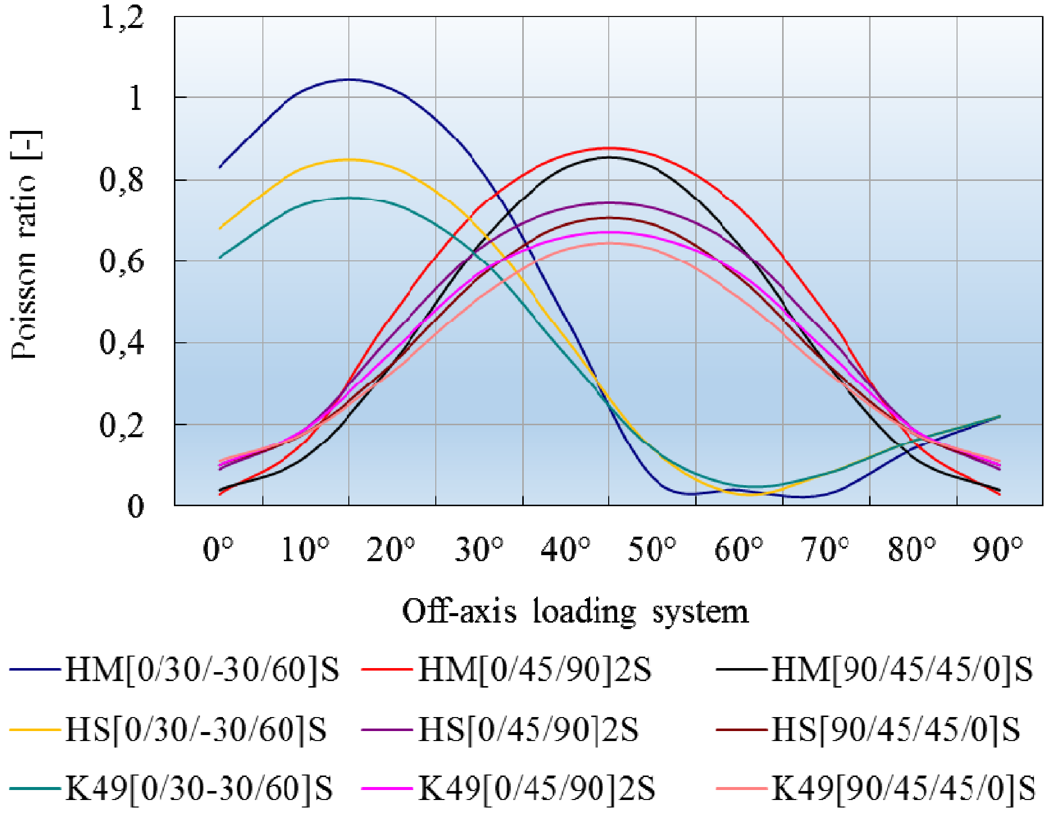


E_{yy} distribution of some carbon and aramid fibers-reinforced epoxy based symmetric laminates

2. Contributions to the simulations of elastic properties of fibers-reinforced laminates under off-axis loading system – Symmetric laminates



G_{xy} distribution of some carbon and aramid fibers-reinforced epoxy based symmetric laminates

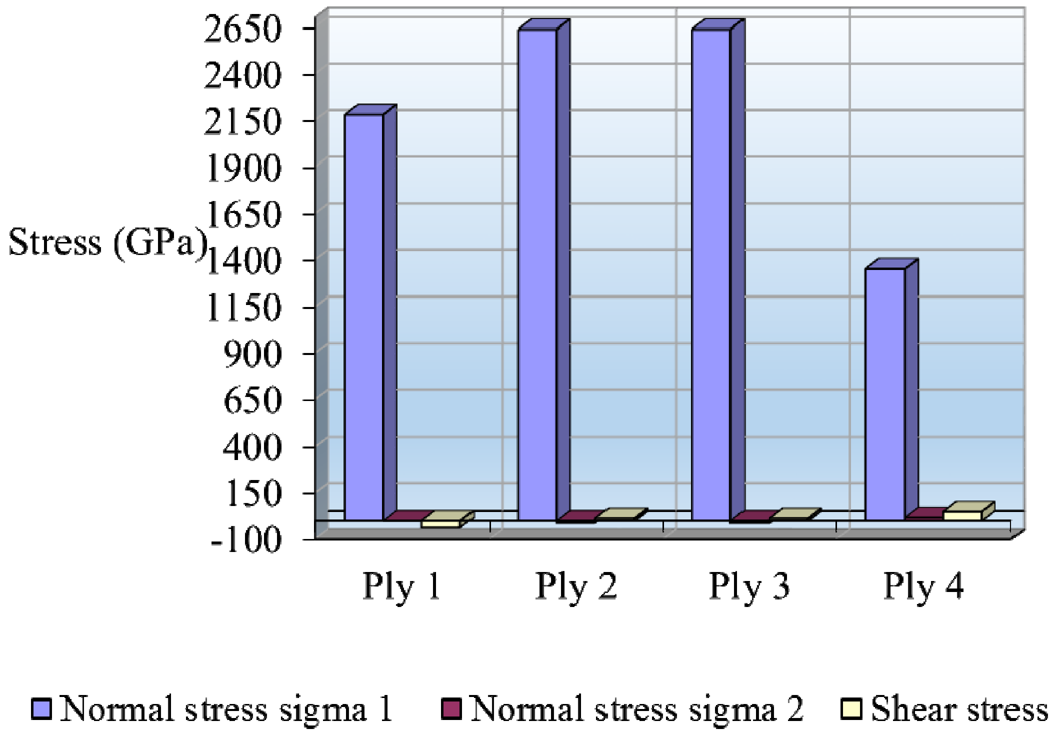


υ_{xy} distribution of some carbon and aramid fibers-reinforced epoxy based symmetric laminates

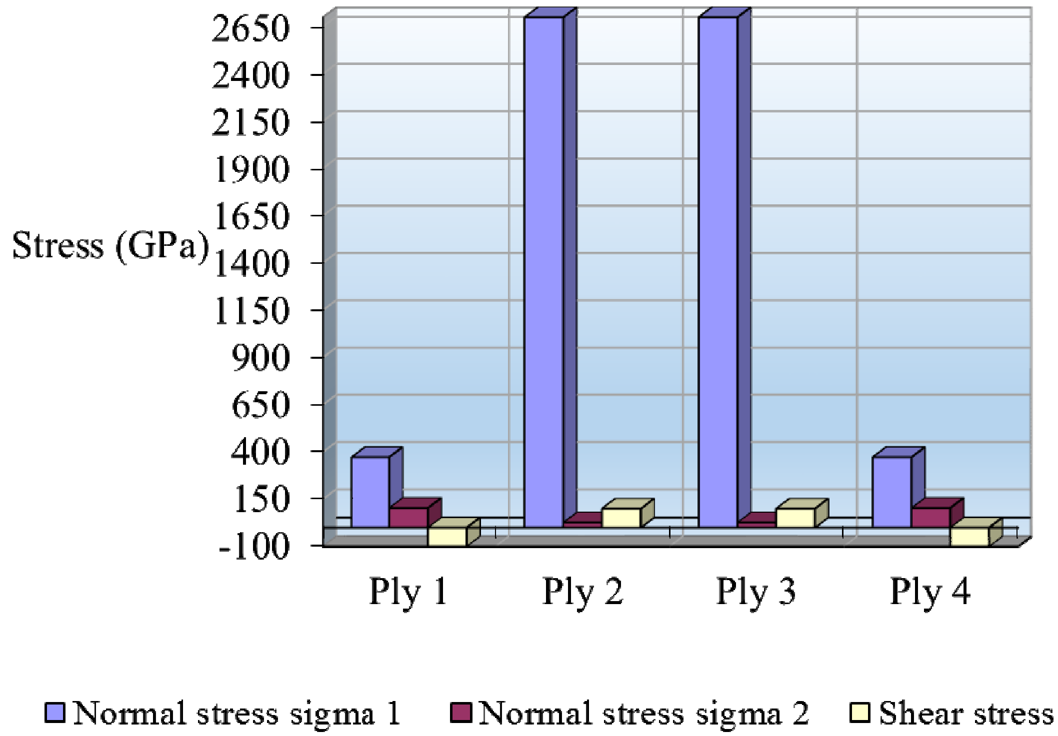
2. Contributions to the simulations of elastic properties of fibers-reinforced laminates under off-axis loading system - Stresses evaluation in various laminates for general set of applied in-plane loads

- Four examples of laminates have been chosen: anti-symmetric laminate with following plies sequence: [30/0/0/-30]; symmetric cross-ply laminate with plies distribution: [90/0/0/90]; symmetric angle-ply laminate with plies sequence: [30/-30/-30/30]; balanced angle-ply laminate with following plies distribution: [30/30/-30/-30].
- Input data:
  - Matrix axial and transverse Young's modulus: 3.2 GPa;
  - Fibers axial Young's modulus: 290 GPa;
  - Fibers transverse Young's modulus: 4.8 GPa;
  - Matrix axial-transverse Poisson ratio : 0.3 ;
  - Fibers axial-transverse Poisson ratio : 0.05 ;
  - Matrix axial-transverse shear modulus: 1.15 GPa;
  - Fibers axial-transverse shear modulus: 4.2 GPa;
  - Fibers volume fraction: 0.51;
  - Applied normal stress in x-direction: 2000 MPa;
  - Applied normal stress in y-direction: 200 MPa;
  - Applied shear stress in x-y plane: 100 MPa;
  - Off-axis loading system: between 0° and 90°.

2. Contributions to the simulations of elastic properties of fibers-reinforced laminates under off-axis loading system - Stresses evaluation in various laminates for general set of applied in-plane loads

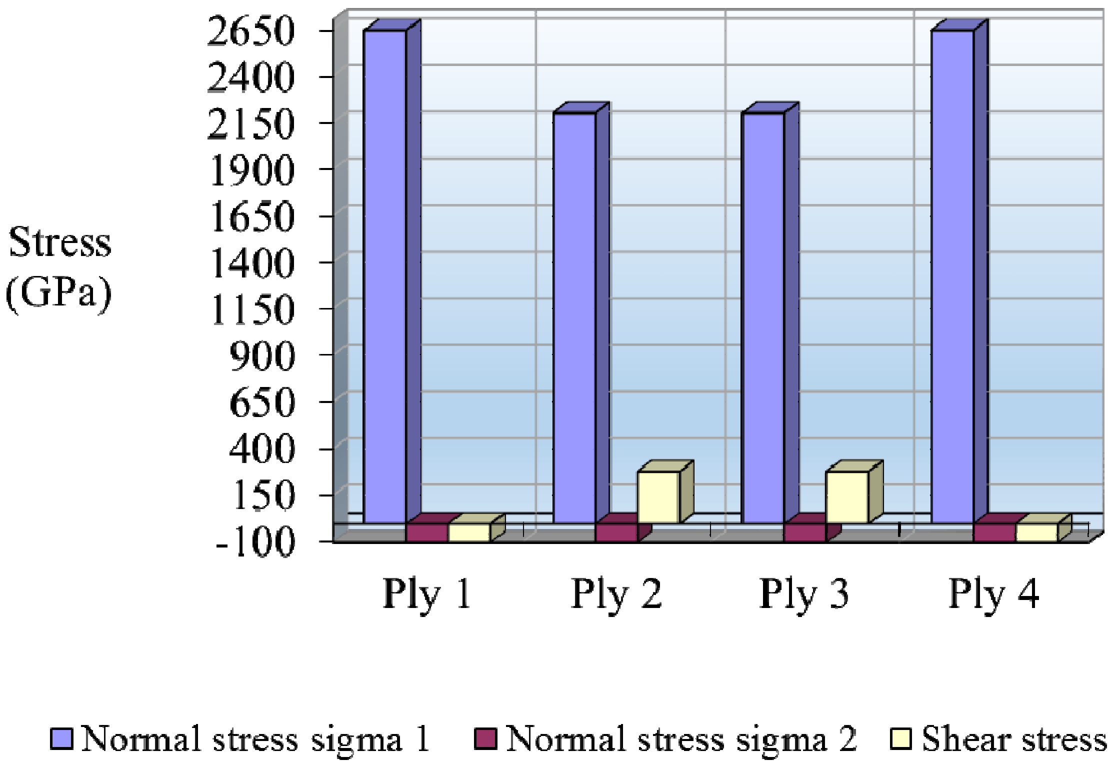


Stresses in anti-symmetric laminate [30/0/0/-30]

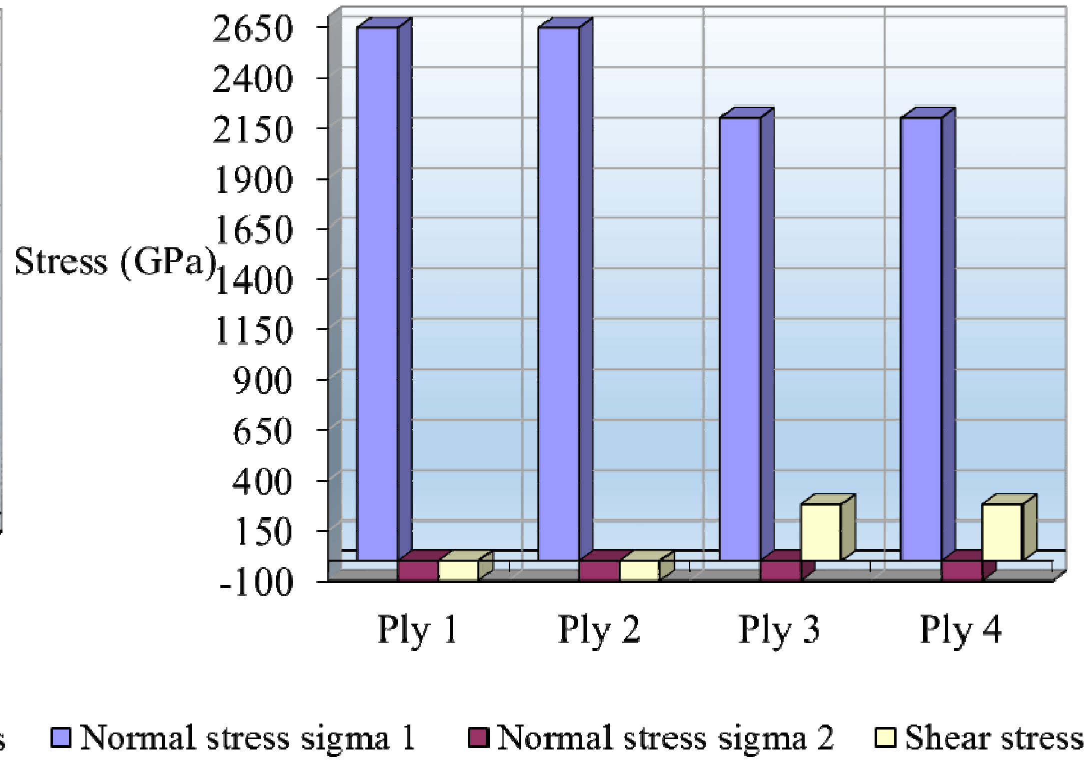


Stresses in symmetric cross-ply laminate [90/0/0/90]

2. Contributions to the simulations of elastic properties of fibers-reinforced laminates under off-axis loading system - Stresses evaluation in various laminates for general set of applied in-plane loads



Stresses in symmetric angle-ply laminate [30/-30/-30/30]



Stresses in balanced angle-ply laminate [30/30/-30/-30]

3. Contributions to the thermo-mechanical behavior of fibers-reinforced laminates subjected to temperature and humidity variations – Abstract of contributions

- Personal simulations regarding thermo-mechanical behavior of various unidirectional fibers-reinforced laminae subjected to temperature and humidity variations have been published in 2006, 2008 and 2010 in different proceedings [50], [63] and [76].

- I have performed simulations regarding the thermo-mechanical behavior of different unidirectional reinforced laminae with various fibers, subjected to some sequential and combined temperature and humidity variations.

- I have computed the coefficients of thermal and humidity expansions of these laminae.

- I have simulated the axial and transverse thermal conductivities of different unidirectional carbon fibers-reinforced thermo-conductive resins, with possible applications in heating radiant systems. These simulations have been carried aut using the ESHCON software developed by Clyne and Withers [7].

- I have presented the thermal response of a sandwich structure with nonwoven polyester mat as core and dissimilar skins.

