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EXPERIMENTAL VERIFICATION OF IN-PLANE STRESS CALCULATION OF THIN COMPOSITE PLATE BASED ON THE FINITE ELEMENT METHOD

EKSPERIMENTALNA VERIFIKACIJA PRORAČUNA RAVANSKOG NAPREZANJA KOMPOZITNIH TANKIH PLOČA NA BAZI METODE KONAČNIH ELEMENATA

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Ključne reči
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Abstract

The paper presents a realistic basis for performing an experimental verification of the material strength theory of a composite plate exposed to plane stress. Logical theoretical relations for calculating parameters for the sake of comparison to experimental results are given. A reliable measuring and testing system with a technology for acquisition of experimental data is used. On the basis of an identical given model for the calculation and experimental verification of theoretical results, the parameters are calculated, then measured and compared. The results show a good level of accordance and maintain a satisfying level of accuracy of the applied theory. Some results have shown dispersion, mainly with measured displacements in the normal direction to the loading axis. The final evaluation of the theory requires the calculation to be carried out with correct real values of mechanical characteristics. Since the correction factors for elastic mechanical characteristics of composite materials, that appear as a consequence of specific manufacture (possible defects include: de-lamination, broken fibres, material nonhomogeneity), are in the range 1.2 to 1.4, depending on the composite type, we can assume that the obtained results are within acceptable limits. This may confirm the sustainability of the presented structural analysis theory of composites with linear elastic behaviour.

Izvod

U radu je prezentirana realna osnova vođenja procesa eksperimentalne verifikacije teorije otpornosti kompozitne ploče izložene naprezanju u ravni. Izložene su logične teorijske relacije, izabran je pouzdan merno-ispitni sistem sa tehnologijom prikupljanja podataka o izmerenim veličinama i izvršena su adekvatna ispitivanja.

Na osnovu istovetnog zadatog modela za proračun i eksperimentalnu verifikaciju teorijskih rezultata, proračunati su, a zatim i izmereni, rezultati koji kada se uporede pokazuju zadovoljavajuću saglasnost, čime se dokazuje održivost nivoa tačnosti primenjene teorije. Evidentirana je i disperzija nekih rezultata, pre svega kod izmerenih pomeranja u poprečnom pravcu u odnosu na osu opterećenja.

Za konačnu ocenu teorije, proračun treba da se izvede sa tačnim stvarnim vrednostima mehaničkih karakteristika. Obzirom da se korekcioni faktori za elastomehaničke karakteristike kompozitnih materijala, koji su posledica konkretne realizacije konstrukcije (mogući defekti su: delaminacija, prekinuta vlakna, nehomogenost materijala), kreću od 1,2 do 1,4, u zavisnosti od tipa kompozita, može se smatrati da su ovde dobijeni rezultati u granicama prihvatljivih, te se time može potvrditi održivost predmetne teorije za strukturalnu analizu kompozita sa linearno elastičnim ponašanjem.

INTRODUCTION

The nature of composite materials is such that it requires careful selection of concepts that describe its elastic mechanical behaviour. So in the case of plane stress analysed here, an experimental verification of the theory is required to reach a sustainable calculation of an orthotropic structure with linear elastic behaviour, to know with certainty how do theoretical results deviate from the exact (experimental) results, and to be able to compensate for defects resulting from manufacture and processing of composite structures, /1, 2/.

Subject thin plate structures are common in complex composite structures of aircraft, ships, cars, products with specialised purposes, various interiors and so on. At first, theoretical relations are presented, and secondly, the agreement is shown of experimental and theoretical results, based on the relations of composite material plate strength (examples of various structures) in a block of structural analysis based on the finite element analysis (FEM).

BASIC THEORETICAL RELATIONS APPLIED TO THE DISPLACEMENT – STRAINS OF FINITE ELEMENT

The basic element of the structure is taken as a triangular plate in the plane stress state, Fig. 1. Experimental verification shall be conducted for the numerical concept of material strength on a triangular element, based on composite laminate, in such a manner with the use of geometric parameters vs. displacement relations in order to determine the deformations that can be further compared to measured values at the same locations or positions in the structure, /3, 4/. Obviously, the proof of compliance of displacements can be obtained by comparing calculated and measured corresponding displacements.

