Српска наука данас / Serbian Science Today 2017 ▪ Vol. 2 ▪ No. 1 ▪ 120–122

Столице од ламината: експериментално нумерички приступ у анализи и дизајну

Laminated chairs. Experimental numerical approach in analysis and design

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In this monograph, the theory of elasticity of orthotropic and anisotropic composite materials was presented, the experimental determination of elastic constants of orthotropic composites and load bearing capacity (strength) of chair systems was performed, and numerical verification of obtained experimental results was based on finite element analysis.

Based on the presented theoretical, experimental and numerical considerations, we made several important conclusions and provided some suggestions that may be interesting for further research.

To determine material constants of the laminate as rheological material model for planar stress conditions, we conducted three separate uniaxial tension tests for complex and uniform arrangement of the laminate, from which we determined four independent elastic orthotropic constants: modulus of elasticity E_x, E_y, Poisson's ratio ν_{xy} and shear modulus G_{xy}.

In the mentioned experiments, we determined Poisson's ratio ν_{yx}, but for the known value ν_{xy} it does not represent independent elastic constant. The bending tests were also conducted, and from them we obtained bending modulus of elasticity E_{fx}, E_{fy} and stresses σ_x, σ_y.

Laminates with the uniform arrangement of veneer sheets and complex arrangement of veneer sheets, represent two composites and in rheological terms two different material models, but not independent, because the material constants of the complex arrangement can be unambiguously determined from the material constants of uniform composite, which can be easily observed from experimental results. Modules of elasticity both for the uniform and crossed laminate in both material directions were determined from the diagram σ-ε using the method of linear regression.

Material constants of the composite elasticity with two orthogonal directions of fiber intersection differ significantly from the case of massif, which can be noticed from the experimental results of specimens E1.1, E1.2 and E1.3. However, based on the careful analysis of the results of the aforementioned specimens, we can notice that the resulting material constants converge to a reduced membrane stiffness of the composite of unit thickness. With an increase in the number of layers, the difference between these values reduces. Since membrane stiffness of the laminate of unite thickness is equal to the required constitutive matrix, it follows that the composite with the crossed fibers basically is not an independent material because its elastic constants can be derived from the elastic constants of the massif. This conclusion is particularly important for us because it is not necessary to carry out experimental measurements of composites with crossed directions. As for the bending test, the modulus of elasticity determined by this test cannot be new material constants for the simple reason that membrane stress and bending stress generate the same components of stress and strain tensors, and from the standpoint of the continuum mechanics it is contradictory that for the same state of stress and strain we define two different material models in dependence of the type of stress. On the other hand, regardless of the fact that such a test is commonly used in testing of the laminate, we can question its reliability. When it comes to the real beam systems and surface systems, elastic constants E_z, G_{xz}, G_{yz}, ν_{xz} and ν_{yz} are not always necessary for their stress and strain analysis. Exceptions in this regard are spatial beam elements, which were calculated in accordance with Timoshenko beam approach as well as thick plates and shells, whose behavior is described by Mindlin-Reissner theory. In these theories shear deformation is explicitly defined both in x-z and y-z planes, which requires knowledge of the shear modulus in these planes. Bearing in mind that thin elastic plates and shells are most often in application, as well as beams for which we assume that the shear deformation in specified planes is zero (Bernoulli-Euler rod), in the end we can say that four independent material constants E_x, E_y, ν_{xy} and G_{xy} are necessary and sufficient for any elastic analysis of orthotropic structures.

In chapter 4 we formulated a composite finite plate and shell element. Such a finite element is applicable to the problems of membrane and bending of composite structures. Volume integration of the stiffness matrix is translated as the integration over middle plane of the plate by the introduction of the so-called "reduced stiffness" of the composite both for the membrane stress and bending. Kirchhoff-Love hypothesis of flat sections of the plate before and after deformation implies linear change of the componential strains along the thickness of the laminate. As the mechanical properties of the layers generally differ mutually then the linear change in deformation leads to the abrupt change of componential stresses through the thickness of the composite Figure 1.