3. Contributions to the thermo-mechanical behavior of fibers-reinforced laminates subjected to temperature and humidity variations – Basic relations

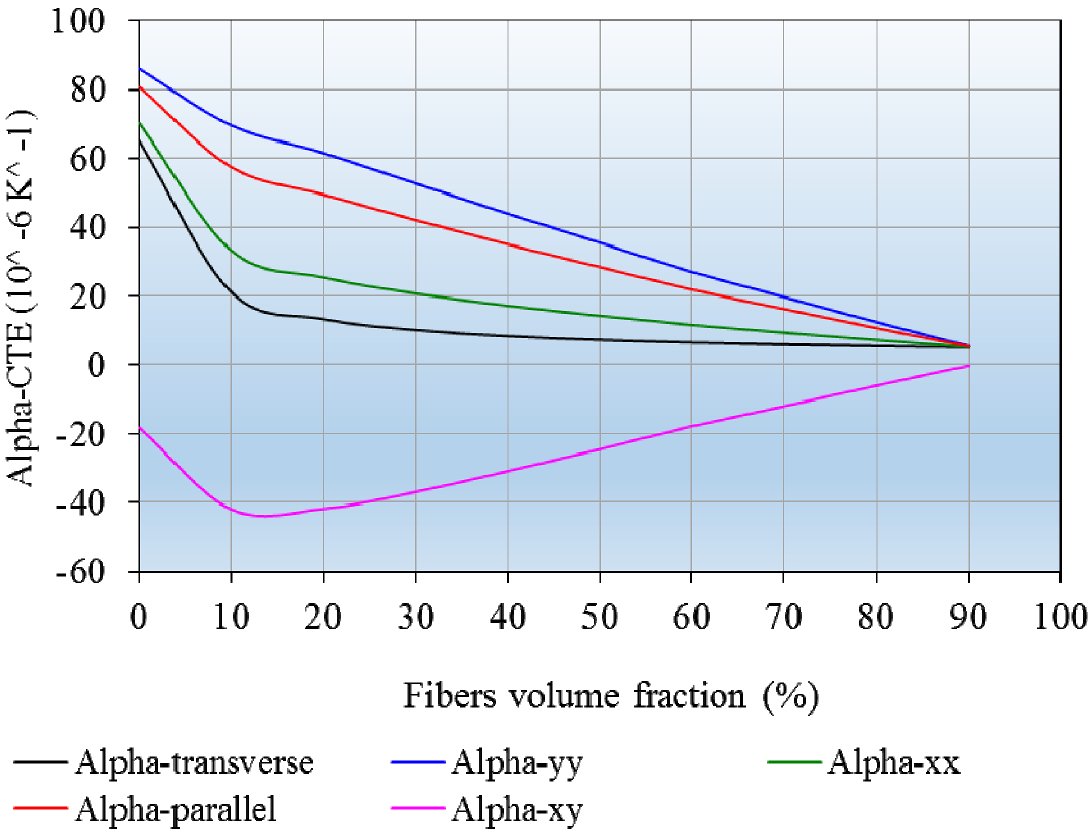
- The coefficients of expansion in x and y directions, due to humidity, if the fibers are disposed at an angle θ with the x-axis direction, can be computed in the following way. Where β_{xx} and β_{yy} are coefficients of linear expansion and β_{xy} is the coefficient of shear expansion due to humidity.

$$\beta_{xx} = \beta_{II} \cos^2\theta + \beta_{\perp} \sin^2\theta,$$
$$\beta_{yy} = \beta_{II} \sin^2\theta + \beta_{\perp} \cos^2\theta,$$
$$\beta_{xy} = (2\sin\theta\cos\theta)(\beta_{II} - \beta_{\perp}),$$

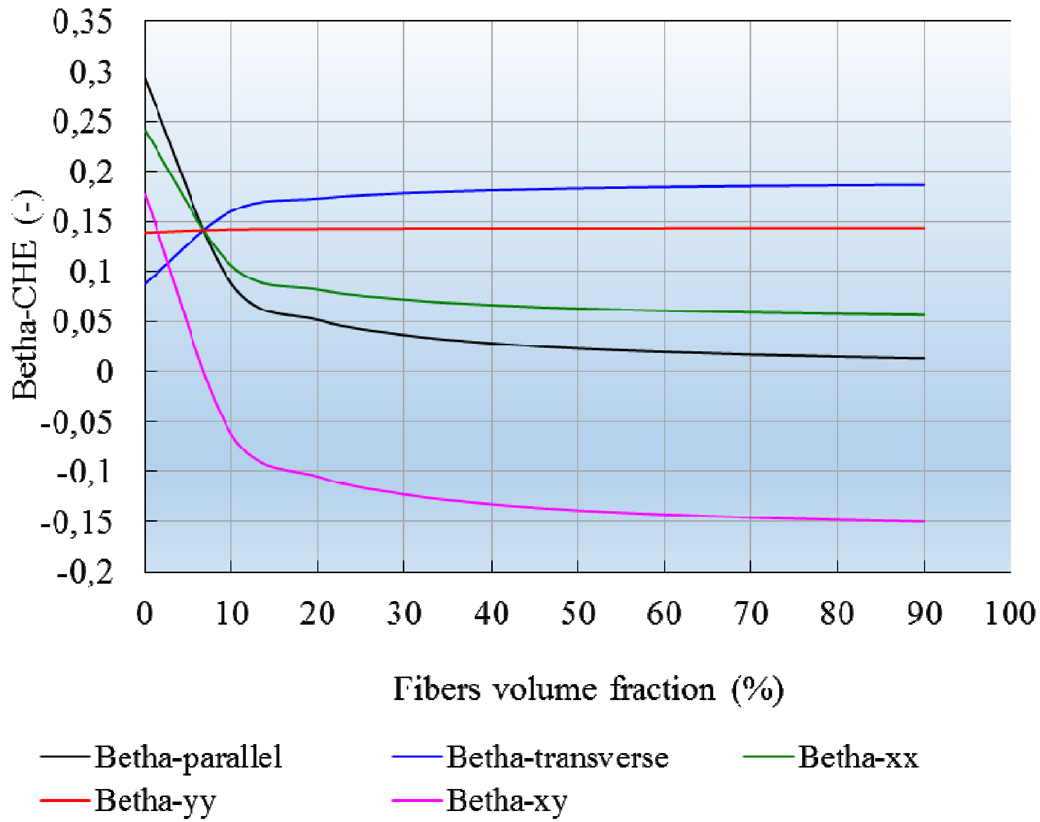
- The strains of a fibers-reinforced composite lamina $\varepsilon_{xx\ t\text{-}h}$, $\varepsilon_{yy\ t\text{-}h}$ and $\gamma_{xy\ t\text{-}h}$ due to a ΔT temperature and ΔH humidity variation, without a mechanical loading, can be computed in the following manner:

$$\varepsilon_{xx\ t-h} = \alpha_{xx} \cdot \Delta T + \beta_{xx} \cdot \Delta H,$$
$$\varepsilon_{yy\ t-h} = \alpha_{yy} \cdot \Delta T + \beta_{yy} \cdot \Delta H,$$
$$\gamma_{xy\ t-h} = \alpha_{xy} \cdot \Delta T + \beta_{xy} \cdot \Delta H,$$

3. Contributions to the thermo-mechanical behavior of fibers-reinforced laminates subjected to temperature and humidity variations – Applications



Coefficients of thermal expansion in case of a unidirectional [30] glass/epoxy lamina



Coefficients of humidity expansion in case of a unidirectional [30] glass/epoxy lamina

3. Contributions to the thermo-mechanical behavior of fibers-reinforced laminates subjected to temperature and humidity variations – Applications

- A symmetric $[0/90/45/-45]_S$ carbon fibers-reinforced composite laminate is considered. The fibers volume fraction of each lamina is 57% and the thickness of each lamina is 0.25 mm. The aim is to compute the strains in each lamina knowing that the laminate is subjected to:
  - A temperature variation of $\Delta T = -100$ K that appears due to its cooling from the cure to environment temperature;
  - A humidity variation of $\Delta U = 2.3\%$;
  - A biaxial field of normal loads $n_{xx} = 215$ N/mm and $n_{yy} = 185$ N/mm as well as a shear load $n_{xy} = 75$ N/mm that acts in x-y plane.
- Following input date have been used:
  - $\alpha_{F\parallel} = -0.45 \cdot 10^{-6}\ K^{-1}$;
  - $\alpha_{F\perp} = 29 \cdot 10^{-6}\ K^{-1}$;
  - $\alpha_M = 65 \cdot 10^{-6}\ K^{-1}$;
  - $\rho_{composite} = 1700\ kg/m^3$;
  - $\rho_M = 1100\ kg/m^3$;
  - $\beta_M = 0.18$
  - $E_{F\parallel} = 528$ GPa;
  - $E_{F\perp} = 21$ GPa;
  - $\upsilon_F = 0.3$; $E_M = 3.84$ GPa; $\upsilon_M = 0.37$.

3. Contributions to the thermo-mechanical behavior of fibers-reinforced laminates subjected to temperature and humidity variations – Results

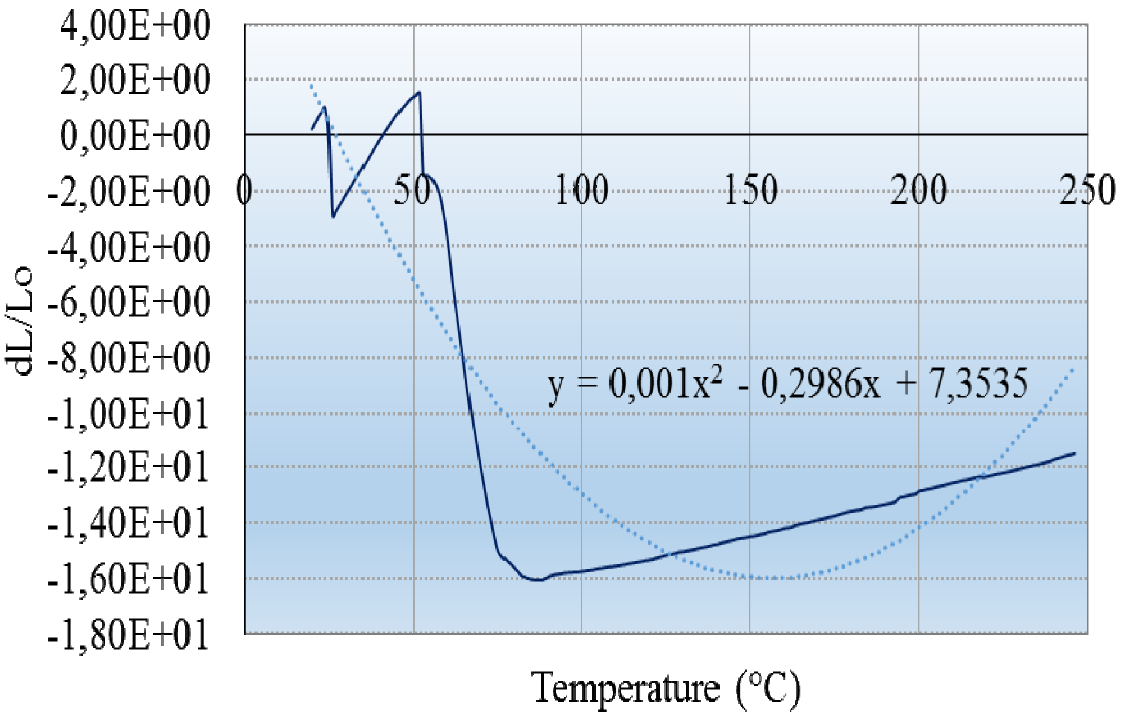
Table 3.3. Stresses and strains in a symmetric $[0/90/45/-45]_S$ carbon fibers-reinforced composite laminate subjected to complex loadings. Stresses are given in GPa.

	Plies 1 and 8	Plies 2 and 7	Plies 3 and 6	Plies 4 and 5
$\varepsilon_{\parallel}$	0.036184	0.028602	0.012785	0.052
$\varepsilon_{\perp}$	0.028602	0.036184	0.052	0.012785
$\gamma_{\parallel\perp}$	0.039216	- 0.039216	0.007582	- 0.007582
$\sigma_{\parallel}$	11.11	8.83	4.09	15.85
$\sigma_{\perp}$	0.49	0.55	0.68	0.36
$\tau_{\parallel\perp}$	0.22	- 0.22	0.043	- 0.043

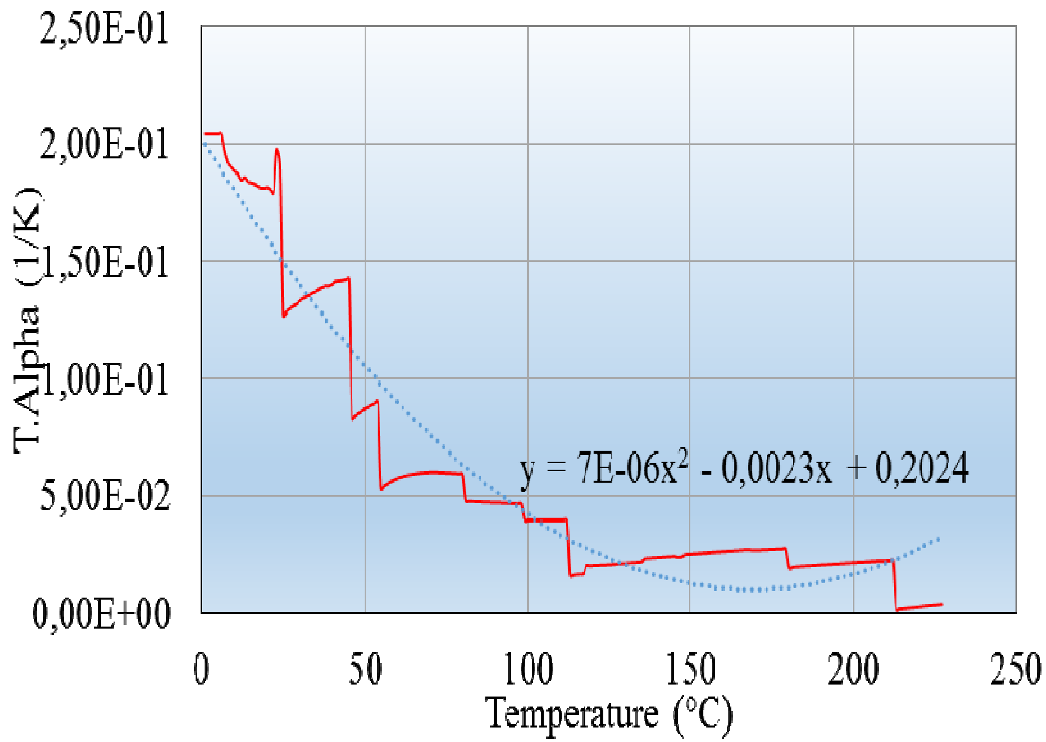
3. Contributions to the thermo-mechanical behavior of fibers-reinforced laminates subjected to temperature and humidity variations – Thermal response of a thin sandwich composite structure

- Thermal response of a sandwich structure with thin nonwoven polyester mat as core has been experimentally determined.
- The structure presents dissimilar skins from which one is a glass fabric reinforced polyester.
- Following layers has been used:
  - 1 layer RT500 glass roving fabric;
  - 2 layers RT800 glass roving fabric;
  - 1 layer CSM450 chopped strand mat;
  - 1 layer 4 mm thick nonwoven polyester mat as core;
  - 1 layer CSM450 chopped strand mat;
  - A usually used gelcoat layer.
- Thermal expansions have been measured using a DIL 420 PC dilatometer from NETZSCH GmbH, on both glass fabric reinforced polyester skin and for the whole structure.
- The coefficients of thermal expansion have been experimentally determined only for the structure's upper skin.

3. Contributions to the thermo-mechanical behavior of fibers-reinforced laminates subjected to temperature and humidity variations – Thermal response of a thin sandwich composite structure. Results

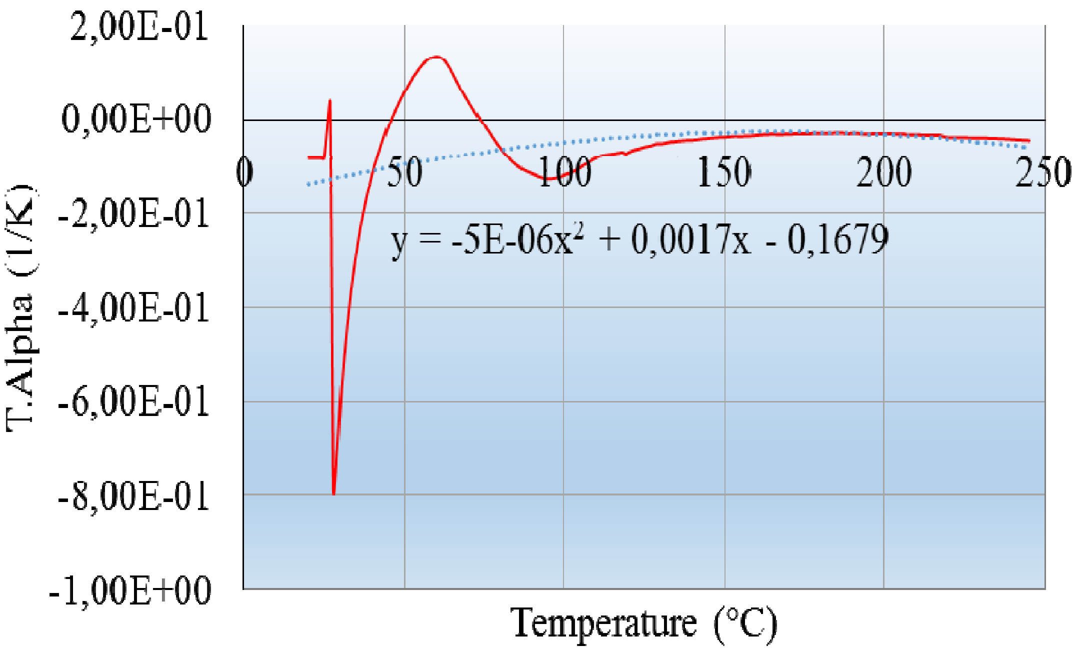


Distribution of upper skin's thermal expansion
(the negative thermal expansion in the first heating stage is due to the beginning of curing in the upper skin's structure)

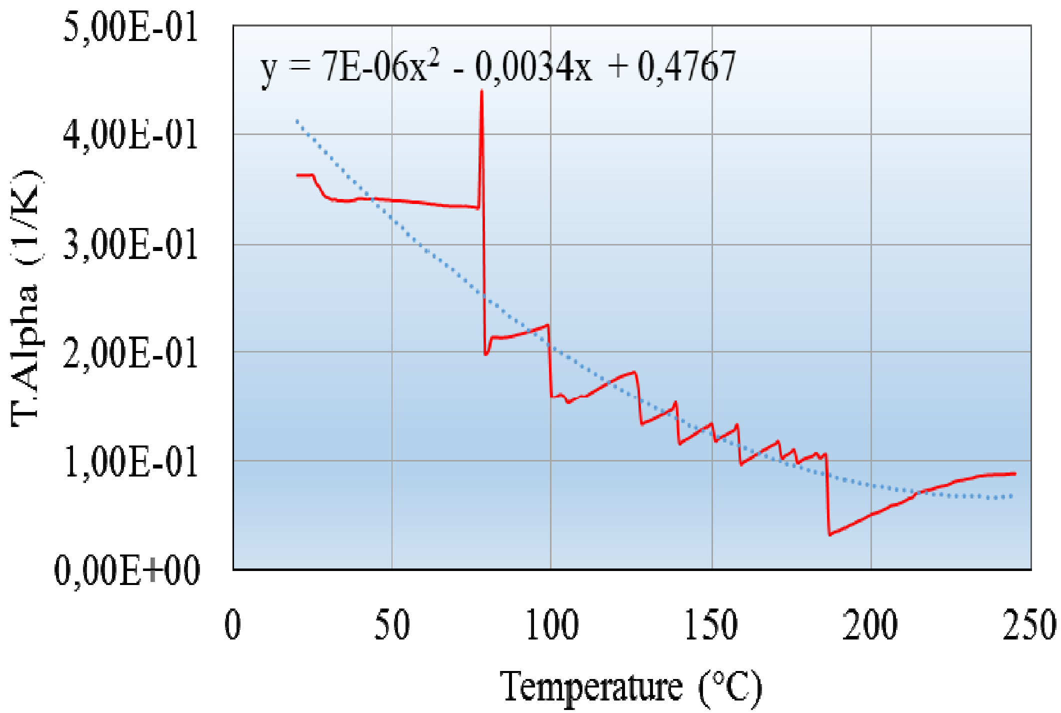


Distribution of upper skin's coefficient of thermal expansion (technical alpha)

3. Contributions to the thermo-mechanical behavior of fibers-reinforced laminates subjected to temperature and humidity variations – Thermal response of a thin sandwich composite structure. Results



Distribution of sandwich structure's coefficient of thermal expansion in the first heating stage



Distribution of sandwich structure's coefficient of thermal expansion in the second heating stage

4. Contributions to the damping's analysis of a twill weave carbon/epoxy fabric – Abstract of contributions

- The most important damping's features in case of a twill weave carbon/epoxy fabric have been computed and published in references [53], [68], [75], [77].