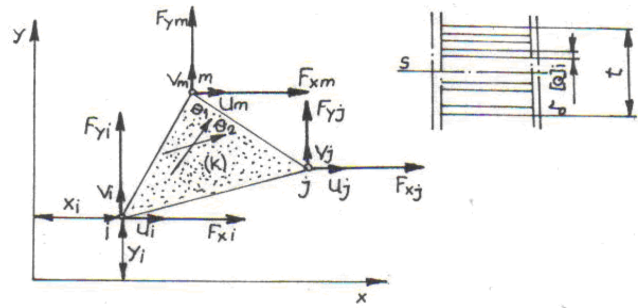


Figure 1. Triangular finite element (composite plate-plane element).
Slika 1. Trouglasti konačni element (kompozitna ploča-ravanski element)

For a triangular element with identification of nodes at vertices, numbered as *i*, *j*, *m*, set in the *xy* coordinate system, in case of plane stress state /3, 4/, the vector displacement of nodes of the triangle is as follows,

$$\{\delta\}_{(k)}=\{u_i \quad v_i \quad u_j \quad v_j \quad u_m \quad v_m\}^T \tag{1}$$

Coordinates of the node elements are:

$$(x_i,y_i);\ (x_j,y_j);\ (x_m,y_m) \tag{2}$$

Displacements of any point inside the triangle as a linear combination of its coordinates and the displacement function can be expressed as,

$$\begin{aligned} u&=a_1+a_2x+a_3y \\ v&=a_4+a_5x+a_6y \end{aligned} \tag{3}$$

A matrice form of these equations can be written as,

$$\{f\}=[N]\{a\} \tag{4}$$

The displacement vector of any point inside the triangle is

$$\{f\}=\begin{Bmatrix} u \\ v \end{Bmatrix} \tag{5}$$

Now the matrix form $[N]$ and vector of coefficients $\{a\}$ are written as

$$[N]=\begin{bmatrix} 1 & x & y & ; & 0 & 0 & 0 \\ 0 & 0 & 0 & ; & 1 & x & y \end{bmatrix} \text{ – shape matrice} \tag{6}$$

$$\{a\}=\{a_1 \quad a_2 \quad a_3 \quad a_4 \quad a_5 \quad a_6\}^T \text{ –vector of coefficients} \tag{7}$$

Using Eq.(4) and the coordinates of nodes (2), we obtain

$$\{\delta\}_{(k)}=[C]_{(k)}\{a\} \tag{8}$$

Where the matrix $[C]_{(k)}$ is given as

$$[C]_{(k)}=\begin{bmatrix} 1 & x_i & y_i & . & 0 & 0 & 0 \\ 0 & 0 & 0 & . & 1 & x_i & y_i \\ . & . & . & . & . & . & . \\ 1 & x_j & y_j & . & 0 & 0 & 0 \\ 0 & 0 & 0 & . & 1 & x_j & y_j \\ . & . & . & . & . & . & . \\ 1 & x_m & y_m & . & 0 & 0 & 0 \\ 0 & 0 & 0 & . & 1 & x_m & y_m \end{bmatrix}_{(k)} \tag{9}$$

The vector of unknown coefficients $\{a\}$ is then

$$\{a\}=[C]_{(k)}^{-1}\{\delta\}_{(k)} \tag{10}$$

On the basis of Eqs.(4), (9) and (10) the following matrix relations are obtained

$$\{f\}=[IN_i \quad , \quad IN_j \quad , \quad IN_m]\{\delta\}_{(k)} \tag{11}$$

where *f* is the second order identity matrix and

$$N_r=\frac{1}{2\Delta}(a_r+b_rx+c_ry); \quad (r=i,j,m) \tag{12}$$

The Δ is the triangle area obtained by determinant

$$\Delta=\begin{bmatrix} 1 & x_i & y_i \\ 1 & x_j & y_j \\ 1 & x_m & y_m \end{bmatrix} \tag{13}$$

Values of a_r, b_r i c_r are obtained through Eqs.(14),

$$\begin{aligned} a_i&=x_jy_m-x_my_j \\ b_i&=y_j-y_m \\ c_i&=-(x_j-x_m) \end{aligned} \tag{14}$$

Other users get a cyclical permutation of the index.

