SOME COMPARATIVE OPINIONS REGARDING THE EVALUATION OF MAXIMUM STRESSES IN LONG FIBER REINFORCED COMPOSITES

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Abstract: This paper falls within the scope of current concerns for scientific and technical research, relating to technical structures made of composite materials, recognized for their mechanical, thermal and chemical or erosive resistance characteristics. In this case, the study is characterized by the analysis of the bearing capacity of some composites: a) with fibers applied along them, b) in a certain direction, c) in a direction perpendicular to the fibers, d) the stability of the structure along the fibers, e) in a direction perpendicular to the fibers or f) combined stress.

Keywords: comparative opinions, reinforced composite, long fibers, maximum stresses

1. INTRODUCTION

The permanent development of the human civilization, both numerically and in the preferences of life, has continuously required the finding of new consumer goods with an increasing degree of complexity. This cannot be achieved without the construction of high-performance industrial equipment in terms of processing the necessary substances, in quite difficult conditions in terms of chemical, mechanical and thermal attack, single or combined. This state has forced researchers in the field of the chemical technological processes, but also in the construction of specific mechanical equipment and manufacturing technologies, to find optimal technical solutions from an economic and technical point of view. Classical, natural materials, limited in quantity, or for the manufacture of which high energy consumption is required, are increasingly being replaced by composite materials. Thus, these materials were called "**composite materials**", "**materials of the future**", "**materials of the second generation**", respectively "**materials of the third generation**". It should be noted that such materials have a structure in which the components retain their identities, even after the formation process.

The specialized literature has paid great attention to the composition and the calculation necessary for the design of mechanical structures from such materials [1-22]. The existence on the market of an increasing number of composite structures implies the difficulty of choosing the optimal combination to obtain a suitable laminate that satisfies the desired requirements, both technical and economic. Currently, the industry is occupied by the

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"*syndrome of minimization*" of the masses of the mechanical structures [21], with chain reactions at all the stages of the design, the manufacture and the use of the products, to achieve lighter finished components, lower fuel and energy consumption, payload or greater autonomy (in transport, for example), longer service life, combined with lower production and operating costs, reduced pollution of the external environment. One of the most advantageous characteristics of a composite material is the flexibility / the adaptability in design, which allows the engineer to model it in structural and architectural form, obtaining the best performance. In general, the composite structures are usually manufactured by arranging the reinforcing fibers by default. The individual layers are arranged in such a way that the reinforcing fibers, existing in the matrix, are either parallel or cross-linked, or in the form of texture, with equal arrangement for warp and weft (these ensuring the strength and the rigidity of the structure). Chopped fiber structures are not neglected, anyway arranged, in the mass of the matrix (with the help of a special pistol).

This state engages increasing investments for theoretical and experimental research, with high-performance equipment. The activities carried out over time have brought very important results to achieve the desired performance of the achieved structures [23-37]. The physical-elastic and mechanical characteristics of the composite material can be estimated starting from the individual characteristics of each of the constituents (the mixing rule [9]). The values of these characteristics, for a given structure, are determined by tests on test tubes (with well-specified geometry) cut from the same structure, subjected to simple stresses [24].

The composite materials have found use in the field of the car constructions, the aerospace constructions, the sports boats, the under pressure equipment, the sound and thermal isolation, the impure water treatment etc. [38-57]. For performance in the mentioned fields, a careful analysis of the intimate behavior between the matrix and the reinforcing material, simple or texture longitudinal fibers, respectively individual particles or chopped is required. A study in this regard refers to the situation in which the matrix has longer lengths than the fibers, but also the state when the matrix material has maximum lengths, lower than those of the fibers - this paper.

This paper, taking into account the behavior of the link between the composite matrix and the reinforcing elements, presents some opinions of the researchers on the bearing capacity of the composite structures reinforced with long fibers.

2. MATRICES OF MATERIALS WITH MAXIMUM LENGTH STRENGTHS, LESS THAN THOSE OF FIBERS (POLYMERIC OR METAL MATRICES)

The same elastic deformation is considered for both components of the composite (assuming excellent contact between the matrix material and the fibers).