- I have computed the fabric's dampings, rigidities and compliances using an equivalent model of it.

- At the damping's analysis of fibers-reinforced composite materials, a so called concept of complex moduli has been used in which the elastic constants will be replaced through their viscoelastic correspondences.

- The mechanical modeling is based on the correspondence principle of linear viscoelastic theory [8], [14], [85].

- The maximum value of the damping seems to be at 45° against the fibers direction.

4. Contributions to the damping's analysis of a twill weave carbon/epoxy fabric – Scientific context

- In general technique, damping is usually defined as the decrease of oscillations, in which the mechanical energy contained in the system is converted into heat.
- In materials science, this dissipation process which occurs at the interior of materials is called material's damping.
- When a composite material is subjected to a sinusoidal varying stress in which the strain is also sinusoidal, the angular frequency is retarded in phase by an angle δ, retardation which takes place due to viscoelastic behavior of the matrix.
- In the analysis of harmonic systems is more convenient to write the stress function as a complex quantity σ^* which presents a real and an imaginary part [26]:

$$\sigma^* = \sigma_0' \cos \omega t + i\sigma_0'' \sin \omega t$$

- A dynamic or "storage" Young's modulus and a "loss" modulus can be defined [26]:

$$E' = \frac{\sigma_0'}{\varepsilon_0} \qquad E'' = \frac{\sigma_0''}{\varepsilon_0}$$

- The ratio between the loss Young's modulus and the dynamic modulus defines the material's damping [26]:

$$\frac{E''}{E'} = \frac{\sigma_0''}{\sigma_0'} = \tan \delta = d$$

4. Contributions to the damping's analysis of a twill weave carbon/epoxy fabric – Scientific context

- For the analysis of micromechanical lamina behavior, the prism model described by Tsai has been used [78]. So, the dynamic modulus along the fibers direction can be computed from the mixture rule as following [78]:

$$E'_{\parallel} = E'_{F\parallel} \cdot \varphi + E'_M (1 - \varphi)$$

- Perpendicular to fibers direction, the dynamic modulus presented by Niederstadt, as a function of fibers and matrix dynamic moduli as well as the fibers and matrix dampings, can be used [26]:

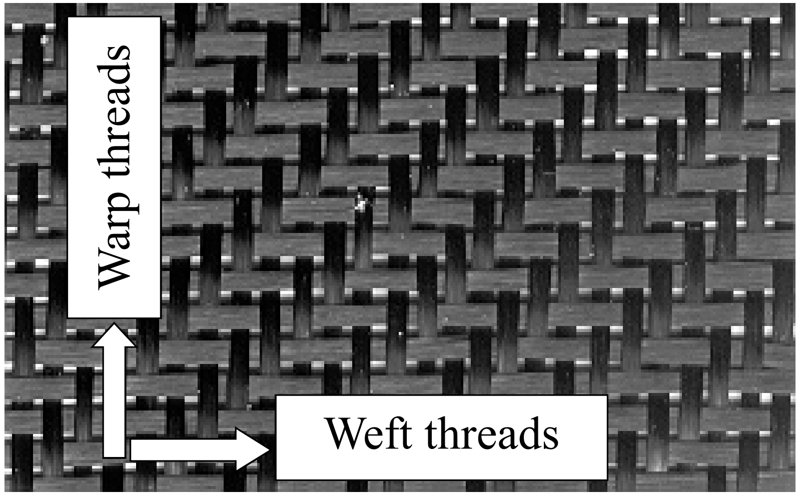
$$E'_{\perp} = -\frac{E'_{F\perp}E'_M\{d^2_{F\perp}E'_{F\perp}(\varphi-1)-[d^2_M E'_M\varphi+E'_M\varphi-E'_{F\perp}(\varphi-1)]\}}{d^2_{F\perp}E'^2_{F\perp}(\varphi-1)^2-2d_{F\perp}d_M E'_{F\perp}E'_M\varphi(\varphi-1)+d^2_M E'^2_M\varphi^2+\cdots} - \frac{E'_{F\perp}E'_M\{d^2_{F\perp}E'_{F\perp}(\varphi-1)-[d^2_M E'_M\varphi+E'_M\varphi-E'_{F\perp}(\varphi-1)]\}}{\ldots+E'^2_{F\perp}(\varphi-1)^2-2E'_{F\perp}E'_M\varphi(\varphi-1)+E'^2_M\varphi^2}$$

- For the damping of unidirectional reinforced lamina, the computing relations given by Saravanos and Chamis can be used, starting from the cylinder model presented by Tsai [21], [31], [78]:

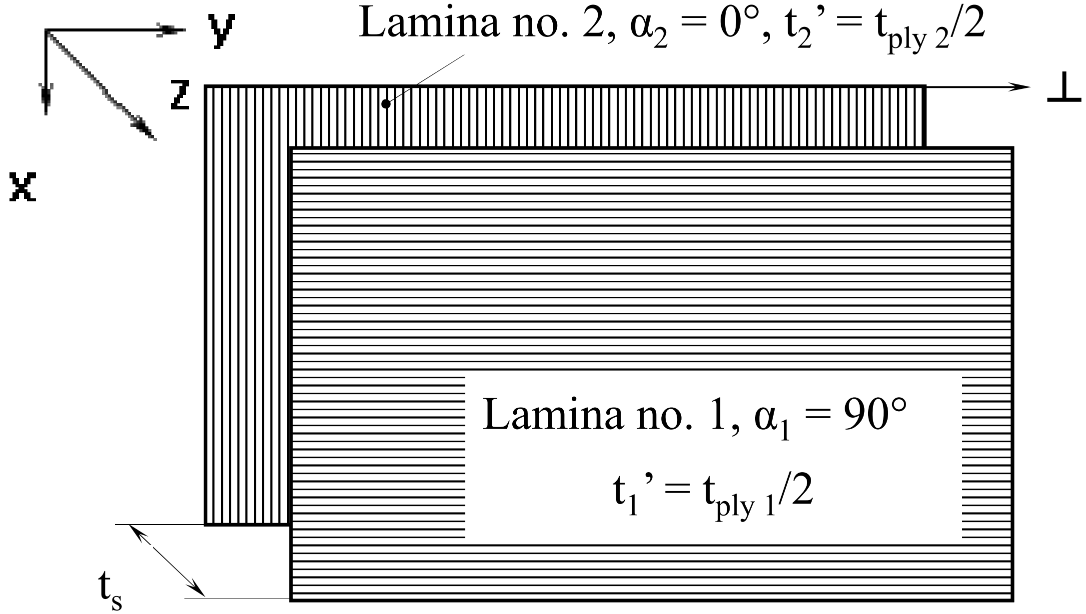
$$d_{\parallel} = \frac{d_{F\parallel}E'_{F\parallel}\varphi+d_M E'_M(1-\varphi)}{E'_{\parallel}} \qquad d_{\perp} = d_{F\perp}\sqrt{\varphi}\frac{E'_{\perp}}{E'_{F\perp}} + d_M(1-\sqrt{\varphi})\frac{E'_{\perp}}{E'_M} \qquad d_{\#} = d_{F\#}\sqrt{\varphi}\frac{G'_{\#}}{G'_{F\#}} + d_M(1-\sqrt{\varphi})\frac{G'_{\#}}{G'_M}$$

4. Contributions to the damping's analysis of a twill weave carbon/epoxy fabric – Damping's simulation of twill weave carbon/epoxy fabric. Theoretical approach

- The carbon-fibers fabric used in this simulation is a high rigidity one, that presents a so-called twill weave with 0.3 kg/m^3 specific weight.



The architecture of carbon/epoxy twill weave fabric



The carbon/epoxy twill weave fabric equivalence model

4. Contributions to the damping's analysis of a twill weave carbon/epoxy fabric – Damping's simulation of twill weave carbon/epoxy fabric. Theoretical approach

- The viscoelastic material's law according to the concept of complex moduli, for an orthotropic lamina, can be written as following:

$$\begin{bmatrix} \varepsilon_{\parallel}^* \\ \varepsilon_{\perp}^* \\ \gamma_{\#}^* \end{bmatrix} = \begin{bmatrix} c_{\parallel}^* & c_{\parallel\perp}^* & 0 \\ c_{\perp\parallel}^* & c_{\perp}^* & 0 \\ 0 & 0 & c_{\#}^* \end{bmatrix} \cdot \begin{bmatrix} \sigma_{\parallel}^* \\ \sigma_{\perp}^* \\ \tau_{\#}^* \end{bmatrix} = \begin{bmatrix} \frac{1}{E_{\parallel}^*} & \frac{-\upsilon_{\parallel\perp}}{E_{\perp}^*} & 0 \\ \frac{-\upsilon_{\perp\parallel}}{E_{\parallel}^*} & \frac{1}{E_{\perp}^*} & 0 \\ 0 & 0 & \frac{1}{G_{\#}^*} \end{bmatrix} \cdot \begin{bmatrix} \sigma_{\parallel}^* \\ \sigma_{\perp}^* \\ \tau_{\#}^* \end{bmatrix}$$

- Expressing the complex stresses as a function of complex strains, it can be obtained:

$$\begin{bmatrix} \sigma_{\parallel}^* \\ \sigma_{\perp}^* \\ \tau_{\#}^* \end{bmatrix} = \begin{bmatrix} r_{\parallel}^* & r_{\parallel\perp}^* & 0 \\ r_{\perp\parallel}^* & r_{\perp}^* & 0 \\ 0 & 0 & r_{\#}^* \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_{\parallel}^* \\ \varepsilon_{\perp}^* \\ \gamma_{\#}^* \end{bmatrix} = \begin{bmatrix} \frac{E_{\parallel}^*}{1-\upsilon_{\parallel\perp}^2 \frac{E_{\perp}^*}{E_{\parallel}^*}} & \frac{\upsilon_{\parallel\perp} E_{\perp}^*}{1-\upsilon_{\parallel\perp}^2 \frac{E_{\perp}^*}{E_{\parallel}^*}} & 0 \\ \frac{\upsilon_{\parallel\perp} E_{\perp}^*}{1-\upsilon_{\parallel\perp}^2 \frac{E_{\perp}^*}{E_{\parallel}^*}} & \frac{E_{\perp}^*}{1-\upsilon_{\parallel\perp}^2 \frac{E_{\perp}^*}{E_{\parallel}^*}} & 0 \\ 0 & 0 & G_{\#}^* \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_{\parallel}^* \\ \varepsilon_{\perp}^* \\ \gamma_{\#}^* \end{bmatrix}$$

- For $d^2 << 1$, the dynamic compliances and rigidities can be written in the following forms:

$$[C'] = \begin{bmatrix} c_{\parallel}' & c_{\parallel\perp}' & 0 \\ c_{\perp\parallel}' & c_{\perp}' & 0 \\ 0 & 0 & c_{\#}' \end{bmatrix} = \begin{bmatrix} \frac{1}{E_{\parallel}'} & \frac{-\upsilon_{\parallel\perp}}{E_{\perp}'} & 0 \\ \frac{-\upsilon_{\perp\parallel}}{E_{\parallel}'} & \frac{1}{E_{\perp}'} & 0 \\ 0 & 0 & \frac{1}{G_{\#}'} \end{bmatrix}$$

$$[R'] = \begin{bmatrix} r_{\parallel}' & r_{\parallel\perp}' & 0 \\ r_{\perp\parallel}' & r_{\perp}' & 0 \\ 0 & 0 & r_{\#}' \end{bmatrix} = \begin{bmatrix} \frac{E_{\parallel}'}{1-\upsilon_{\parallel\perp}^2 \frac{E_{\perp}'}{E_{\parallel}'}} & \frac{\upsilon_{\parallel\perp} E_{\perp}'}{1-\upsilon_{\parallel\perp}^2 \frac{E_{\perp}'}{E_{\parallel}'}} & 0 \\ \frac{\upsilon_{\parallel\perp} E_{\perp}'}{1-\upsilon_{\parallel\perp}^2 \frac{E_{\perp}'}{E_{\parallel}'}} & \frac{E_{\perp}'}{1-\upsilon_{\parallel\perp}^2 \frac{E_{\perp}'}{E_{\parallel}'}} & 0 \\ 0 & 0 & G_{\#}' \end{bmatrix}$$

4. Contributions to the damping's analysis of a twill weave carbon/epoxy fabric – Damping's simulation of twill weave carbon/epoxy fabric. Results

Table 4.1. Input data

E'_M (GPa)	2.6
υ_M (-)	0.34
d_M (%)	1.4
$E'_{F\,II}$ (GPa)	226
$E'_{F\perp}$ (GPa)	16
$G'_{F\#}$ (GPa)	43
$d_{F\,II}$ (%)	0.13

Table 4.2. Results of the computational micromechanics of lamina's damping

E'_{II} (GPa)	127.7
$E'_{\perp}$ (GPa)	5.89
d_{II} (%)	0.141
$d_{\perp}$ (%)	0.833
$d_{\#}$ (%)	1.929
G'_M (GPa)	0.97

4. Contributions to the damping's analysis of a twill weave carbon/epoxy fabric – Damping's simulation of twill weave carbon/epoxy fabric. Results

Table 4.3. Twill weave carbon/epoxy fabric's dynamic compliances, rigidities and dampings

c'_{II} (GPa^{-1})	0.00783
$c'_{II\perp}$(GPa^{-1})	- 0.04923
$c'_{\perp}$ (GPa^{-1})	0.16977
$c_{\#}$ (GPa^{-1})	0.18939
d_{cII} (%)	0.141
$d_{cII\perp}$(%)	- 0.833
$d_{c\#}$ (%)	- 1.929
r'_{II} (GPa)	128.19
$r'_{II\perp}$ (GPa)	1.71
$r'_{\perp}$ (GPa)	5.91
$r'_{\#}$ (GPa)	5.28
d_{rII} (%)	0.143
$d_{rII\perp}$(%)	0.835
$d_{r\#}$ (%)	1.929

- The dampings of twill weave carbon/epoxy fabric are very different along and transverse to the fibers direction.
- The maximum value of the damping seems to be at 45° against the fibers direction.

5. Contributions to the hysteresis effect in a three-phase polymer matrix composite subjected to static cyclic loadings – Abstract of contributions

- Experimental researches regarding hysteresis behaviors of three-phase polymer matrix composite material (Chopped Strand Mat-Al_2O_3 ceramic particles-reinforced polyester resin) subjected to static cyclic tension-compression loadings have been carried out and published in two issues of *Optoelectronics and Advanced Materials-Rapid Communications (OPTOELECTRON ADV MAT)* in 2011 [47], [83].

- Various cyclic tests with different test speeds, load limits and number of cycles have been accomplished on a Lloyd Instruments LS100Plus materials testing machine using a STGA/50/50 E85454 extensometer and Nexygen software.

- Among over forty-five mechanical properties determined in extended experimental researches, maximum hysteresis data as well as stiffness distributions of specimens that exhibit maximum hysteresis have been determined.

- The difference between first and last cycle extension in every single test has been computed to determine maximum hysteresis effect reported to be at 10 mm/min test speed with a decreasing tendency once test speed is increased.

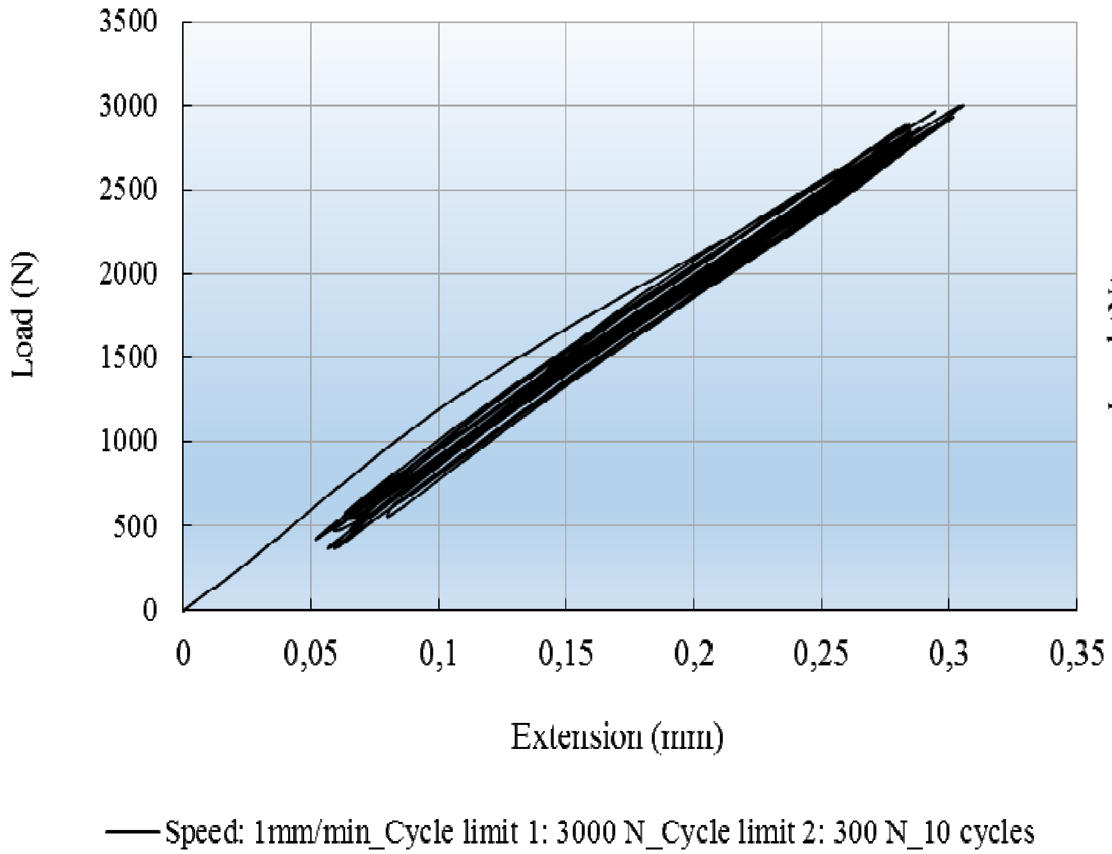
5. Contributions to the hysteresis effect in a three-phase polymer matrix composite subjected to static cyclic loadings – Materials and experimental procedure

- The composite material used in static cyclic tension-compression loadings is a three-phase one based on following compounds:
  - Chopped strand mat CSM 600 (up to 60% E-glass fibers volume fraction);
  - Al2O3 ceramic particles (up to 10% volume fraction);
  - Polyester resin.
- A 5 mm thick composite plate has been manufactured from which specimens (dimensions: 5 x 15 x 150 mm) have been cut.