Strains at any point within the triangle are obtained by partial derivatives of displacements according to

$$\{\varepsilon\}=\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix}=\begin{Bmatrix} \dfrac{\partial u}{\partial x} \\ \dfrac{\partial v}{\partial y} \\ \dfrac{\partial u}{\partial y}+\dfrac{\partial v}{\partial x} \end{Bmatrix} \tag{15}$$

So by applying the partial differentiation of Eq.(11), we obtain

$$\{\varepsilon\}=\begin{bmatrix} \dfrac{\partial N_i}{\partial x} & 0 & \dfrac{\partial N_j}{\partial x} & 0 & \dfrac{\partial N_m}{\partial x} & 0 \\ 0 & \dfrac{\partial N_i}{\partial y} & 0 & \dfrac{\partial N_j}{\partial y} & 0 & \dfrac{\partial N_m}{\partial y} \\ \dfrac{\partial N_i}{\partial y} & \dfrac{\partial N_i}{\partial x} & \dfrac{\partial N_j}{\partial y} & \dfrac{\partial N_j}{\partial x} & \dfrac{\partial N_m}{\partial y} & \dfrac{\partial N_m}{\partial x} \end{bmatrix}\begin{Bmatrix} u_i \\ v_i \\ u_j \\ v_j \\ u_m \\ v_m \end{Bmatrix} \tag{16}$$

That is,

$$\{\varepsilon\}=\frac{1}{2\Delta}\begin{bmatrix} b_i & 0 & b_j & 0 & b_m & 0 \\ 0 & c_i & 0 & c_j & 0 & c_m \\ c_i & b_i & c_j & b_j & c_m & b_m \end{bmatrix}\{\delta\}_{(k)} \tag{17}$$

or $$\{\varepsilon\}=[B]\{\delta\}_{(k)}=\begin{bmatrix}B_i & , & B_j & , & B_m\end{bmatrix}\{\delta\}_{(k)} \qquad (18)$$

Where the matrices $[B_r]$ are given in Eq.(19),

$$[B_r]=\frac{1}{2\Delta}\begin{bmatrix}b_r & 0\\ 0 & c_r\\ c_r & b_r\end{bmatrix};\quad r=i,j,m \qquad (19)$$

In order to realise the complete procedure with an analysis of stress calculation of structure $\{\sigma\}$, it is necessary to present the basic equations for calculating the displacement $\{\delta\}$ on the basis of a known load $\{P\}$ and structural stiffness matrix $[K]$, according to /1, 5, 6/. Therefore, the load connections and logical displacements established through the structural stiffness matrix $[K]$, according to Eq.(20)

$$\{P\}=[K]\{\delta\};\quad \{\delta\}=[K]^{-1}\{P\} \qquad (20)$$

By applying Eqs.(17) and (18) it is clear that now we can obtain the strain $\{\varepsilon\}$, and then, with the introduction of the elasticity of the matrix material $[\bar{Q}]$, we finally receive the stress, Eq.(21),

$$\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_{xy}\end{Bmatrix}=\begin{bmatrix}\bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16}\\ \bar{Q}_{21} & \bar{Q}_{22} & \bar{Q}_{26}\\ \bar{Q}_{61} & \bar{Q}_{62} & \bar{Q}_{66}\end{bmatrix}\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \gamma_{xy}\end{Bmatrix} \qquad (21)$$

Finally we apply some of the strength criteria for evaluating the achieved limit, or critical stress, of composite structures (eg. Tsai-Hill criterion, based on the Mises criterion, applied to each composite layer, TSH ≥ 1):

$$\mathrm{TSH}=\left(\frac{\sigma_x}{X}\right)^2-\frac{\sigma_x\sigma_y}{X^2}+\left(\frac{\sigma_y}{Y}\right)^2+\left(\frac{\tau_{xy}}{S}\right)^2\leq 1 \qquad (22)$$

where σ_x, σ_y, σ_{xy} – operating stress and X, Y, S – appropriate boundary strength, /1, 5/.