This category includes the refractory composites whose destruction is influenced by the elongation of the matrix material. For a perfect contact between fibers and matrix, the [58, 59] equality can be used:

$$\left(\sigma_{fm}\right)_M = E_f \cdot \left(\varepsilon_{tm}\right)_M , \tag{1}$$

in which $\left(\sigma_{fm}\right)_M$ the allowable tensile strength of the fibers, $\left(\varepsilon_{tm}\right)_M$ - the maximum specific deformation of the matrix material , E_f - the modulus of longitudinal elasticity of the fiber material are found (evaluated on the basis of the mixture theory [6, 21, 58]).

The paper [45, chap. 15], referring to reinforced concrete structures with steel wires, indicates the following relationship for the evaluation of breaking strength:

$$\sigma_{cr} = A \cdot \sigma_m \cdot \left(1 - p_{vf}\right) + B \cdot \sigma_f \cdot \left(l_f / d_f\right), \tag{2}$$

which can be used for the comparison with the minimum strength $\left(\sigma_{cr}\right)_m$, when the cement deterioration begins:

$$\left(\sigma_{cr}\right)_m = A \cdot \sigma_{mr} \cdot \left(1 - p_{vf}\right) + B \cdot \sigma_f \cdot \left(l_f / d_f\right), \tag{3}$$

respectively the maximum strength $\left(\sigma_{cr}\right)_M$, in which case all the metal fires in the contents break:

$$\left(\sigma_{cr}\right)_M = A\cdot\sigma_{mr}\cdot\left(1 - p_{vf}\right) + B\cdot\sigma_{fr}\cdot\left(l_f / d_f\right). \tag{4}$$

In the equalities (2) - (4) the notations are used: $A, B-$ the experimentally established constants; σ_m, σ_{mr} $-$ the resistance of the cement, respectively the breaking value; σ_f, σ_{fr} $-$ the current resistance and breaking resistance of fibers; l_f, d_f $-$ the length and the diameter of the fibers/steel fibers; p_{vf} $-$ the percentage occupied by fibers in the composite structure.

From the analysis of the previous expressions it is found that the best composite is the one with fibers whose longitudinal modulus of elasticity has the highest value.

The [60] paper draws attention to a very important characteristic of a fiberglass composite for reinforcement, namely that of the uniformity/the non-uniformity of the mixture. For such a structure, the σ^*_{cr} breaking strength of the composite, for a portion of the composite, can be evaluated with [60] the relation:

$$\sigma^*_{cr} = \sigma_f\cdot\left[\alpha_d\cdot p_{vf} + p_{vm}\cdot\left(E_m / E_f\right)\right], \tag{5}$$

where p_{vm} $-$ the percentage occupied by the matrix material in the mass of the composite; $\alpha_d \in \left[0,1\right]$- the coefficient of participation of the glass fibers.

The degree of uniformity/non-uniformity of the distribution of the fibers on a certain length of the composite can be established with the expression:

$$c_n = \left(\sigma^*_{cr} / \sigma_f\right)\cdot\left[E_f / \left(\alpha_d\cdot p_{vf}\cdot E_f + p_{vm}\cdot E_m\right)\right], \tag{6}$$

or in another form:

$$c_n = \frac{\left[\alpha_d\cdot p_{vf}\cdot\left(\gamma_{fm} + 0{,}5\right) + 0{,}5\right]\cdot\left[1 + \gamma_{fm}\cdot p_{vf}\cdot\left(\alpha_d + \beta_l - \alpha_d\cdot\beta_l\right)\right]}{\left(\alpha_d\cdot\gamma_{fm}\cdot p_{vf} + 1\right)\cdot\left(\gamma_{fm}\cdot p_{vf} + 1\right)}\ , \tag{7}$$

in which γ_{fm} - the parameter dependent of the values of the longitudinal elastic modulus of the fibers and the matrix, according to the analysis length, respectively:

$$\beta_l = l / l_0\ ;\ \gamma_{fm} = \left(E_f / E_m\right) - 1\ , \tag{8}$$

where l - the length cut from the l_0 total length of the analyzed composite.