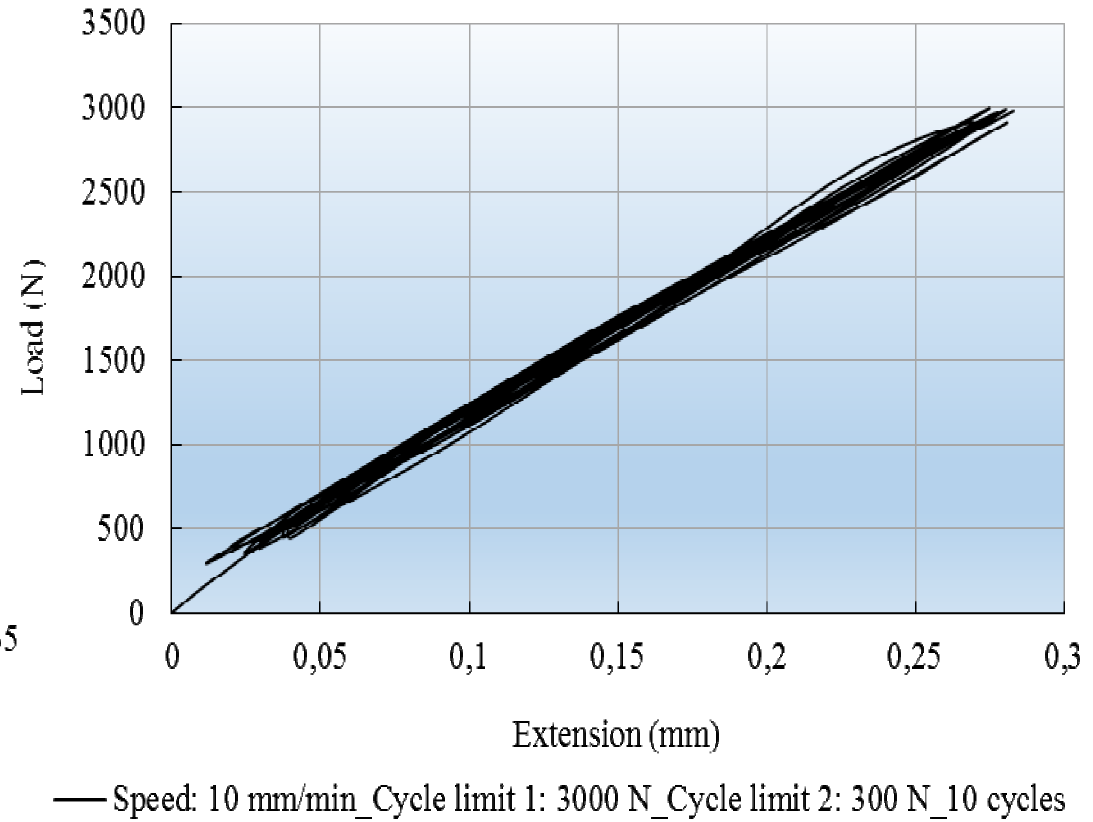
Table 5.1. Test speeds, cycle limits, number of cycles and specimens features used in cyclic tests

Gauge length [mm]	50	50	50	50	50	50
Test speed [mm/min]	1	10	20	40	60	60
Specimens’ width [mm]	15	15	15	15	15	15
Specimens’ thickness [mm]	4.86	4.86	4.86	4.86	4.86	4.86
Cycle limit 1 [kN]	3	3	3	3	3.5	3.5
Cycle limit 2 [kN]	0.3	0.3	0.3	-2	-3.5	-3.5
Number of cycles	10	10	10	10	10	100

5. Contributions to the hysteresis effect in a three-phase polymer matrix composite subjected to static cyclic loadings – Results

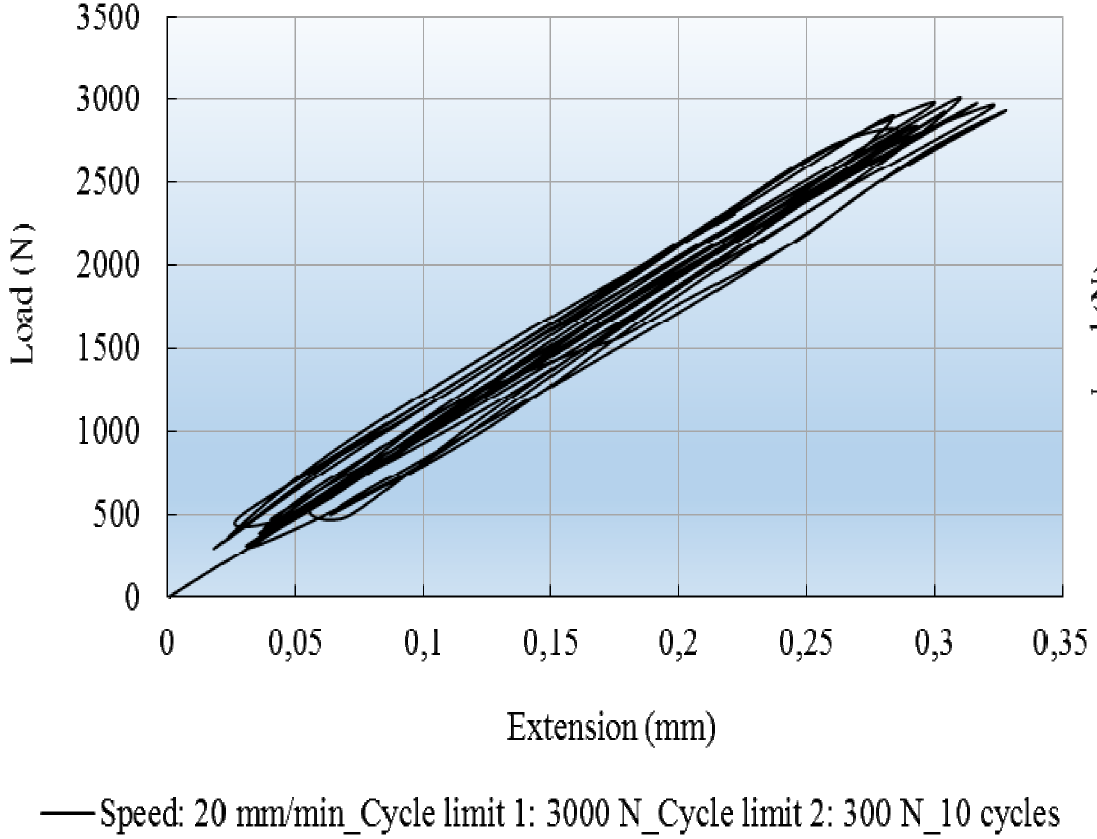


Tension-compression loadings (1 mm/min test speed, 10 cycles). Maximum hysteresis specimen

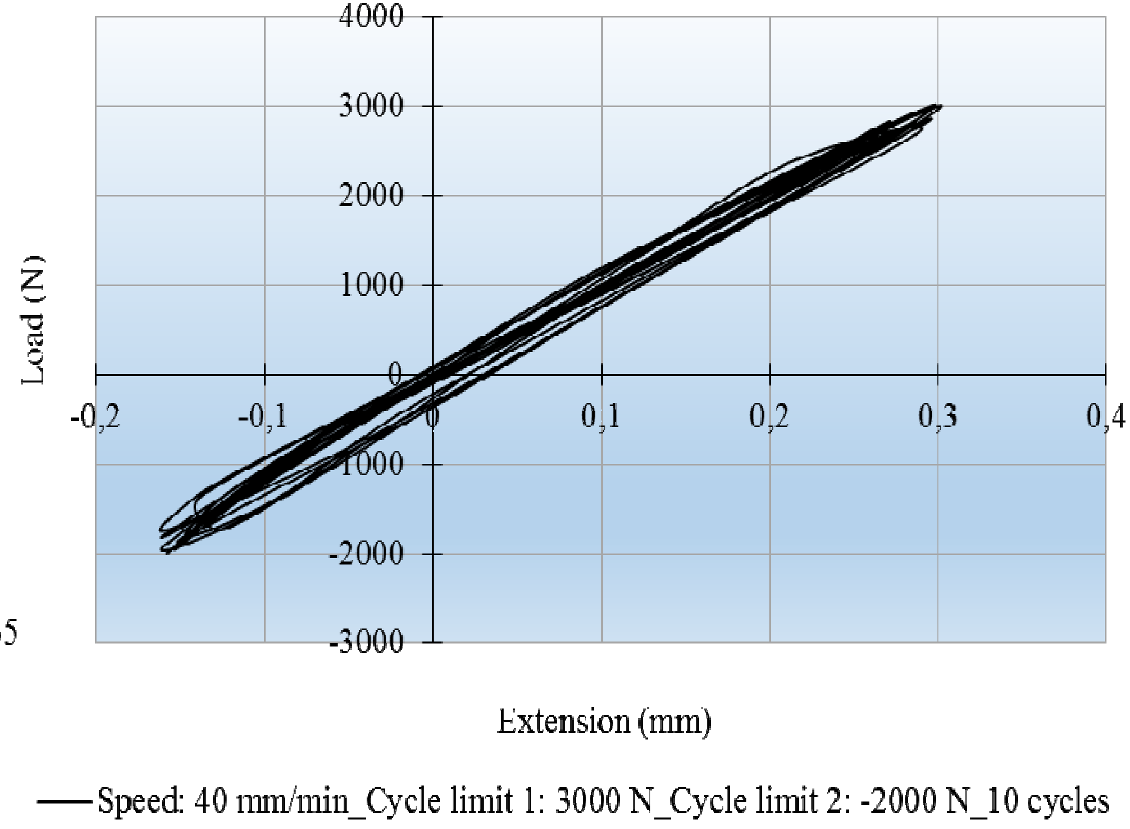


Tension-compression loadings (10 mm/min test speed, 10 cycles). Maximum hysteresis specimen

5. Contributions to the hysteresis effect in a three-phase polymer matrix composite subjected to static cyclic loadings – Results

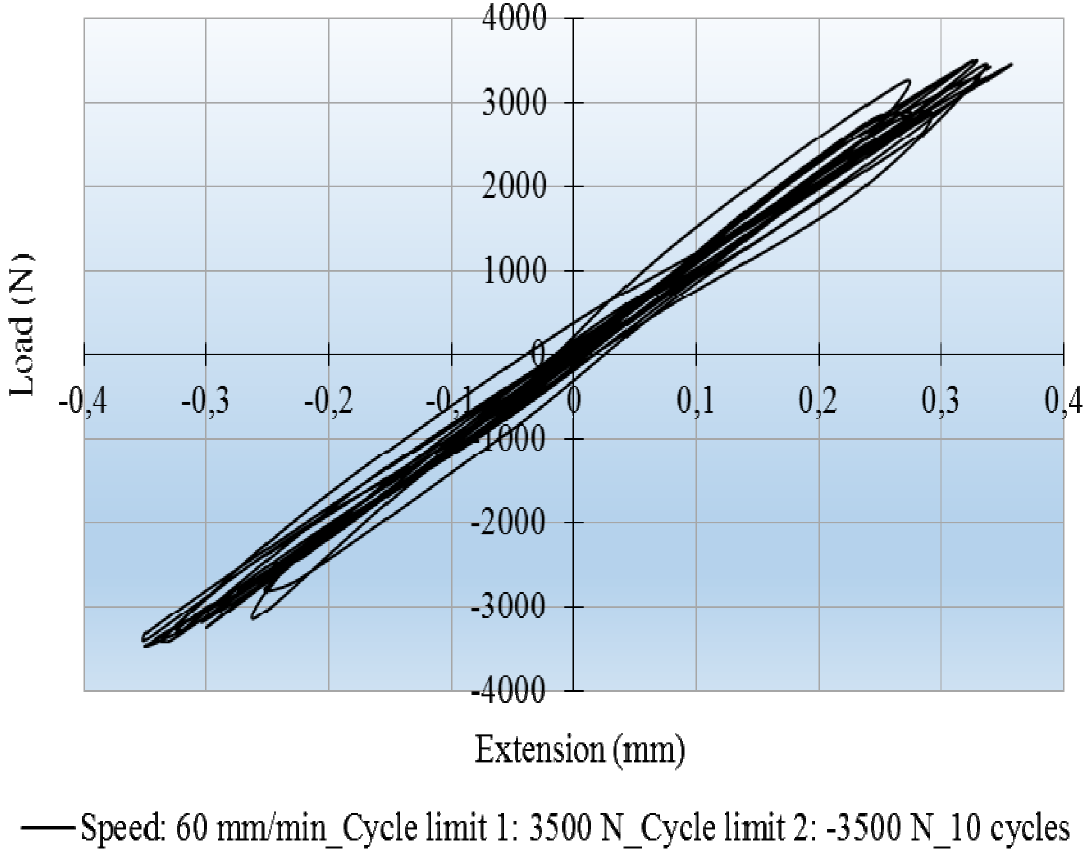


Tension-compression loadings (20 mm/min test speed, 10 cycles). Maximum hysteresis specimen

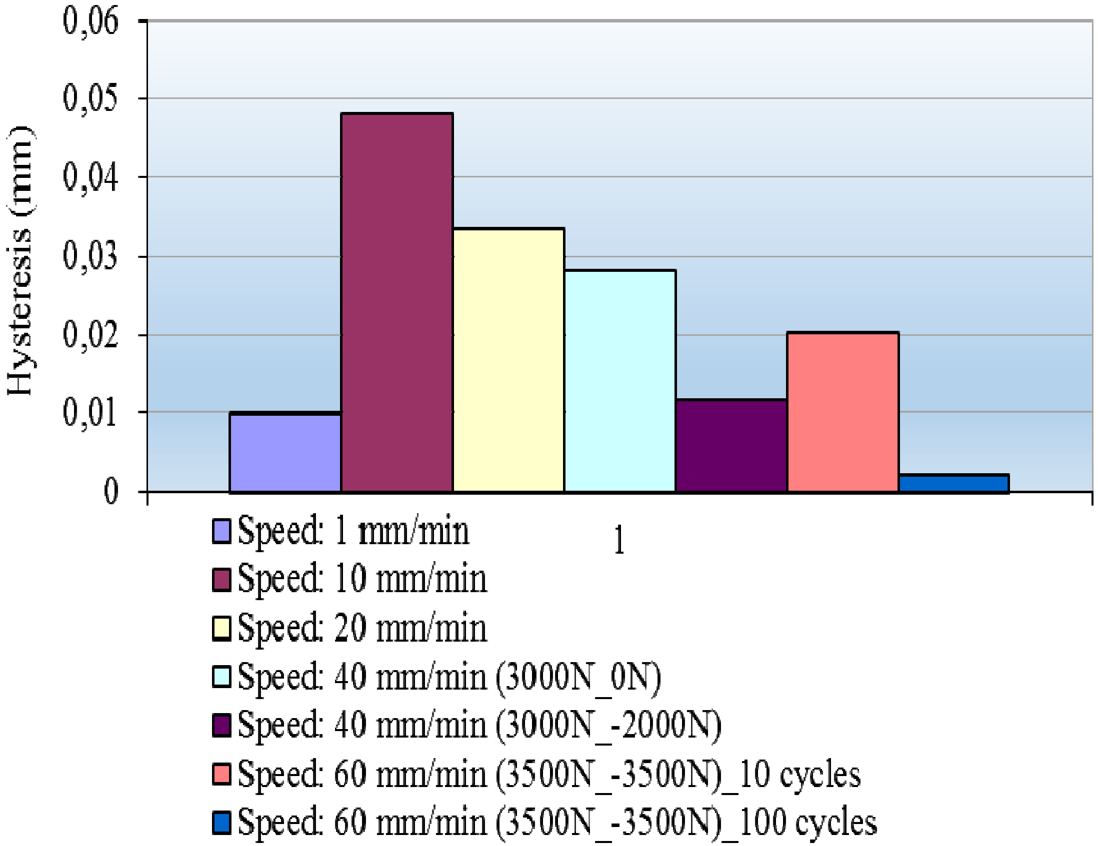


Tension-compression loadings (40 mm/min test speed, 10 cycles). Maximum hysteresis specimen

5. Contributions to the hysteresis effect in a three-phase polymer matrix composite subjected to static cyclic loadings – Results



Tension-compression loadings (60 mm/min test speed, 10 cycles). Maximum hysteresis specimen



Maximum hysteresis at different test speeds and cycle limits

5. Contributions to the hysteresis effect in a three-phase polymer matrix composite subjected to static cyclic loadings – Conclusions

- It can be noticed that with the test speed increase, non-linear behavior at unloading phase is more significant.

- Maximum hysteresis value has been determined at 10 mm/min test speed with a decreasing tendency once the test speed increases.

- Maximum stiffness has been determined at 60 mm/min tests speed, the general tendency is the increase of this stiffness.

- With the increase of cycle limits, the maximum hysteresis presents a decreasing tendency while the stiffness distribution increases.

- The same specimens have been subjected to increased loading conditions; this means increased cycle limits, test speeds and number of cycles.

- The break detector reported breaking of the composite material after 115 static cyclic tension-compression loadings.

6. Contributions to the experimental characterization of polyester and epoxy/glass fibers-reinforced laminates – Abstract of contributions

- Seven types of composite laminates have been developed at Compozite Ltd., Brasov, based on polyester and epoxy resins reinforced with chopped strand mats (CSM) and glass fabrics of various specific weights and then subjected to three and four-point bend tests both on warp and weft direction to determine their mechanical properties.

- One type of Polylite 440-M888/RT300 glass fabric composite laminate has been developed and subjected to tensile loads until break.

- These experimental researches, have been published in four issues of *Optoelectronics and Advanced Materials-Rapid Communications (OPTOELECTRON ADV MAT)* [25], [36], [45], [81] and one issue of *Journal of Optoelectronics and Advanced Materials (J OPTOELECTRON ADV M)* [82].