However, it should be noted, the correct calculation for the structures necessarily means to transform the stress parameters from the global level (global coordinate system) into the local level (local coordinate system), and only then we obtain the current results of stress levels and reserves of the resistance.

VERIFICATION MODEL

In case of a sample presented in Fig. 2a, and structural problem presented in Fig. 2b, the verification is based on theoretical relations from previous chapters. Values are calculated for a representative strain of triangle (namely the nodes 6, 7, 11) and a comparison to experimental results. A wider consideration of the validity of theoretical relationships shall require the comparisons to be made on theoretical and experimental values for displacement nodes 2, 6, 7, 11.

The special sample for performing the experiment, Fig. 2, consists of a thin composite plate with the laminate $(+35°, -17°)_s$ with an uni-directional carbon fibre CFC 108/42%/G 808 and an epoxy matrix (Brochier). Mechanical characteristics of the base material are given in Table 1.

The structural analysis of the calculated model, Fig. 2b, is made on the basis of already presented theoretical relations. Theoretical results for the problem of resistance of the composite plate are obtained from our own software solutions, /4, 5/, and related to the displacement of all nodes and the mean strain discretized composite structures by the load P.

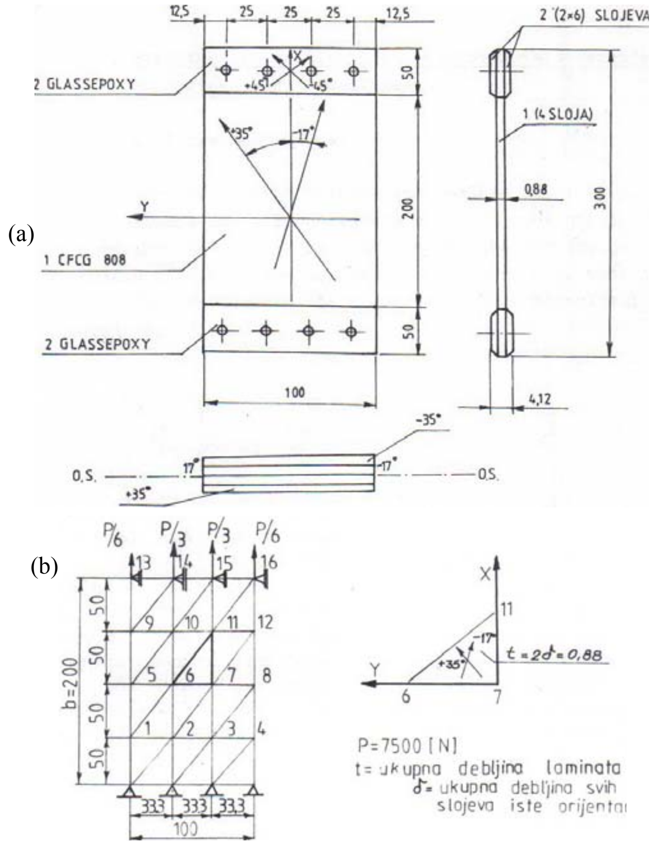


Figure 2. Composite panel sample (a) and the corresponding model of discretized plate (b).
Slika 2. Epruveta kompozitnog panela (a) i odgovarajući model diskretizovane ploče (b)

Table 1. Material properties of CFC 108/42%/808 G
Tabela 1. Osobine materijala CFC 108/42%/808 G

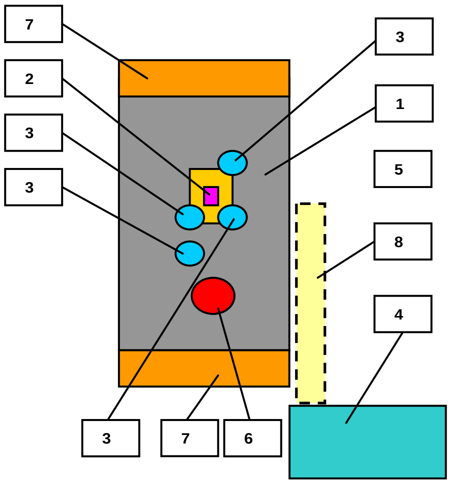
E_1	E_2	ν_{12}	ν_{21}	G_{12}	t	Data
GPa	GPa	–	–	GPa	mm	
98.0	15.7	0.13	0.0208	4.5	0.22	Background values
Real	Real	Calculated	Calculated	Catalogue	Real	

Experimental models, selection methods, techniques and tests of samples, planning experiments, determination of manufacturing errors, measuring and test equipment and the like, certainly are subjected to a special research. Therefore, this paper will only emphasize on the prediction of experimental results for comparison with corresponding theoretical indicators, in accordance with the model-based analysis of composite plate structures.