3. MAXIMUM SOLICITATION ALLOWED TO STRETCH IN ANY DIRECTION RELATED TO THE ORIENTATION OF THE LONG FIBERS

The $\left(\sigma^{\theta}_{c}\right)_{x\,max}$ breaking resistance, for a θ certain direction, related to the orientation of the fibers, can be evaluated with the relation [9, 16, 61, 62]:

$$\left(\sigma_c^{\theta}\right)_{x\,max} = \frac{1}{\dfrac{(cos\,\theta)^4}{(\sigma_c)_{x\,max}} + \dfrac{(sin\,\theta)^4}{(\sigma_c)_{y\,max}} + (cos\,\theta)^2 \cdot (sin\,\theta)^2 \cdot \left[\dfrac{1}{\tau_{f\,R}^2} + \dfrac{1}{(\sigma_c)_{x\,max}^2}\right]}\,, \tag{9}$$

where $(\sigma_c)_{x\,max}$, $(\sigma_c)_{y\,max}$ - the maximum normal stresses along the x and y axes; x, y - the direction of the fibers, respectively the direction perpendicular to the fibers; $\tau_{f\,R}$ – the breaking stress by shearing in the plane of the fibers.

4. MAXIMUM SOLICITATION FOR STRENGTH ON A PERPENDICULAR DIRECTION ON FIBERS

The $\left(\sigma_c^{tr}\right)_{x\,M}$ elasticity limit stress of the composite, the fibers and the matrix having a linear behavior, can be established with equality [1, 6, 12]:

$$\left(\sigma_c^{tr}\right)_{x\,M} = \left(\sigma_m\right)_{el} \cdot \left[\left(E_c\right)_{tr} / E_m\right] \cdot \left(1 - \sqrt[3]{p_{vf}}\right), \tag{10}$$

where $(E_c)_{tr}$ - the transverse / normal elasticity limit on the fiber length; $\left(\sigma_m\right)_{el}$ - the limit stress of elasticity of the matrix material.

The $\left(\varepsilon_c\right)_{tr}$ - the specific linear deformation of the composite in a direction perpendicular to the direction of the fibers, can be calculated by the formula [6, 43]:

$$\left(\varepsilon_c\right)_{tr} = \varepsilon_m \cdot \left(1 - \sqrt[3]{p_{vf}}\right), \tag{11}$$

where ε_m - the specific linear deformation of the matrix material.

The [21, 29] papers present the following calculation relation for the mentioned request case:

$$\left(\sigma_c\right)_{tr} = \left[1 - \left(\sqrt{p_{vf}} - p_{vf}\right) \cdot \left(1 - E_m / E_2\right)\right] \cdot \sigma_{mt}\,, \tag{12}$$

where E_2 - the modulus of longitudinal elasticity of the composite in the transverse direction on the fibers; σ_{mt} - the stress limit of elasticity of the matrix material at the tensile load.

5. STABILITY OF COMPOSITE TO COMPRESSION THROUGH FIBERS

Upon compression application of the composite, the constituent fibers may buckling [63], after one or the other of the two representative modes (Figure 1). Some fibers have very little resistance to such solicitation (example is given by the *kevlar* fibers).

The first buckling mode (Figure 1) can occur for a reinforcement volumetric percentage less than 30 %, in which case the matrix resist at the stretching - compression solicitation. In the second buckling mode the matrix has a higher volumetric reinforcement percentage, in which case it resists shear [1, 6, 16]. The justification, for each structure, is given by the experimental results undertaken [6, 9].

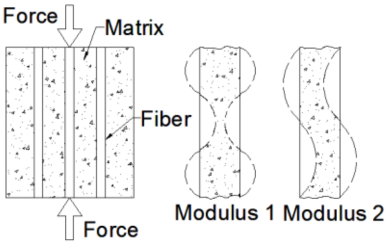

Fig. 1. Ways of buckling the long fibers of the composite [1, 6, 17].

When **the compressive solicitation of a composite reinforced with long fibers**, the evaluation of the elastic limit stress $\left(\sigma_c\right)^f_{el}$ for them can be calculated with the expression (Figure 1 - deformation modulus 1) [17, 23, 29, 63, 64]:

$$\left(\sigma_c\right)^f_{el} = 1{,}155 \cdot p_{vf} \cdot \sqrt{p_{vf} \cdot E_f \cdot E_m \Big/ \left(1 - p_{vf}\right)}\ , \tag{13}$$

attributed to ***Rosen W. B.*** [23, 64] and, independently, to ***Scheuerch H.*** [23].