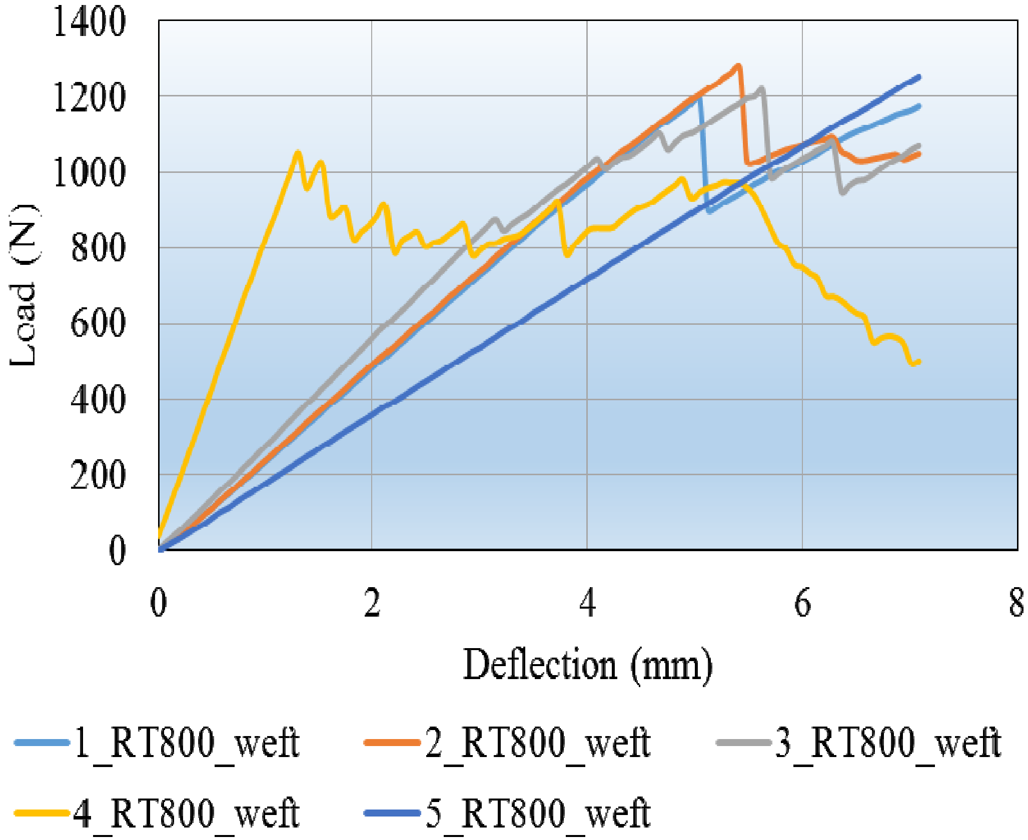
- Some specimens have been used to determine strain distributions inserting strain gages between specimens' layers and connecting them in SPIDER8 data acquisition system. The resistive strain analysis has been accomplished using the CATMAN software.

- My previous researches regarding the mechanical behavior of chopped strand mats and roving fabrics subjected to tensile tests have been published in 2007 in references [72], [73], [74].

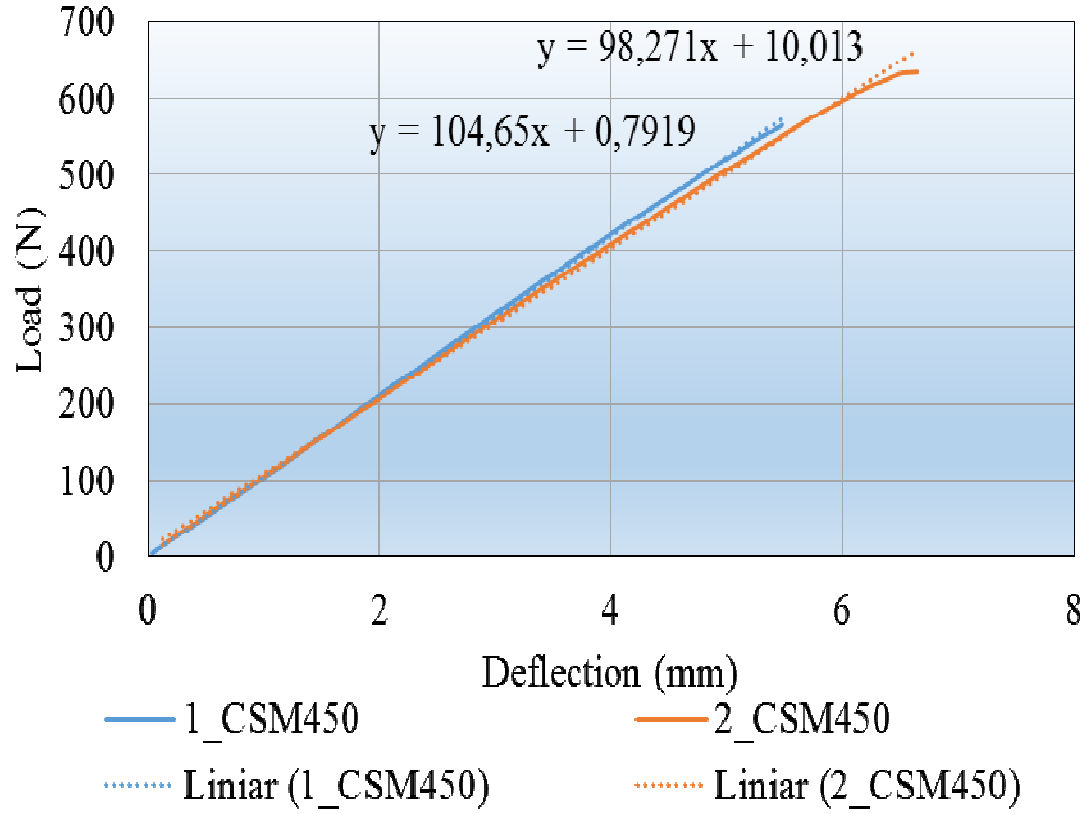
6. Contributions to the experimental characterization of polyester and epoxy/glass fibers-reinforced laminates – Materials and experimental procedure

- Following polyester and epoxy/glass fibers composite laminates have been manufactured at Compozite Ltd., Brasov:
  1. Four layers Epoxy/Chopped Strand Mat CSM450 (450 g/m^2 specific weight), 3.2 – 3.6 mm thick laminate;
  2. Four layers Epoxy/RT800 glass fabric (800 g/m^2 specific weight), 3.2 – 3.6 mm thick laminate, from which specimens have been cut on warp direction;
  3. Four layers Epoxy/RT800 glass fabric (800 g/m^2 specific weight), 3.2 – 3.6 mm thick laminate, from which specimens have been cut on weft direction;
  4. Combination of two layers Epoxy/CSM600 (600 g/m^2 specific weight), 2 – 2.6 mm thick – four layers Epoxy/RT800 on warp (3.2 – 3.6 mm thick) – two layers Epoxy/CSM450 (1.6 – 2 mm thick);
  5. Combination of two layers Epoxy/CSM600 (600 g/m^2 specific weight), 2 – 2.6 mm thick – four layers Epoxy/RT800 on weft (3.2 – 3.6 mm thick) – two layers Epoxy/CSM450 (1.6 – 2 mm thick);
  6. Twelve layers of Polylite 440-M888/RT300 glass fabric on weft (300 g/m^2 specific weight), 4 mm thick laminate;
  7. Five layers of Heliopol 9431ATYX_LSE/Stratimat300 glass fabric (300 g/m^2 specific weight), 6 mm thick laminate.

6. Contributions to the experimental characterization of polyester and epoxy/glass fibers-reinforced laminates – Results

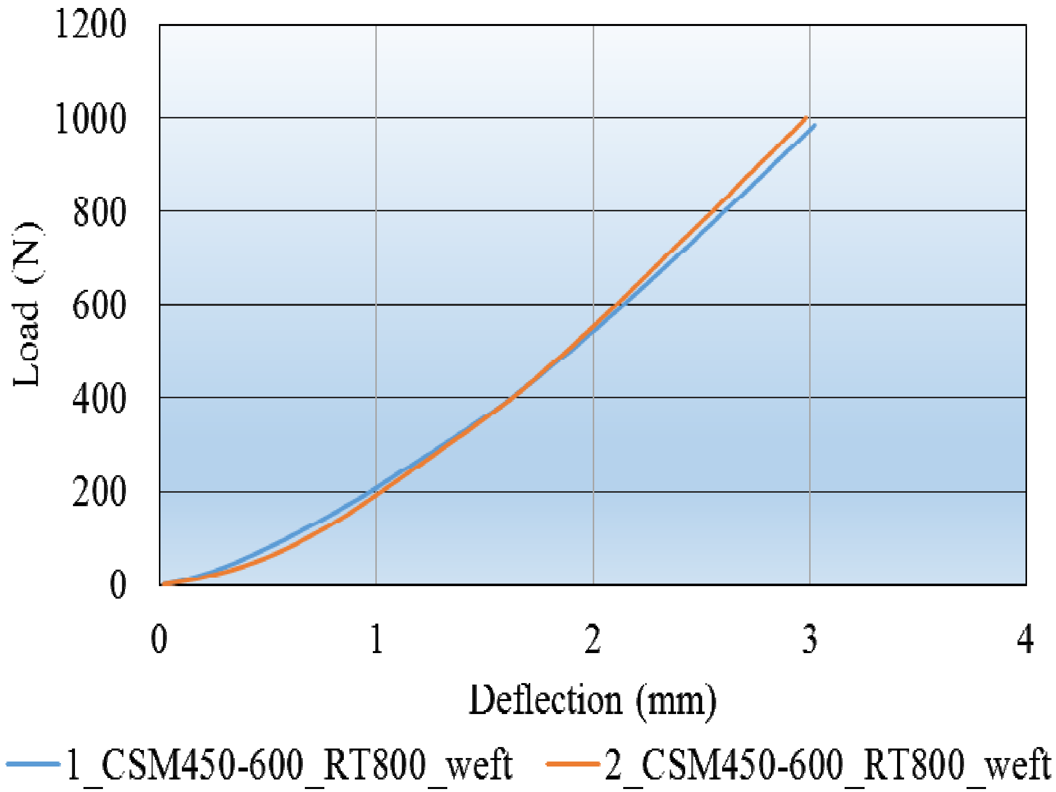


Load-deflection distributions of five Epoxy/RT800 glass fabric specimens cut on weft direction (four-point bend tests)

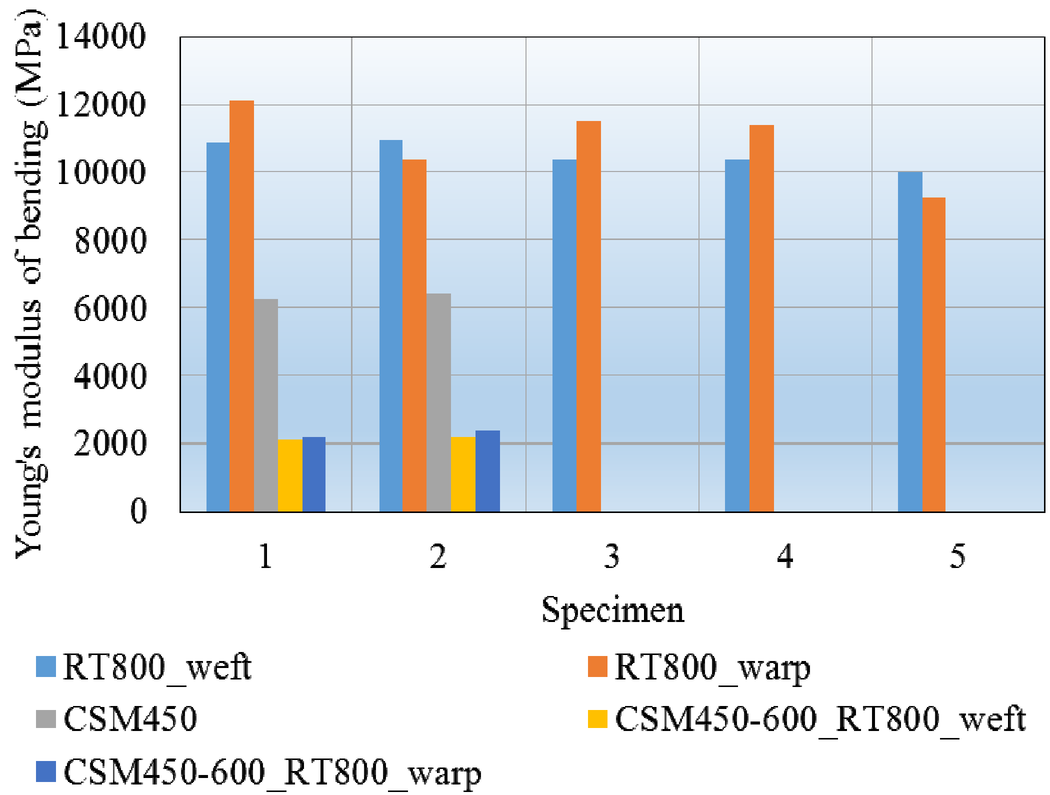


Load-deflection distributions of two Epoxy/CSM450 specimens (four-point bend tests)

6. Contributions to the experimental characterization of polyester and epoxy/glass fibers-reinforced laminates – Results

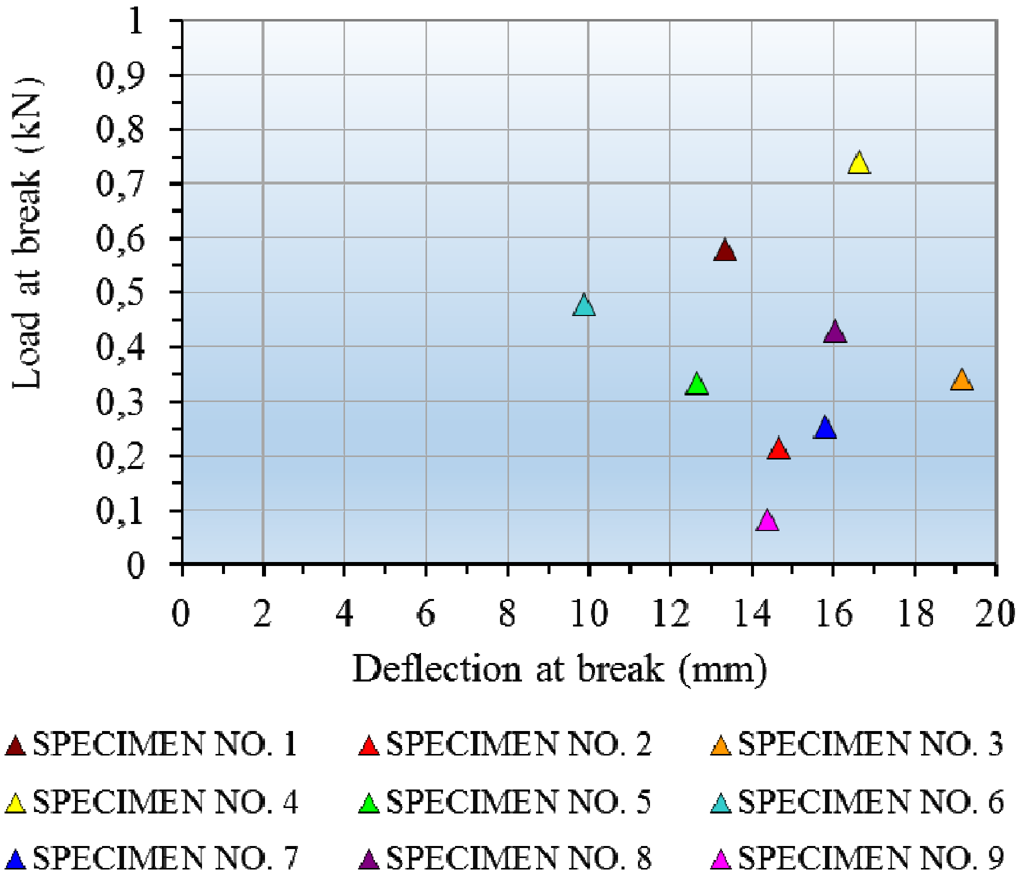


Load-deflection distributions of two Epoxy/CSM450-CSM600_RT800 specimens on weft direction (four-point bend tests)

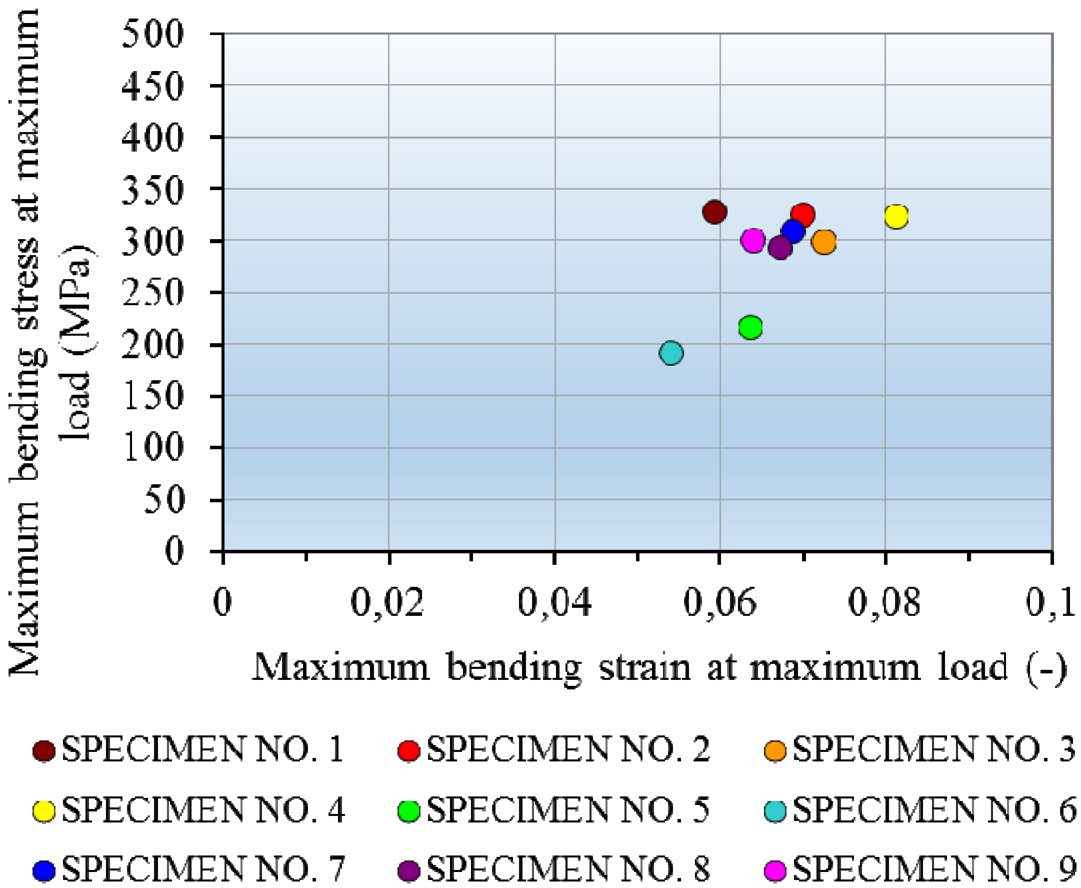


Young's modulus of bending distributions of epoxy/glass fibers composite laminates subjected to four-point bend tests

6. Contributions to the experimental characterization of polyester and epoxy/glass fibers-reinforced laminates – Results



Load-deflection at break distribution of five layers Heliopol/Stratimat300 composite laminate



Maximum bending stress at maximum load distribution of five layers Heliopol/Stratimat300

7. Contributions to the experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS – Abstract of contributions

- Latest researches have been published in one issue of *Journal of Optoelectronics and Advanced Materials (J OPTOELECTRON ADV M)* in 2013 [41].