The sample shown in Fig. 2 is subjected to a maximal static tensile force of 7500 N on the measuring and test system, Fig. 3. Positions labelled 1 through 8 are characteristic components of the measuring system and test sample.

The maximal static load reaches a gradual increase in the intensity of discrete steps of 500 N (Tables contain entered data for increments of 1000 N) every 2 minutes, with the acquired process results in order to test the linear elasticity of the base composite material.

Results of the measured size (displacement and dilation) are shown in Figs. 4-6 and in Table 2.



1. Composite sample of CFC cloth, 2. Strain gauges, 3. Pickup of displacement, 4. Six-channel measuring amplifier, 5. Universal testing machine, 6. Dynamometer, 7. Jaws, 8. Cables with connectors

Figure 3. Scheme of the measuring and testing system with parts.
Slika 3. Shema mernog i sistema ispitivanja sa delovima

The diagram in Fig. 4 illustrates the dependence of total elongation in the x direction due to panel forces P, confirming linear elastic behaviour of composite materials.

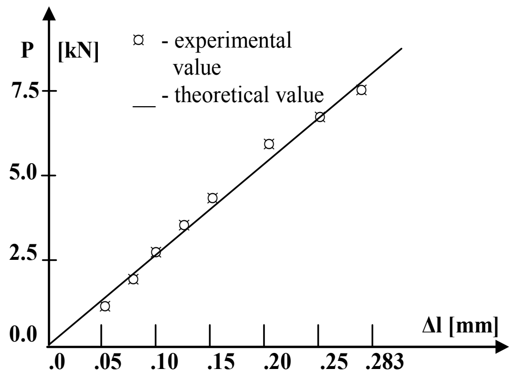


Figure 4. Functional dependency of force and displacement on the level of full model length.
Slika 4. Funkcionalna zavisnost sile i pomeranja na nivou ukupne dužine modela

Table 2. Experimental data.
Tabela 2. Eksperimentalni podaci

Strain and displacement	ε_x	ε_y	$\gamma_{xy} = 2\varepsilon_{XY}$	δ_{x2}	δ_{x6}	δ_{y6}	δ_{x7}	δ_{y7}	δ_{x11}	δ_{y11}
Load P (N)	%	%	% -not measured	mm	mm	mm	mm	mm	mm	mm
1000	0.023	–0.019	–	0.012	0.021	–0.004	0.019	0.005	0.030	0.001
2000	0.045	–0.035	–	0.025	0.039	–0.006	0.040	0.007	0.055	0.002
3000	0.067	–0.060	–	0.030	0.059	–0.008	0.066	0.011	0.087	0.003
4000	0.092	–0.078	–	0.037	0.075	–0.010	0.085	0.014	0.109	0.003
5000	0.117	–0.105	–	0.046	0.093	–0.013	0.108	0.017	0.145	0.005
6000	0.131	–0.122	–	0.057	0.112	–0.016	0.130	0.021	0.176	0.005
7500	0.173	–0.140	–	0.069	0.137	–0.020	0.142	0.025	0.205	0.006

The diagram in Fig. 5 depends on the node displacement characteristic of the force due to P.