Taking into account the influence of the matrix material, too, we can write:

$$\left(\sigma_c\right)^{\bullet}_{el} = 1{,}155 \cdot \left[\, p_{vf} + \left(1 - p_{vf}\right) \cdot \left(E_m / E_f\right)\right] \cdot \sqrt{p_{vf} \cdot E_f \cdot E_m \Big/ \left(1 - p_{vf}\right)}\ . \tag{14}$$

For the deformation 2 modulus - Figure 1, the papers [17, 23] proposes the expression:

$$\left(\sigma_c\right)^f_{el} = G_m \Big/ \left(1 - p_{vf}\right), \tag{15}$$

in which the modulus of transverse elasticity (shear) of the matrix material intervenes:

$$G_m = 0{,}5 \cdot E_m \,/\, \left(1 + \nu_m\right), \tag{16}$$

where it is present ν_m - the coefficient of transverse contraction of the matrix material.

The [1, 12, 23] papers, taking into account the values of the volumetric percentage of the fibers in the composition of the composite, indicate the relations:

$$\left(\sigma_c\right)_{el} = 0{,}917 \cdot p_{vf} \cdot \sqrt{p_{vf} \cdot E_f \cdot E_m \Big/ \left(1 - p_{vf}\right)}\ , \text{ for } p_{vf} \ \langle\ 0{,}1\ ; \tag{17}$$

$$\left(\sigma_c\right)_{el} = 0{,}63 \cdot \mathrm{G}_{xy} \cdot \left(1 - p_{vf}\right), \quad \text{for} \quad p_{vf} \ \rangle\ 0{,}1\ , \tag{18}$$

where G_{xy} – the modulus of transverse elasticity, relative to the axis system x, y.

The experimental results are very close to those deduced from the above relationships, except for glass fiber reinforced composites [1].

The [43, 56] papers indicate the following equality for the assessment of the elasticity limit stress of the fibers composite:

$$\left(\sigma_c\right)_{el} = min\left(\sigma_{fm1}, \sigma_{fm2}\right), \tag{19}$$

where:

$$\sigma_{fm1} = 2\cdot\left[p_{vf} + \left(1 - p_{vf}\right)\cdot\left(E_m / E_f\right)\right]\cdot\sqrt{p_{vf}\cdot E_m\cdot E_f \Big/ \left[3\cdot\left(1 - p_{vf}\right)\right]}, \tag{20}$$

σ_{fm2} respecting the (15) form.

The difference between the (15) and (18) expressions is noticeable, by the presence of the coefficient equal to $0{,}63$; it drawing attention to the fibers content.

6. LIMIT OF ELASTICITY TO COMPRESSION IN THE PERPENDICULAR DIRECTION ON THAT OF THE FIBERS

The [29, 65] papers give the following calculation relation of the transverse compression stress for the unidirectional fiber-reinforced composite:

$$\left(\sigma_c\right)_{com} = \left[1 - \left(\sqrt{p_{vf}} - p_{vf}\right)\cdot\left(1 - E_m / E_2\right)\right]\cdot\sigma_{mc}. \tag{21}$$

Similar to the previous relation, the [21, 29, 61] expression can be used for shear stress:

$$\tau_c^{com} = \left[1 - \left(\sqrt{p_{vf}} - p_{vf}\right)\cdot\left(1 - E_m / E_2\right)\right]\cdot\tau_{mc}, \tag{22}$$

in which they are present τ_c^{com}, τ_{mc} $-$ the shear stresses for composite and the matrix material.

The [6] paper presents the following equality for the evaluation of the shear stress in the plane 1 - 2, limit, considering the shear stress of the fibers and of the matrix, respectively the volumetric percentages contained of the composite:

$$\left(\tau_{12}\right)_{lim} = \tau_f\cdot p_{vf} + \tau_m\cdot p_{vm}. \tag{23}$$

7. RESISTANCE OF THE COMPOSITE TO TRANSVERSE STRETCHING, CROSS COMPRESSION AND FIBERS SHEAR

For such demands, the stresses induced in matrix and in fibers are equivalent [6] - with the observation that the manufacturing technology strictly respects the imposed requirements [n.a.]. It is obvious that the properties of the fiber-reinforced composite, under the action of such stresses, depend on the limit values, on the mechanical strength, of the matrix material. It should not be overlooked that at the cross-sectional stretching of the fibers, the allowable stresses are higher than those corresponding to the matrix material [6].