- Previous researches in this field have been published between 2006 – 2010 in references [13], [30], [61].

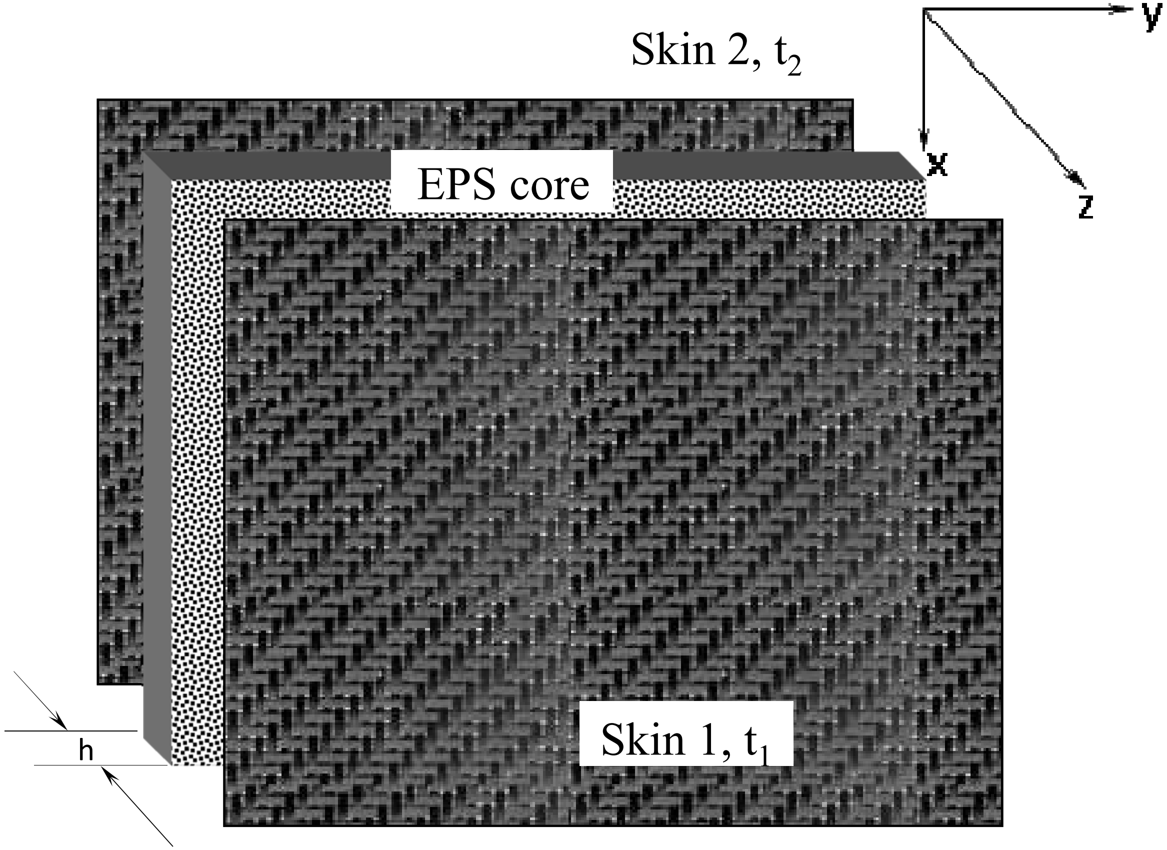
- Following researches present the most important mechanical properties that I have determined in a simple tensile test on a 0.4 mm thickness 2/2 carbon twill weave fabric impregnated with epoxy resin, used as skins for an advanced ultralight sandwich composite structure with expanded polystyrene (EPS) as core.

- The sandwich panel developed at Compozite Ltd., Brasov, has been subjected to flexural load-unload tests.

- A comparison with a sandwich structure with EWR-300 glass fabric/epoxy resin skins has been accomplished.

- The flexural load-unload tests show an outstanding stiffness of the whole sandwich panel.

7. Contributions to the experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS – Materials and experimental procedure



The architecture of sandwich structure

- Panel dimensions: 10 × 2350 × 4070 mm;
- Overall weight: maximum 10 kg.
- thickness of each ply: 0.175 mm;
- skins thickness: 0.35 mm;
- core thickness: 9 mm;
- fibers' volume fraction of each ply: 56%.
- skins reinforcement: HM carbon fibers;
- fibers' specific weight: 0.3 kg/m^2;
- core's type: expanded polystyrene.
- core density: 30 kg/m^3;
- core Young's modulus: 30 MPa;
- core Poisson's ratio: 0.35;
- core shear modulus: 11 MPa;
- fibers' Young's modulus in longitudinal direction: 540 GPa;
- fibers' Young's modulus in transverse direction: 27 GPa;
- fibers' Poisson's ratio: 0.3;
- fibers' shear modulus: 10.38 GPa.

7. Contributions to the experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS – Materials and experimental procedure

- Following experimental determinations have been accomplished:

  - *Two flexural load-unload tests of the sandwich panel clamped on contour*
  - *One simple three-point bend test (load-unload) of the sandwich panel supported linearly on two opposite edges*

- The loads are applied in the middle of the panel and a displacements' measuring device has been placed under panel at its center.

- The tensile test on one layer 2/2 twill weave carbon fabric impregnated with epoxy resin has been accomplished on a "LR5K Plus" materials testing machine produced by Lloyd Instruments.

7. Contributions to the experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS – Materials and experimental procedure

Flexural load-unload test detail. Sandwich panel clamped on contour

Three-point bend load-unload test detail. Sandwich panel supported linearly on two opposite edges

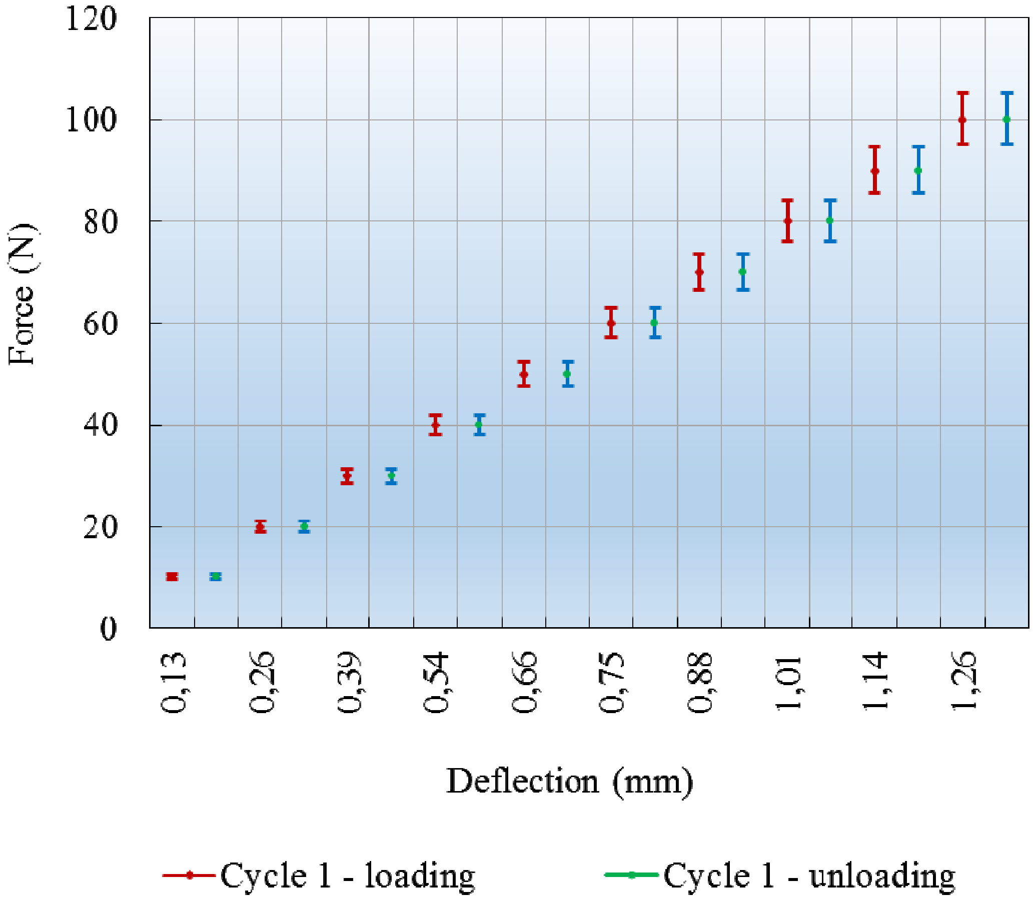
Tensile test detail on an epoxy impregnated 2/2 twill weave carbon fabric

7. Contributions to the experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS – Results

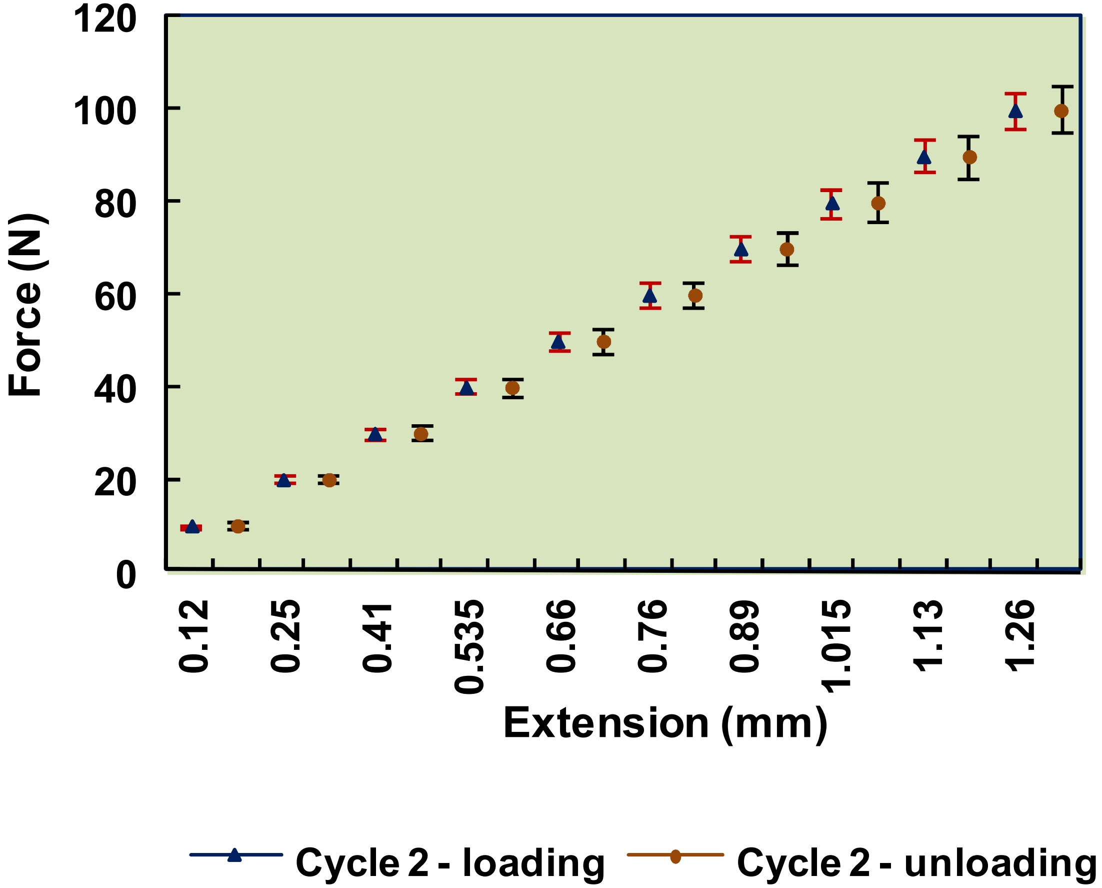
Table 7.1. Tensile test results on an epoxy impregnated 2/2 twill weave carbon fabric

Characteristics	Value
Length between extensometer's lamellae (mm)	50
Preload stress (kN)	0.0056
Preload speed (mm/min)	21
Test speed (mm/min)	1
Fabric width (mm)	18.5
Fabric thickness (mm)	0.4
Stiffness as ratio between load and extension (N/m)	5785656.99
Young's modulus (MPa)	31273.82
Load at maximum load (kN)	1.92
Stress at maximum load (MPa)	207.61
Strain at maximum load (-)	0.009
Strain at maximum extension (-)	0.344
Strain at minimum load (-)	0.087
Load at break (kN)	1.919
Stress at break (MPa)	207.55
Strain at break (-)	0.009
Tensile strength (MPa)	207.61

7. Contributions to the experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS – Results

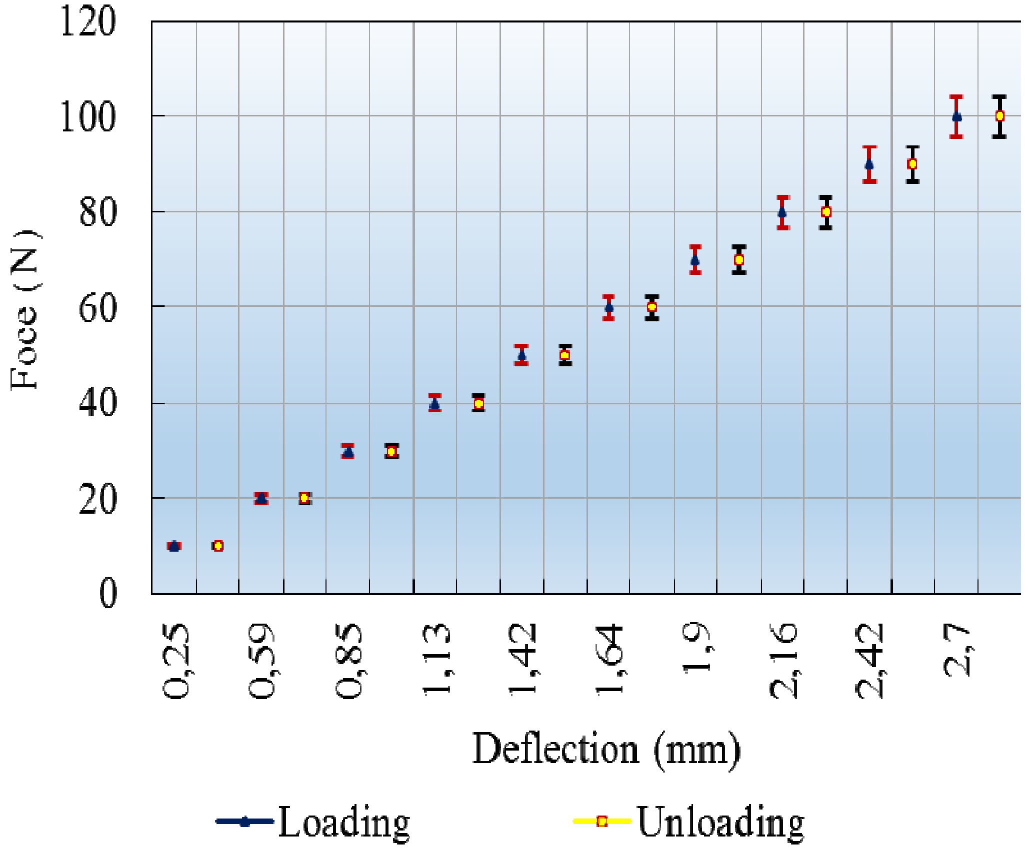


Flexural test of the sandwich panel clamped on contour. Cycle 1 loading-unloading

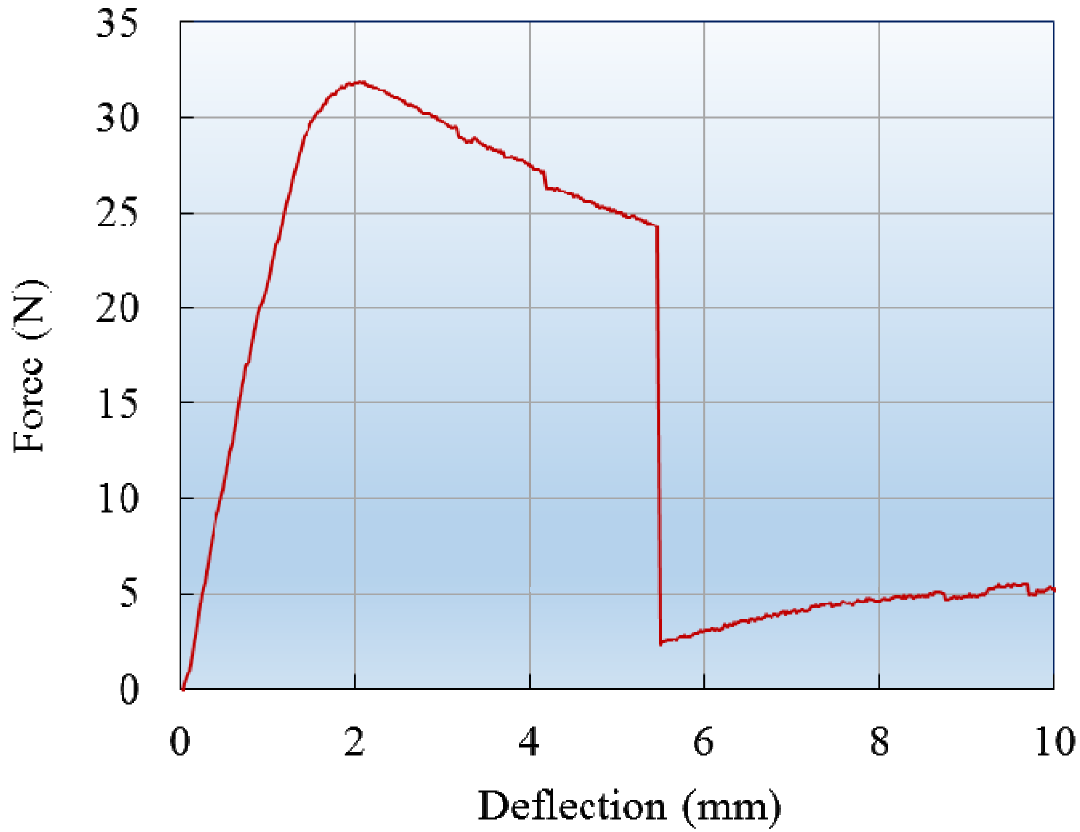


Flexural test of the sandwich panel clamped on contour. Cycle 2 loading-unloading