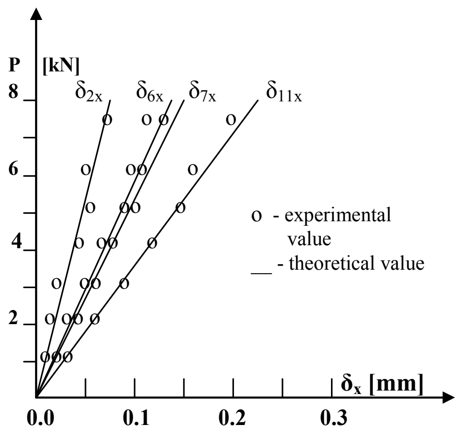


Figure 5. Functional dependency $P(\delta_x)$.
Slika 5. Funkcionalna zavisnost $P(\delta_x)$

The diagram in Fig. 6 is given according to a representative of the triangle plate deformation due to the force P. Mean values for η-faults and joints displacement ($\eta_\varepsilon = 1 - \varepsilon^{teor}/\varepsilon^{exp}$; $\eta_\delta = 1 - \delta^{teor}/\delta^{exp}$) are given for the corresponding experimental values of parameters taken as exact. The theoretical results are in line with the above developed relationships, /3, 4/.

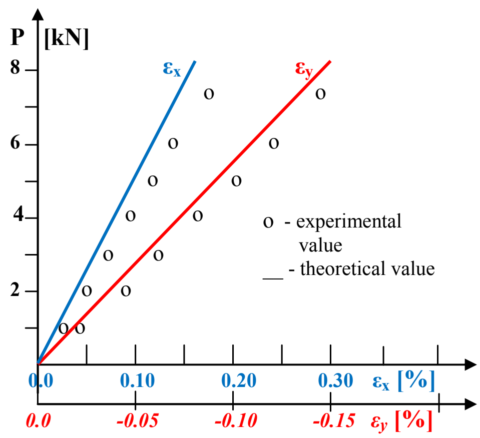


Figure 6. Functional dependency $P(\varepsilon_x)$ and $P(\varepsilon_y)$.
Slika 6. Funkcionalna zavisnost $P(\varepsilon_x)$ i $P(\varepsilon_y)$

If one knows the origin of the transverse displacement (practically known, is the result of longitudinal displacements and relationships of mechanics in material structure), it could be possible to apply a hybrid model. Therefore, experimental data for longitudinal displacements remain the same as measured on the basis of experimental data and theoretical data for longitudinal and transverse displacements, through proportional relationships,

$$f_T^{teor} / f_L^{teor} = f_T^{exp} / f_L^{exp} \tag{23}$$

can be adopted for further calculation of quasi-experimental data for transverse displacements that are normally hard to be correctly measured by contact methods, i.e. recording by comparators. Here, it is taken that the function $f = \delta$, the Eq.(23). Specifically, the fibres are, as a rule, in well-balanced structural composites, oriented approximately parallel to the main axis (it is best to be exactly in the direction of the major axis), while a smaller number of fibres have transverse directions, at practically no particular impact on the behaviour of the group with the basic fibres in the longi tudinal direction (reflects in the relative Poisson ratio - $V_{TL} << V_{LT}$). Theoretical and experimental corrected δ^*_{yr} data in accordance with Eq.(24) are given in Table 3.

$$f_T^* = f_T^{kv.exp} = f_T^{teor} \cdot f_L^{exp} / f_L^{teor} \tag{24}$$

If the relative error referring as,

$$\eta = 1 - f^{teor} / f^{exp} \tag{25}$$

including the relative error for the deformation $\eta = 1 - \varepsilon^{teor}/\varepsilon^{exp}$ (i.e. $\eta^* = 1 - \varepsilon^{exp*}/\varepsilon^{exp}$), then one may receive the following approvals from the theoretical (and experimental values with correction) and the experimental results:

– Theoretical results for ε_x have the average deviation of 14.5% compared to experimental results, and the results based on experimental values with correction have a deviation of up to 27.2% compared to the experimental results.
– Theoretical results for ε_y have the average deviation of 14.3% compared to experimental results, and the results based on experimental values deviate from the correction by 18.6% compared to experimental results.
– Theoretical results for δ_x have the average deviation of 2.5 to 6.0 % compared to experimental results ($\eta = 1 - \delta^{teor}/\delta^{exp}$ and $\eta^* = 1 - \delta^{exp*}/\delta^{exp}$).
– Theoretical results for δ_y have the average deviation of 5 to 16 % compared to experimental results, and results based on experimental values with the correction have a deviation of 10 to 20 % compared to experimental results.
– Finally, it should be said, that the calculated deformation $\varepsilon^{R-\exp}$ based on the measured displacement $\delta^{\exp}$ also differ from the measured strain $\varepsilon^{\exp}$, so here the error occurs at the level of 27.2% for $\varepsilon_x^{R-\exp}$, while the error $\varepsilon_y^{R-\exp}$ amounts to 3.6%. So, it is obvious that different possible measurements could be given different errors that are caused by the use of different measurement techniques and instrumentation systems and test equipment.