8. CONCLUSIONS

In the content of this paper there are some expressions for assessing the bearing capacity of the long fibers-reinforced composites. In this context, the cases in which the following are present are discussed:

- The fibers reinforcement, in which case the matrix material has maximum lengths lower than those of the fibers.
- The composite is applied to stretch in a certain direction in relation to the direction of the long fibers.
- The tensile stress of the composite, in a direction perpendicular to that of the fibers.
- The study of the stability of the composite form along the fibers.
- The limit of elasticity when compressing the composite in a direction perpendicular to that of the fibers.
- The resistance of the composite to transverse stretching or transverse compression and to the shearing of the fibers.

An adequate attention will be paid, in a subsequent paper, to the composites reinforced with chopped fibers or particles, in which case the results provided for estimating the bearing capacity of such materials will be specified.

REFERENCES

[1] Alamoreanu, E., Negrut, C., Jiga, G., Calculul structurilor din materiale compozite, Universitatea Politehnica din Bucuresti, 1993.
[2] Stefanescu, F., Neagu, G., Mihai, A., Materiale compozite, Editura Didactica si Pedagogica, Bucuresti, 1996.
[3] Stefanescu, F., Compozite metalice, Editura MatrixRom, Bucuresti, 1996.
[4] Fu, Z. Sh., Lauke, B., Effects of fiber length and fiber orientation distributions on the tensile strength of short – fiber – reinforced polymers, Composites Sciences and Technology, 56, 1996, p. 1179 – 1190.
[5] Hull, D., Clyne, W. T., An introduction to composite materials (second edition), Cambridge University Press, New York, USA, 1996.
[6] Alamoreanu, E., Chirita, R., Bare si placi din materiale compozite, Editura Tehnica, Bucuresti, 1997.
[7] Aerospatiale – Composite a stress manual, MTS 006Iss.B, 1999.
[8] Harris, B., Engineering composite materials, The Institute of Materials, London, 1999.
[9] Hadar, A., Structuri din compozite stratificate, Editura Academiei si Editura AGIR, Bucuresti, 2002.
[10] Bataev, A. A., Batev, A. V., Kompozitionnae materiali /stroenie, polucienie, primenenie, Novosibirskii Gosudarstvennai Tehniciesckii Universitet, Novosibirsk, 2002.
[11] Tuttle, E. M., Structural analysis of polymeric composite materials, Marcel Dekker, Inc. New York, USA, 2004.
[12] Alamoreanu, E., Constatinescu, D. M., Proiectarea placilor compozite laminate, Editura Academiei Romane, Bucuresti, 2005.
[13] Kainer, U. K., Metal matrix composites, WILEY – VCH Verlag GmbH and Co, KgaA, Veinheim, Germany, 2006.
[14] Kaw, K. A., Mechanics of composite materials (second edition), CRC Press, Taylor & Francis Group, New York, 2006.
[15] Mallick, K. P., Fiber-reinforced composites-materials, manufacturing and design (third edition), CRC Press Taylor&Francis Group, New York, USA, 2008.
[16] Taca, C. D., Paunescu, M., Materiale compozite, Editura MatrixRom, Bucuresti, 2012.
[17] Talreja, R., Singh, V. Ch., Damage and failure of composite materials, Cambridge University Press, USA, New York, 2012.
[18] Boufaida, Z., Analyse des proprietes mecaniques de composites taffetas verre/matrice acrylique en relation avec les proprietes d'adhesion des fibres sur la matrice, These, Universite de Lorraine, France, 2015.
[19] Sima, E., Materiale compozite - necesitate si provocare in contextul dezvoltarii durabile, Buletinul AGIR, no. 4, 2017, p. 143 – 146.
[20] Hudisteanu, I., Taranu, N., Isopescu, N. D., Bejan, L., Axinte, A., Ungureanu, D., Imbunatatirea caracteristicilor mecanice ale stratificatelor compozite prin alegerea rationala a materialelor si configuratiilor corespunzatoare, Revista Romana de Materiale, vol. 47, no. 2, 2017, p. 252 - 267.
[21] Iatan, I. R., Enachescu, L. G., Solicitari mecanice si termice in placi compozite stratificate, Editura Matrix Rom, Bucuresti, 2017.
[22] Gajaraj, G., Lal, P., Raguraman, M., Comparison of mechanical and flammability properties of benzoxazine and epoxy resin based carbon fibre composite sandwich structures, International Journal of Composite Materials, vol. 10, no. 1, 2020, p. 18 – 27.
[23] Turkmen, D., Compressive behavior of CFRP laminates exposed in hot – wet environments, Thesis, University of Leicester, England, 1996.
[24] Minoiu, St., Incercari experimentale pentru determinarea caracteristicilor elastice ale unor materiale compozite, Buletinul Universitatii Petrol – Gaze din Ploiesti, vol. LII, Seria Tehnica, no. 2, 2000, p. 153 – 162.
[25] Bos, L. H., The potential of flax fibres as reinforcement for composite materials, Thesis, University Press Facilities, Technische Universiteit Eindhoven, Netherlands, 2004.
[26] Crookston, J. J., Prediction of elastic behavior and initial failure of textile composites, Thesis, The University of Nottingham, England, May 2004.
[27] Gharbi, Ab., Analyse des fissuration des materiaux composites et determination de leur delaminage utilisant des capteurs piezo-electrique, Memoire presente pour l'obtention de diplome de magister-option construction mecanique, Universite Mantouri-Constantine, Republique Algerienne Democratoque et Poplaire, 2005.
[28] Carcea, L. Materiale compozite – fenomene la interfata, Editura Politehnium, Universitatea Tehnica “Gh. Asachi”, Iasi, 2008.