7. Contributions to the experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS – Results

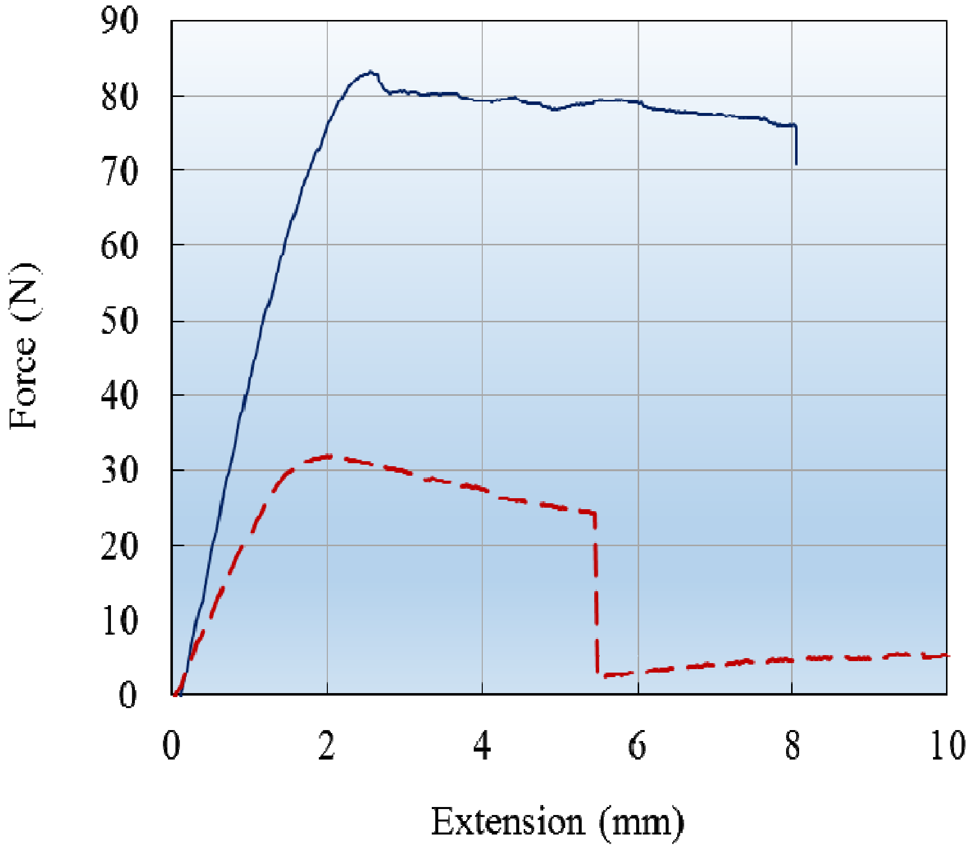


Three-point bend test of the sandwich panel supported linearly on two opposite edges

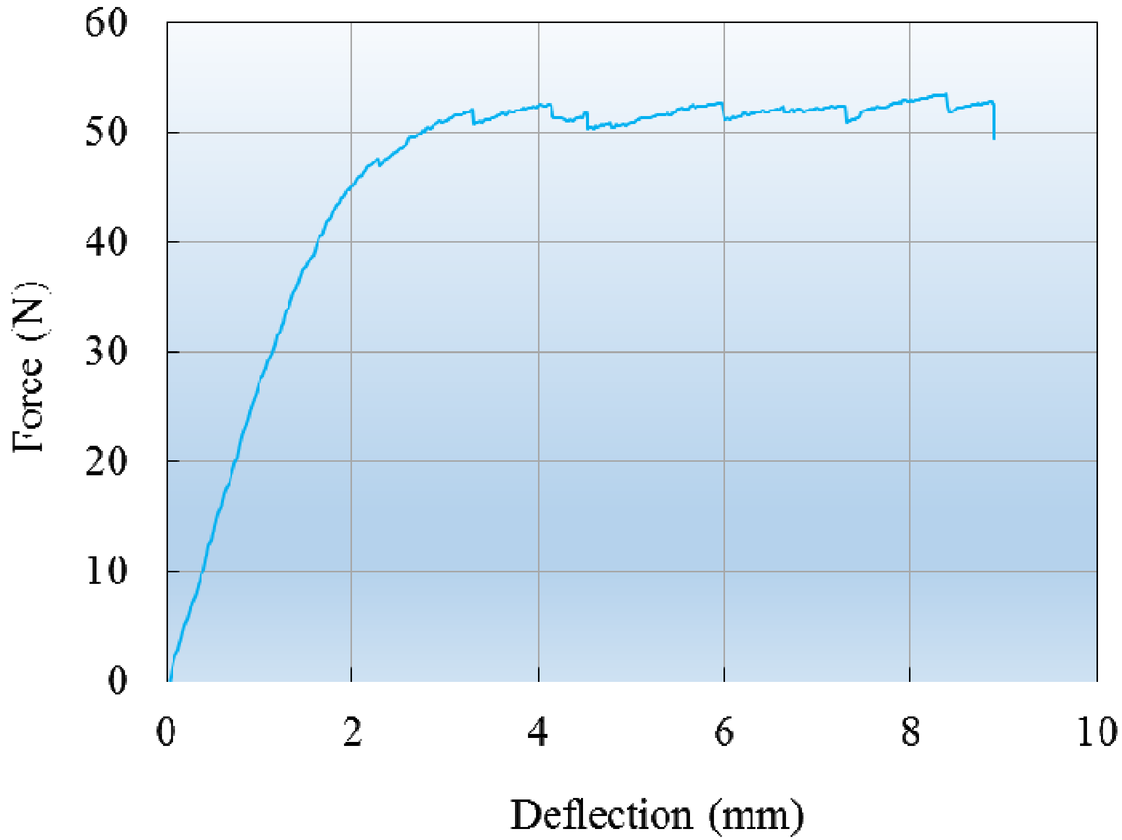


Force-deflection distribution on 10 mm thickness specimen subjected to three-point bend test

7. Contributions to the experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS – Results

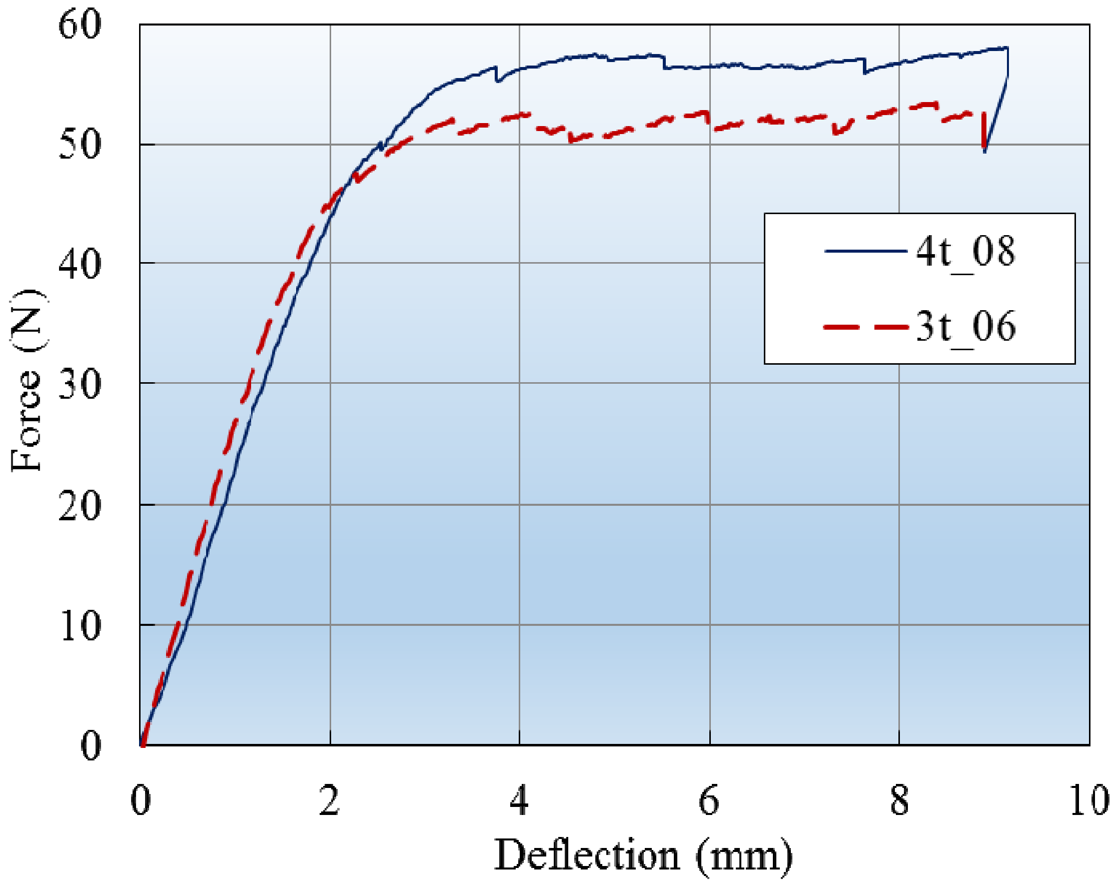


Force-deflection distribution on 20 mm thickness specimen subjected to three-point bend test



Force-deflection distribution on 30 mm thickness specimen subjected to three-point bend test

7. Contributions to the experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS – Results



Comparison between force-deflection distributions on 30/40 mm thickness specimens subjected to three-point bend tests

7. Contributions to the experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS – Conclusions

- The sandwich structure's strains with skins based on twill weave carbon fabric reinforced epoxy resin are comparable with those of the structure with skins based on EWR-300 glass fabric/epoxy resin;
- Stresses in fibers direction in case of the sandwich structure with carbon fabric/epoxy resin reinforced skins, are up to six times higher than those existent in EWR-300 glass fabric/epoxy resin skins;
- Stresses transverse to the fibers direction in case of the sandwich structure with carbon fabric/epoxy resin reinforced skins are 20% lower than those existent in EWR-300 glass fabric/epoxy resin skins;
- The shear stresses in carbon fabric/epoxy resin reinforced skins' plies are almost identical with those existent in EWR-300 glass fabric/epoxy resin skins' plies;
- The core stresses are almost zero, so the loading is taken over exclusively by skins;
- Using a 9 mm thick expanded polystyrene core (EPS) the stiffness of the sandwich structure with carbon fibers reinforced epoxy resin skins is more than ten times higher than the skins' plies stiffness.

8. Professional and academic achievements

- In 1985 I graduated from Transilvania University of Brasov, Faculty of Technology of Machine Construction.
- In 2001 I was granted the title of Ph.D. in Sciences, field of Mechanical Engineering, after defending the thesis: "Contributions to the increase of loading capability of fibers-reinforced polymer matrix composite tubes by introducing supplementary internal stresses", during the May 5th 2001 meeting at Mechanical Engineering Faculty, Department of Strength of Materials and Vibrations, Transilvania University of Brasov.
- I began my professional career at IMASA Sf. Gheorghe plant in 1985.
- Between 1987 and 2000 I was Main Technologist Engineer 3rd rank at the research institute ICDEM Bucharest.
- Between 2000 and 2002 I worked as Design Manager at SC METALOPLAST SA Brasov.
- At COMPOZITE Ltd., Brasov I followed my activity as Quality Manager between 2002 and 2005.
- I began my academic career as Assistant Professor in Department of Mechanics, Faculty of Mechanical Engineering within Transilvania University of Brasov.
- Currently, I am Associate Professor and also hold the position of Secretary of Scientific Committee of the Senate of Transilvania University of Brasov.

8. Professional and academic achievements

- Regarding the teaching activities, currently I am the course coordinator of Experimental Methods in Mechanical Engineering at the Department of Mechanical Engineering (Licence studies in Romanian), the seminar coordinator of Theoretical Mechanics (Kinematics and Dynamics) at the Department of Automotive and Transport within Faculty of Mechanical Engineering (Licence studies in English), as well as the course coordinator of Advanced Notions of Dynamic Systems (Master of Science studies, in Romanian).

- I am the coordinator of Materials Testing Laboratory from the Department of Mechanical Engineering where usually there are practical seminars for students both at Licence and Master of Science studies as well for PhD students.

- As first author I have published two books: *Basics and Mechanics of Polymer Matrix Composite Materials*, Transilvania University of Brasov Publishing House, 2007, ISBN 978-635-878-4 (178 pgs.) and *Mechanics of Composite Materials*, Transilvania University of Brasov Publishing House, 2013, ISBN 978-606-19-0300-9 (252 pgs.) and 41 articles at international level: 4 articles published in ISI indexed journals with impact factor, 16 articles in ISI indexed proceedings, 2 articles in BDI indexed journals, 4 articles in BDI indexed proceedings, 19 articles published in proceedings issued for symposiums and conferences.

8. Professional and academic achievements

- Regarding my research activity, I have been involved in 22 research projects in the field of polymer matrix composite materials, with following positions:
  - Execution in 1 international research project by competition, on behalf Compozite Ltd., Brasov for Competitive and Sustainable Growth Programme/CRAF-1999-71564, Contract No. G5ST-CT-2002-50329.
  - Project manager in 2 national research projects by competition, on behalf Compozite Ltd., Brasov, for program INVENT, project STAR2 (contract 171/10.2004) and on behalf SC INAR SA Brasov for program POSCCE, priority axis 2, operation 2.1.1, project no. 1132/code SMIS: 35420 (contract 379/16.01.2012).
  - Project responsible in 3 national research projects by competition on behalf Transilvania University of Brasov, program CEEX, project SICOMSUV (contract 129/2006) and program INOVARE, projects SISCOMP (contract 218/2008) and MARECICLA (contract 267/2008).
  - Project responsible in 1 national research project by competition on behalf Compozite Ltd., Brasov for program CEEX, project ROBOSIS (contract 41/2005).
  - Researcher in 6 national research projects by competition on behalf Transilvania University of Brasov for program CEEX, projects: COMPMEF (contract 42/2005), CAMCOM (contract 23/2006), MECPMC (contract 35/2006), IMAGID (contract 212/2006), ADEL (contract 61/2006), PROECO (contract 220/2006).
  - Execution in 9 national research projects by competition on behalf Compozite Ltd., Brasov for program RELANSIN, project SIRTEM (contract 1795/17.09.2003), program CEEX, projects: DITEH (contract 191/2006), CAFICMEIS (contract 240/2006), MOSCOM (contract 202/2006), program CEEX-AMTRANS, project COMPAS (contract X1C05/2005), program CNMP-P4, projects: MAVIAT (contract 71-125/2007), NANOAERO (contract 71-027/2007), SISUAR (contract 81-020/2007), SUPERSOLID (contract 71 – 001/2007).

8. Professional and academic achievements

- Between 2002 and 2008 I have participated at following specializations and qualifications:
  - Specialization firm WOLFANGEL GmbH Germany, 2002, in the field of technology of polymer matrix composite materials.
  - Specialization firm GOM GmbH Germany, 2007, in the field of optical measurement techniques.
  - Participation at "Computational and Experimental Mechanics of Advanced Materials" course, CISM, Udine, Italy, 2008.
- As coauthor I have two patents abstracts published in the Official Bulletin of Industrial Property as well as at international level:
  - Patent title: "Carbon-hemp hybrid composite material and its process for the application in the automotive and engineering" (CBI_A_00297_11.04.13_Rez_BOPI_4_2014__Espacenet14_SCUTARU_ML_sa.pdf; http://worldwide.espacenet.com/publicationDetails/biblio?DB=worldwide.espacenet.com&II=3&ND=3&adjacent=true&locale=en_EP&FT=D&date=20140430&CC=RO&NR=129354A0&KC=A0)
  - Patent title: "Composite material based on COREMAT used in the construction of underground shelters and auto parts" (CBI_A_00401_24.05.13__Rez_BOPI_8_2014__Espacenet14_PurcareaR_sa.pdf; http://worldwide.espacenet.com/publicationDetails/biblio?DB=worldwide.espacenet.com&II=1&ND=3&adjacent=true&locale=en_EP&FT=D&date=20140829&CC=RO&NR=129712A0&KC=A0)

8. Professional and academic achievements

- I hold the Inovator Certificate No. 454 / 04.11.1988 released by Romanian Defense Department. The innovation was registered at 04.11.1988 at UM 02550 S, Bucharest.
- Regarding the activity for editorial and/or scientific boards representing publications and scientific conferences, I will mention the following:
  - Member in organizing committee of following conferences: 7^{th} WSEAS International Conference on Non-Linear Analysis, Non-Linear Systems and Chaos (NOLASC'08) Corfu Island, Greece, October 26-28, 2008;
  - 2^{nd} Int. Conf. "Advanced Composite Materials Engineering" COMAT 2008, 9-11 October 2008, Transilvania University of Brasov, Romania;
  - 3^{rd} International Conference "Computational Mechanics and Virtual Engineering" COMEC 2009, Transilvania University of Brasov, Romania, 29-30 October, 2009;
  - 3^{rd} Int. Conf. "Advanced Composite Materials Engineering" COMAT 2010, 27-29 October 2010, Transilvania University of Brasov, Romania;
  - 4^{th} Int. Conf. "Computational Mechanics and Virtual Engineering" COMEC 2011, Transilvania University of Brasov, Romania, 20-22 October, 2011;
  - 5^{th} Int. Conf. "Computational Mechanics and Virtual Engineering" COMEC 2013, Transilvania University of Brasov, Romania, 24-25 October, 2013;
  - 5^{th} International Conference "Advanced Composite Materials Engineering" COMAT 2014, Transilvania University of Brasov, Romania, 16-17 October, 2014.