Presented grades and attitudes, just show at a glance the relative discrepancy of theory and experimental results. It should however be noted that in the calculation entered are catalogue values of mechanical properties (specifically the sliding module), which are certainly different from the real, and material defects, inevitably present, that occur during the curing of the structure /1, 2/. In fact, directly in line with /2/, and based on numerous examples from practice (in general published references), it seems safe to say that the correction factors for the mechanical characteristics of composite materials, which are a consequence of specific implemented structures, ranging from 1.2 to 1.4, depending on the type of composites, so the following observations can be considered to have the results within the limits of acceptable, and therefore the sustainability of the respective theory of structural analysis of composite plates with linear elastic behaviour can be definitely confirmed.

Table 3. Theoretical and experimental corrected δ^*_{yr} data in accordance with Eq.(24).
Tabela 3. Teorijski i eksperimentalni korigovani δ^*_{yr} podaci prema izrazu (24)

Strain and displacement	ε_x	ε_y	$\gamma_{xy} = 2\varepsilon_{XY}$	δ_{x6}	δ^*_{y6}	δ_{x7}	δ^*_{y7}	δ_{x11}	δ^*_{y11}
Load P = 7500 N	%	%	% -not measured	mm	mm	mm	mm	mm	mm
Theoretical value	0.148	–0.120	0.046	0.145	–0.019	0.151	0.021	0.225	0.007
Experimental value (measured)	0.173	–0.140	–	0.137	–0.020	0.142	0.025	0.205	0.006
Exp. value with correction*	0.126	–0.114	0.039	0.137	–0.018	0.142	0.020	0.205	0.005
Calculated strain based on the exp. displacements	0.126	–0.135	0.045						

STRESS ANALYSIS - A DEFECT IN COMPOSITES

The proposed model comparisons of experimental and theoretical results for displacements and strains, in conjunction with the adopted theoretical calculation model, clearly can be used to identify defects in the composite (e.g. broken fibres, Fig. 7b), where for a model of intensity and strain distribution of a regular composite and the structure with broken fibres is given in graphical format. The illustration is itself a clear indicator of proportionality based on the absence of strain, according to the adopted theoretical model, making clear of the defects present in the composite (reduction and redistribution of stiffness and strength compared to the idealised model with possible manufacturing defects: de-lamination, broken fibres, nonhomogeneous material).

In accordance with the analysed in /6/, it is evident that after curing the composite structure, there are residual stresses in the formed structure after cooling to ambient temperature levels. The line, which represents an increase of stress due to temperature rise during the curing process does not match the line of relaxation.

There are so many different connections (in compounds) among fibres and matrix (where the fibres are practically inert, i.e. with low thermal coefficients, while the resin has thermal coefficients of significant values). The reasons are related to the specific disconnection of links which are broken due to the structural relaxation or due to composite defects (due to connections that formed in the process of curing and the boundaries of adjacent parts, the nonhomogeneous zones in materials-composites, due to the presence of foreign substances or air, due to possible cracks in the matrix, due to delamination of layers, fibre disorientation or broken fibres), so the process goes to the state with permanent residual stresses in the composite after the treatment.

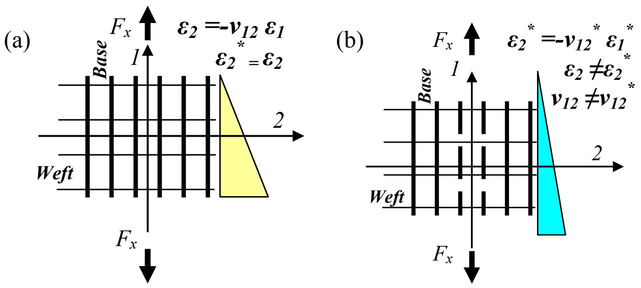


Figure 7. Model of composite materials with regular fibres (a), and broken fibres (b), in the direction of the base.
Slika 7. Model kompozitnih materijala sa ispravnim vlaknima (a), i slomljenim vlaknima (b), u pravcu osnove