[29] Boccolini, V., Dimensionamento strutturale effettuato con le norme CE 94/25 e confront atteaverso il metodo degli elementi finite, Tesi di Dottorato di ricerca in Ingenera Industriale, Universita degli studi di Napoli Federico II di Napoli, Italy, 2009.
[30] Rosu, D., Contributii teoretice si exprimentale la structuri din materiale compozite noi, Teza de doctorat, Universitatea “Transilvania” din Brasov, 2010.
[31] Falaschetti, P. M., Caratterizzazione meccanica di materiali composite mediante attrezzatura CLC, Tesi di Laurea, Universita di Bologna, Italia, 2013.
[32] Al-Bahadly, O. A. E., The mechanical proprieties of natural fiber composites, Thesis, Swinburne University of Technology, Melbourne, Australia, 2013.
[33] Jamali, J., Mechanistic failure criterion for unidirectional and random fibre polymer composites, Thesis, The University of Western Ontario, Canada, 2014.
[34] Lepetit, A., Elaboration de materiaux composites a base de filaments de cellulose et de polyethylene, These, Universite de Lomoges, Canada, 2017.
[35] Rotaru (Paraschiv), F., Fenomene de degradare la impactul mecanic al structurilor compozite de tip sandwich, Teza de doctorat, Universitatea “Dunarea de Jos” din Galati, 2018.
[36] Durbaca, C. A., Cercetari teoretice Si experimentale privind evaluarea caracteristicilor fizico-mecanice ale placilor polimerice de tip sandwich cu miez compus din celule triunghiulare, Teza de doctorat, Universitatea Politehnica din Bucuresti, 2018.
[37] Boboc (Capatana), A., Contributii la studiul proprietatilor materialelor compozite armate cu tesaturi si a efectului solicitarilor ciclice asupra acestor proprietati, Teza de doctorat, Universitarea “Dunarea de Jos” din Galati, 2019.
[38] Pupazan, C., Acustica in constructii (propagarea zgomotului si izolarea fonica), Editura Academiei Romane, Bucuresti, 1970.
[39] Wu, Ch. H., Advanced civil infrastructure materials (science, mechanics and applications), Woodhead Publishing Limited, Cambridge, England, 2006.
[40] Ghafar, A. M., Mazen, A. A., El-Mahallawy, A. N., Application of the rule of mixture and Halpin-Tasi equations to woven fabric reinforced epoxy composites, Journal of Engineering Sciences, Assiut University, Egipt, vol. 14, no. 1, 2006, p. 227 – 236.
[41] Rules for the classificattion and the certification of yachts, Part B (Hull and stability, chapter 12), Bureau Veritas – NR 500 DT R00 E, 2006 (http://www.veristar.com; veristarinfo@bureauveritas.com).
[42] Natanail, R., Cercetari privind conceptia si fabricatia pieselor din material compozit pentru productia speciala din industria auto, Teza de doctorat, Universitatea “Lucian Blaga” din Sibiu, 2011.
[43] Slade, A. R., Failure analysis of impact-damage metallic poles repaired with reinforced polymer composites, Thesis, University of Central Florida Orlando, USA, 2012.
[44] Gheorghe, V., Structuri cu rigiditate ridicata, din material compozit, utilizate in constructia de autovehicule, Teza de doctorat, Universitatea Transilvania din Brasov, 2013.
[45] Bai, J., Advanced fibre – reinforced polymer/FRP) composites for structural aplications, Woodhead Publishing Limitd, Oxford, 2013.
[46] Eamon, D. Ch., Wu, Ch. W., Makkawy, A. A., Siavashi, S., Design and construction guidelines for strengthening bridges using fiber reinforced polymers (FRP), Final Report, Michigan Department of Transportation, USA, 2014.
[47] Burova, I. N., Zorin, A. V., Primenenie polimernah kompozitionnah materialov pri proizvodstve i remonte masin, Madi, Moskva, 2016.
[48] Bolcu, Al. Contributii la studiul comportamentului mecanic al materialelor compozite, cu aplicatii la automobile, Teza de doctorat, Universitatea din Craiova, 2018.
[49] Galateanu, M., Studii asupra materialelor compozite avansate destinate reactoarelor de fuziune nucleara, Teza de doctorat, Universitatea din Bucuresti, 2018.
[50] Chung, W. S., Ju, S. G., Details of semi-membrane shell theory of hybrid anisotropic materials, International Journal of Composite Materials, vol. 8, no. 3, 2018, p. 47 – 56.
[51] Dragan, N., Elemente de calcul al eficientei tratamentelor acustice cu material compozit fonoabsorbante pentru cabinele utilajelor tehnologice mobile, Sinteze de Mecanica Teoretica si Aplicata, vol. 10, no. 2, 2019, p. 103 – 110.
[52] Bolcu, D., Stanescu, M. M., A study of the mechanical properties of composite materials with a dammar – based hybrid matrix and tuo types of flax fabric reinforcement, Polymers, no. 12, 2020, p. 1 – 20.
[53] Apsar, G., Musrhak, Md., Ahmed, J., Study of factors affecting tape-mound composite helical spring prepared by E-glass/epoxy by using Taguchi method and statistical distributions, International Journal of Composite Materials, vol. 10, no. 1, 2020, p. 10 – 17.