8. Professional and academic achievements

- Total number of citations: 18 – from which:
- 5 citations as first author in references:
  - [45] (1 citation in: Scutaru, M.L., Baba, M., Investigation of the mechanical properties of hybrid carbon-hemp laminated composites used as thermal insulation for different industrial applications, *Advances In Mechanical Engineering*, article number 829426, published: 2014, http://dx.doi.org/10.1155/2014/829426),
  - [46] and [47] (4 citations in: Niculita, C., Mechanical behavior of epoxy 1050_GBX300L-1250 glass fabric laminates subjected to three-point bend tests, *Optoelectronics And Advanced Materials-Rapid Communications*, Vol. 6, Issue3-4, p. 487-490, published: MAR-APR 2012, http://oam-rc.inoe.ro/index.php?option=magazine&op=view&idu=1860&catid=71;

  Niculita, C., Mechanical behavior of carbon fibre-reinforced epoxy/plain200 prepregs subjected to three-point bend tests, *Optoelectronics And Advanced Materials-Rapid Communications*, Vol. 6, Issue3-4, p. 504-507, published: MAR-APR 2012, http://oam-rc.inoe.ro/index.php?option=magazine&op=view&idu=1864&catid=71).
- 13 citations as coauthor in references:
  - [15] (1 citation in: Scutaru, M.L., Toward the use of irradiation for the composite materials properties improvement, *Journal Of Optoelectronics And Advanced Materials*, Vol. 16, Issue 9-10, p. 1165-1169, published: SEP-OCT 2014, http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3568&catid=86),

8. Professional and academic achievements

- [25] (3 citations in: Scutaru, M.L., Toward the use of irradiation for the composite materials properties improvement, *Journal Of Optoelectronics And Advanced Materials*, Vol. 16, Issue 9-10, p. 1165-1169, published: SEP-OCT 2014, http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3568&catid=86;

  Scutaru, M.L., Baba, M., Baritz, M.I., Irradiation influence on a new hybrid hemp bio-composite, *Journal Of Optoelectronics And Advanced Materials*, Vol. 16, Issue 7-8, p. 887-891, published: JUL-AUG 2014, http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3524&catid=85;

  Wang Baogang, Wang Xu, Zhou, Jixue, et. al., Modification effects of as cast Mg-Al-Si magnesium alloy with strontium, *Optoelectronics And Advanced Materials-Rapid Communications*, Vol. 8, Issue 1-2, p. 63-67, published: JAN-FEB 2014, http://oam-rc.inoe.ro/index.php?option=magazine&op=view&idu=2240&catid=82),

- [81] (2 citations in: Scutaru, M.L., Toward the use of irradiation for the composite materials properties improvement, *Journal Of Optoelectronics And Advanced Materials*, Vol. 16, Issue 9-10, p. 1165-1169, published: SEP-OCT 2014, http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3568&catid=86;

  Scutaru, M.L., Baba, M., Baritz, M.I., Irradiation influence on a new hybrid hemp bio-composite, *Journal Of Optoelectronics And Advanced Materials*, Vol. 16, Issue 7-8, p. 887-891, published: JUL-AUG 2014, http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3524&catid=85),

8. Professional and academic achievements

- [83] (5 citations in: Scutaru, M.L., Toward the use of irradiation for the composite materials properties improvement, *Journal Of Optoelectronics And Advanced Materials*, Vol. 16, Issue 9-10, p. 1165-1169, published: SEP-OCT 2014, http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3568&catid=86;

  Scutaru, M.L., Baba, M., Baritz, M.I., Irradiation influence on a new hybrid hemp bio-composite, *Journal Of Optoelectronics And Advanced Materials*, Vol. 16, Issue 7-8, p. 887-891, published: JUL-AUG 2014,

  http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3524&catid=85;

  Scutaru, M.L., Baba, M., Investigation of the mechanical properties of hybrid carbon-hemp laminated composites used as thermal insulation for different industrial applications, *Advances In Mechanical Engineering*, article number 829426, published: 2014, http://dx.doi.org/10.1155/2014/829426;

  Niculita, C., Mechanical behavior of epoxy 1050_GBX300L-1250 glass fabric laminates subjected to three-point bend tests, *Optoelectronics And Advanced Materials-Rapid Communications*, Vol. 6, Issue3-4, p. 487-490, published: MAR-APR 2012,

  http://oam-rc.inoe.ro/index.php?option=magazine&op=view&idu=1860&catid=71;

  Niculita, C., Mechanical behavior of carbon fibre-reinforced epoxy/plain200 prepregs subjected to three-point bend tests, *Optoelectronics And Advanced Materials-Rapid Communications*, Vol. 6, Issue3-4, p. 504-507, published: MAR-APR 2012,

  http://oam-rc.inoe.ro/index.php?option=magazine&op=view&idu=1864&catid=71),

8. Professional and academic achievements

- [84] (2 citations in: Niculita, C., Mechanical behavior of epoxy 1050_GBX300L-1250 glass fabric laminates subjected to three-point bend tests, *Optoelectronics And Advanced Materials-Rapid Communications*, Vol. 6, Issue3-4, p. 487-490, published: MAR-APR 2012, http://oam-rc.inoe.ro/index.php?option=magazine&op=view&idu=1860&catid=71;

  Niculita, C., Mechanical behavior of carbon fibre-reinforced epoxy/plain200 prepregs subjected to three-point bend tests, *Optoelectronics And Advanced Materials-Rapid Communications*, Vol. 6, Issue3-4, p. 504-507, published: MAR-APR 2012, http://oam-rc.inoe.ro/index.php?option=magazine&op=view&idu=1864&catid=71).

(B-ii) The evolution and development plans for career development

Directions of scientific research

- My research activity belongs to the field of mechanics of fibers-reinforced polymer matrix composites, focused mainly both on theoretical and experimental approaches. These approaches cover following issues:

- ***Theoretical approaches***

1. Tensile behavior and prediction of elastic properties of pre-impregnated composite materials;
2. Simulations of elastic properties of fibers-reinforced laminates under off-axis loading system;
3. Thermo-mechanical behavior of fibers-reinforced laminates subjected to temperature and humidity variations;
4. Damping's analysis of a twill weave carbon/epoxy fabric.

- ***Experimental approaches***

1. Hysteresis effect in a three-phase polymer matrix composite subjected to static cyclic tension-compression loadings;
2. Experimental characterization of polyester and epoxy/glass fibers-reinforced laminates;
3. Experimental characterization of a new advanced sandwich composite with twill weave carbon and EPS.

Directions of scientific research

1. Regarding the theoretical approaches focused on tensile behavior and prediction of elastic properties of pre-impregnated composite materials, following directions of scientific research will be carried out:

   - Determination of replacement matrix' Young's modulus in case of fibers-reinforced polymer matrix composites with more than three compounds, using various averaging methods and rules of mixture.

   - Development of computing models regarding the longitudinal tensile behavior of multiphase composite materials with various fibers lengths.

   - Predictions of elastic properties of pre-impregnated composite materials with various periodicity cells or representative volume elements (RVEs) in connection with fibers volume fractions.

   - Determination of upper and lower limits of the homogenized coefficients for various prepregs and fibers volume fractions using various averaging methods.

Directions of scientific research

2. Regarding <u>the theoretical approaches</u> focused on the elastic properties of fibers-reinforced laminates under off-axis loading system and subjected to complex loadings, I have in mind to cover following research issues:

- Development of a data base that include various fibers-reinforced laminates and the prediction of their elastic properties simulating the action of some complex loadings on their mechanical behavior.

- Determination of matrix strain increase factor for various unidirectional fibers-reinforced laminae subjected to transverse tensile loadings and with various shapes of disposed fibers.

- Determination of some mathematical expressions to simulate basic experimental tests (tensile and bending) on various fibers-reinforced composite laminates.

Directions of scientific research

- Regarding the experimental approaches, future researches will be focused on following issues:

  - Determination of glass transition temperature for various types of resins and fibers as well as for fibers-reinforced polymer matrix composite laminates using the Differential Scanning Calorimetry (DSC) method. Development of a data base.
  - Experimental characterization (tensile, three and four-point bend tests) of bio-composites reinforced with various natural fibers. Development of a data base.
  - Stiffness evaluation of ultralight composite structures including sandwich structures with various types of cores and skins. Development of a data base.
  - Three and four-point bend tests on thermoplastic honeycomb structures with various cell sizes and thickness. Development of a data base.
  - Compression tests of ultralight sandwich structures and cores as well as the determination of some patterns regarding the cores' failure modes. Development of a data base.
  - Determination of hysteresis effect in various fibers-reinforced polymer matrix composite laminates subjected to static tensile-compression cyclic loadings at various test speeds and cycle limits. Development of a data base.
  - Determination of hysteresis effect in various fibers-reinforced polymer matrix composite laminates subjected to static three and four-point bending cyclic loadings at various test speeds and cycle limits. Development of a data base.

Directions of scientific research

- Development of new composite structures with a wide range of applications in cooperation with Compozite Ltd., Brasov and their mechanical characterization.
- Development of new devices for the existing materials testing machines within Department of Mechanical Engineering used for mechanical characterization of fabrics and yarns.
- Development of new devices to be used for static three and four-point bending cyclic tests of various fibers-reinforced polymer matrix composite laminates.
- Development of new devices for the existing materials testing machines within Department of Mechanical Engineering used for mechanical characterization of composite structures subjected to combined tensile/compression and torsion loadings.
- Determination of mechanical properties of composite tubes with and without liner for various applications subjected to compression loadings as well as their failure modes. Development of a data base.
- Stiffness, Young's modulus of bending and flexural rigidity evaluation of composite rings with and without liner subjected to three-point bending loads. Development of a data base.
- Development of new testing techniques for mechanical characterization of thin unidirectional fibers-reinforced composite laminae and ultrathin fabric-reinforced composite laminates.
- Determination of mechanical properties of thin unidirectional fibers-reinforced composite laminae and ultrathin fabric-reinforced composite laminates. Development of a data base.

Plans for the evolution and development in the professional and academic career

- Implementation of modern technologies and methods of teaching and learning based on information technology to provide a comprehensive training especially in practical applications in the Laboratory For Materials Testing within Department of Mechanical Engineering.
- Updating the laboratory facilities with new devices designed by PhD students that prepare their thesis in the field of mechanics of fibers-reinforced composite materials.
- Support and stimulation of students' research activity.
- Affiliation of young PhD students in research teams with experienced researchers to materialize their ideas.
- Promotion of a national and international recognized multidisciplinary research activity with solid theoretical and experimental background materialized in publication of scientific papers in journals with impact factor.
- Development of partnership agreements with firms, laboratories and universities to facilitate PhD students to participate at these research infrastructures.
- Participation at national and international conferences to sustain the research results of PhD students in the field of mechanics of composite materials.

Plans for the evolution and development in the professional and academic career

- Regarding the doctoral supervision I intend to do following activities:

  - Affiliation to the Doctoral School of the Faculty of Mechanical Engineering within Transilvania University of Brasov.
  - As a doctoral supervisor I will coordinate research topics in the field of mechanics of polymer matrix composites with applications in various industries focused on the scientific trend in this field.

- The future development of academic career will be focused to fulfill the criteria of promotion to the rank of professor.

References

Scientific papers published in ISI indexed journals with impact factor

1. **Teodorescu-Drăghicescu, H.**, Vlase, S. – Homogenization and Averaging Methods to Predict Elastic Properties of Pre-Impregnated Composite Materials. *Computational Materials Science (COMP MATER SCI)*, Vol. 50, Issue 4, February 2011, ISSN: 0927-0256, Elsevier, p. 1310-1314, Proceedings of the 19th International Workshop on Computational Mechanics of Materials - IWCMM 19, Edited by Eduard-Marius Craciun, Niculae Peride and Siegfried Schmauder. http://www.sciencedirect.com/science/article/pii/S0927025610002533 (FI = 2.131)
2. **Teodorescu-Drăghicescu, H.**, Vlase, S., Scutaru, L., Serbina, L., Calin, M.R. – Hysteresis Effect in a Three-Phase Polymer Matrix Composite Subjected to Static Cyclic Loadings. *Optoelectronics and Advanced Materials – Rapid Communications (OPTOELECTRON ADV MAT)*, Vol. 5, Issue 3, March 2011, INOE Publishing House, p. 273-277, ISSN: 1842-6573. URL lista lucrari: http://oam-rc.inoe.ro/index.php?option=magazine&op=list&revid=60 (FI = 0.394)
3. Vlase, S. **Teodorescu-Drăghicescu, H.**, Motoc, D.L., Scutaru, M.L., Serbina, L., Călin, M.R. – Behavior of Multiphase Fiber-Reinforced Polymers Under Short Time Cyclic Loading. *Optoelectronics and Advanced Materials – Rapid Communications (OPTOELECTRON ADV MAT)*, Vol. 5, Issue 4, April 2011, INOE Publishing House, p. 419-423, ISSN: 1842-6573. URL lista lucrari: http://oam-rc.inoe.ro/index.php?option=magazine&op=list&revid=61 (FI = 0.394)
4. Vlase, S. **Teodorescu-Drăghicescu, H.**, Călin, M.R., Serbina, L. – Simulation of the Elastic Properties of Some Fibre-Reinforced Composite Laminates Under Off-Axis Loading System. *Optoelectronics and Advanced Materials – Rapid Communications (OPTOELECTRON ADV MAT)*, Vol. 5, Issue 4, April 2011, INOE Publishing House, p. 424-429, ISSN: 1842-6573. URL lista lucrari: http://oam-rc.inoe.ro/index.php?option=magazine&op=list&revid=61 (FI = 0.394)

Scientific papers published in ISI indexed journals with impact factor

5. **Teodorescu-Drăghicescu, H.**, Stanciu, A., Vlase, S., Scutaru, L., Călin M.R., Serbina, L. - Finite Element Method Analysis Of Some Fibre-Reinforced Composite Laminates, *Optoelectronics and Advanced Materials – Rapid Communications (OPTOELECTRON ADV MAT)*, Vol. 5, Issue 7, July 2011, INOE Publishing House, p. 782-785, ISSN: 1842-6573. URL lista lucrari http://oam-rc.inoe.ro/index.php?option=magazine&op=list&revid=64 (FI = 0.394)

6. Stanciu, A., **Teodorescu-Drăghicescu, H.**, Vlase, S., Scutaru, M.L., Călin, M.R. - Mechanical Behavior of CSM450 and RT800 Laminates Subjected to Four-Point Bend Tests, *Optoelectronics and Advanced Materials – Rapid Communications (OPTOELECTRON ADV MAT)*, Vol. 6, Issue 3-4, March-April 2012, INOE Publishing House, p. 495-497, ISSN: 1842-6573. URL lista lucrari http://oam-rc.inoe.ro/index.php?option=magazine&op=list&revid=71 (FI = 0.394)

7. Vlase, S., **Teodorescu-Drăghicescu, H.**, Călin, M.R., Scutaru, M.L. - Advanced Polylite composite laminate material behavior to tensile stress on weft direction, *Journal of Optoelectronics and Advanced Materials (J OPTOELECTRON ADV M)*, Vol. 14, No. 7-8, July-August 2012, INOE Publishing House, p. 658-663, ISSN: 1454-4164. http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3073&catid=72 (FI = 0.429)

8. **H. Teodorescu-Draghicescu**, M. L. Scutaru, D. Rosu, M. R. Calin, P. Grigore - New Advanced Sandwich Composite with twill weave carbon and EPS, *Journal of Optoelectronics and Advanced Materials (J OPTOELECTRON ADV M)*, Vol. 15, No. 3-4, March-April 2013, INOE Publishing House, p. 199-203, ISSN: 1454-4164. http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3177&catid=76 (FI = 0.429)

Scientific papers published in ISI indexed journals with impact factor

9. A. Modrea, S. Vlase, **H. Teodorescu-Draghicescu**, M. Mihălcică, M.R. Calin, C. Astalos – Properties of Advanced New Materials Used in Automotive Engineering, *Optoelectronics And Advanced Materials – Rapid Communications (OPTOELECTRON ADV MAT)*, Vol. 7, No. 5-6, May-June 2013, INOE Publishing House, p. 452-455, ISSN: 1842-6573. http://oam-rc.inoe.ro/index.php?option=magazine&op=view&idu=2107&catid=78 (FI = 0.394)

10. S. Vlase, R. Purcarea, **H. Teodorescu-Draghicescu**, M.R. Calin, I. Szava, M. Mihalcica - Behavior of a new Heliopol/Stratimat300 composite laminate, *Optoelectronics And Advanced Materials – Rapid Communications (OPTOELECTRON ADV MAT)*, Vol. 7, No. 7-8, July-August 2013, INOE Publishing House, p. 569-572, ISSN: 1842-6573. http://oam-rc.inoe.ro/index.php?option=magazine&op=view&idu=2132&catid=79 (FI = 0.394)

11. T. Heitz, **H. Teodorescu-Draghicescu**, S. Lache, A. Chiru, M.R. Calin – Advanced T700/XB3585 UD carbon fibers-reinforced composite, *Journal of Optoelectronics and Advanced Materials (J OPTOELECTRON ADV M)*, Vol. 16, No. 5-6, May-June 2014, INOE Publishing House, p. 568-573, ISSN: 1454-4164. http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3474&catid=84 (FI = 0.429)

12. **H. Teodorescu-Draghicescu**, S. Vlase, M.D. Stanciu, I. Curtu, M. Mihalcica - Advanced Pultruded Glass Fibers-Reinforced Isophtalic Polyester Resin, *Materiale Plastice (MATER PLAST)*, Vol. 52, No. 1, March 2015, p. 62-64, ISSN: 0025-5289. http://www.revmaterialeplastice.ro/pdf/cuprins%2012015.pdf (FI = 0.824)

13. M. L. Scutaru, **H. Teodorescu-Draghicescu**, S. Vlase, M. Marin - Advanced HDPE with increased stiffness used for water supply networks, *Journal of Optoelectronics and Advanced Materials (J OPTOELECTRON ADV M)*, Vol. 17, No. 3-4, March-April 2015, INOE Publishing House, p. 484-488, ISSN: 1454-4164. http://joam.inoe.ro/index.php?option=magazine&op=view&idu=3690&catid=89 (FI = 0.429)