In accordance with the diagram in Fig. 8, it is evident that after the curing, there are residual stresses in the structure after cooling the formed structure to the level of ambient temperature. The line which represents an increase of stress due to temperature rise during the curing process does not coincide with the line of relaxation. Therefore, the fibre expands a small amount, but the resin expands more with the rise in temperature or the reverse (it compresses) respectively with reducing temperature. In normal exploitation conditions, composite components (fibres and resin) behave as linear elastic materials, where obviously an internal redistribution of stresses exists when acting as a system. At the macro-mechanical level, the composite is only relevant, so that further consideration is reduced to the concept of the behaviour of homogeneous and generalised orthotropic material.

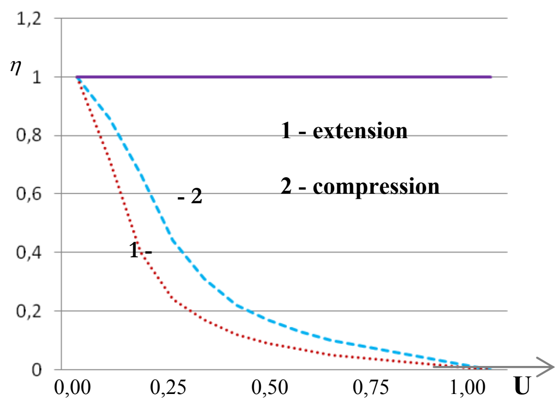


Figure 8. Dependence of correction factor, η (which reduces the characteristics of the composite) on the reserve of elasticity, U.
Slika 8. Zavisnost korekcionog faktora, η (koji smanjuje karakteristike kompozita) i rezerve elastičnosti, U

These calculations appear in the initial crack in the lamella (mostly for cracks in the matrix) and can be set up, i.e. according to /4/, as follows:

(a) *Calculation of resistance of lamellae without taking into account the reserve of elasticity*. When we have the crack in the matrix of a lamella it is necessary to adopt zero mechanical properties of this layer except for the elasticity modulus in the longitudinal direction (direction of material symmetry), which remains unchanged. The aim is to find such characteristics that lead to its full stress utilisation. In this way we can quickly get the selection of optimal orientation of reinforcement in the laminate system.

(b) *Calculation of resistance of lamellae with a reserve of elasticity*. Reserve of elasticity supposes, that because of cracks in the matrix, the transversal characteristics do not reach zero immediately, but gradually with increasing dilation tend to zero, as shown in Fig. 8.

With new values of $E^{1\prime} = \eta E^1$, $E^{2\prime} = \eta E^2$, $G^{12\prime} = \eta G^{12}$, we repeat the calculation for same purposes as under (a). The reserve of elasticity is estimated based on that how the stress level is allowed in the matrix after the appearance of a crack. Relevance assessment has appeared as a big problem, and this concept is necessary to lead very carefully, /4/. In this case, the experimental - and the logistics of experience are particularly important.

CONCLUSION

Based on the set of identical models for the calculation and experimental verification of theoretical results, the parameters are computed and then measured and compared for showing satisfactory agreement, thereby proving the viability of the level of accuracy of the applied theory.

However, please note that apparently here a dispersion of the relatively high level in some of the results is present, and measured are primarily displacements in the inverse direction to the axis of loading. Accordingly, initial assessments and views are expressed, at a first glance, the results had signalled the relative discrepancy of the theory and experiment. Anyhow, for the final assessment, it should be noted that this calculation is mostly based on the input of the catalogue values and calculations of some mechanical properties, which are certainly different then the real values, and that there are inevitably defects in the material structure, occurring during curing /2/ .

Namely, in accordance with /2/, and based on practical examples, it seems to say that correction factors for the mechanical characteristics of composite materials are in the range of 1.2 to 1.4, depending on the type of composite.

With the above mentioned considerations and tips, the results can be considered to be within acceptable limits, and this may confirm the theory of sustainability subjected for structural analysis of composite structures with linear elastic behaviour.

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