[54] Gomes, M. I., Nogueira, de Codes, R., Sandro de Aranjo Silva A., Influence of operating pressure on water absorbtion of a polymeric composite applied in oil pipelines, International Journal of Composite Materials, vol. 10, no. 2, 2020, p. 37 – 39.
[55] Mahandrimanana, A., Lunard, H. A., Rado, R., Composite material based on clay and TIO_2 for wastewater treatment, International Journal of Composite Materials, vol. 11, no. 1, 2021, p. 1 – 4.
[56] Kaw, K. A., Mechanics of composite materials (second edition), CRC Press, Taylor/Francis Group, New York, SUA, 2006.
[57] Boteanu, A. O., Contributii la calculul containerelor utilizate la activitati logistice in armata, Teza de doctorat, Academia Tehnica Militara, Bucuresti, 2009.
[58] Ispas, St., Materiale compozite. Aplicatii, perspective, Tehnologii, Calitate, Masini, Materiale – Progres Tehnic, no. 2, Editura Tehnica, Bucuresti, 1987, p. 170 – 175.
[59] Suciu, V., Suciu V. M., Studiul materialelor, Editura Fair Partners, Bucuresti, 2008.
[60] Bolcu, D., Stanescu, M. M., Ciuca, I., Dumitru, S., Sava, Mihaela, The non-uniformity from the composite materials reinforced with fiber glass fabric, Materiale Plastice, vol. 51, no. 1, 2014, p. 97 – 100.
[61] Tuberosa, B., Proprieta meccaniche a trazione di compositi polimerici rinforzati con fibre lunghe di carbonio di interesse per il settore automative, Tesi, Universita di Bologna Anno accademico, 2011 – 2012.
[62] Gay, D., Materiaux composites, Hermes, Paris, Franta, 1999.
[63] Aboudi, J., Gilat, Rivka, Bucckling analysis of fibers in composite materials by wave propagation analogy, International Journal of Solids and Structures, vol. 43, 2006, p. 5168 – 5181.
[64] Daniel, M. I., Ishai, O., Engineering mechanics of composite materials, Oxford University Press Inc., New York, SUA, 1994.
[65] Bhalchandra, A. S., Shiradhonkar, Y., Daimi, S. S., Comparison of properties of transversely isotropic lamina using method of cells and composite cylinder assemblage, International Journal of Advanced Science and Technology, vol. 64, 2014, p. 43 – 58.