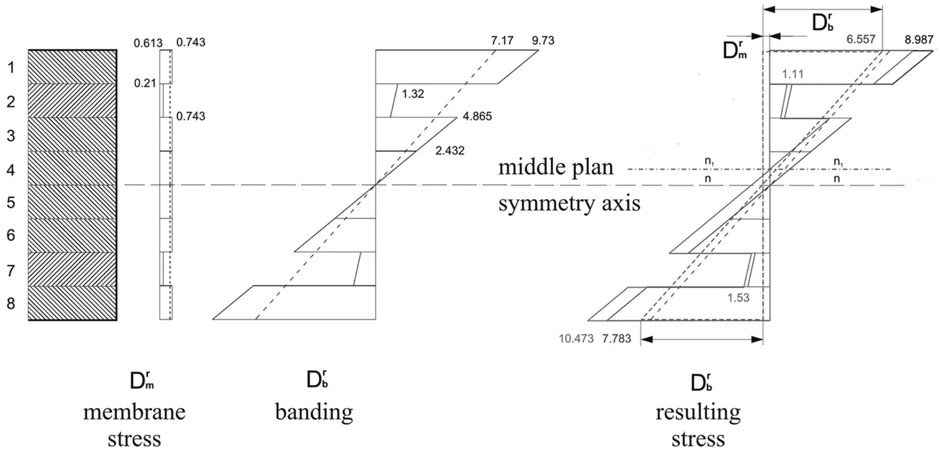

Figure 1. Reduced stiffness

Bearing in mind that the cross-section of the plate is defined by unit width and thickness of the plate, it is clear then that the section forces of the composite are resultants of the componential stresses, i.e. their integrals over the thickness of the laminate. From the condition that the integrals over thickness are the same in real surging change of the stress and fictive linear change, we define the reduced membrane and reduced bending stiffness of the composite. The previous condition entails equality of virtual works of the real and reduced stress change. In this way, the virtual works for the case of composite become the work of the section forces on membrane deformation and bending deformation of the middle plane of the laminate, by which the problem of the composite is transformed into the analysis of homogeneous (single-layers) plates.

The research conducted in the framework of theoretical, experimental and numerical part and the introduction of the reduced stiffness of the complex laminate in finite elements, with experiments on chairs which were carried out in order to determine the stiffness of such systems by measuring real displacements on the selected models, was confirmed by numerical calculations, which allow the design, redesign, construction and dimensioning of not only a chair but any beam or surface system based on the laminate, with the possible variation of material, combination of different materials, thicknesses and fiber orientations.

In this monograph, the exposed procedures as well as guidelines for further research in the conclusion have universal character and could be applied to all types of composites irrespective of the material and the way of laminate composition. For these reasons, I believe that this book is a suitable reading for students of master and doctoral studies on the courses Wood constructions in the interior as well as Furniture and wood products at the University of Belgrade, Faculty of Forestry, Department for Technology, management and design of furniture and wood products.

У монографији ауторка третира питања коришћења ламината у производњи столица путем експериментално нумеричког приступа те рад чини функционални спој теоријског, експерименталног и нумеричког истраживања композитних структура на бази дрвета.

У раду је посвећена одговарајућа пажња механичким карактеристикама ламината. Анализирана су композитна својства дрвета, првенствено са становишта опште теорије еластичности ламината као анизотропног материјалног тела. Са посебном пажњом обрађена је носивост ламелираних столица као предуслов индустријске производње столица од ламината.

Значајан део монографије посвећен је одређивању материјалних константи, што је од великог значаја за серијску производњу ове врсте намештаја која има реалну распрострањену употребну вредност. У монографији је презентиран нумерички модел у циљу да се анализом одабраних форми столица израђених од ламината путем математичког моделирања, применом методе коначних елемената, одређују и добијају подручја на столици са најмањим и највећим оптерећењем, тј. критична напонска стања, што омогућава предвиђања најмањег утрошка материјала са циљем да се утиче на примену адекватног дизајна. Овакав приступ омогућава већу слободу у обликовању и израду комплексних облика појединих делова или столица у целини.

У овој монографији конзистетно је посматран (композит) ламинат у условима равног стања напона од експеримената и теоријских анализа до конкретне примене намештаја за седење, што раду даје одговарајућу употребну вредност у теорији и рационалној производњи заснованој на коришћењу ламината као производног ресурса.

Увођење редуковане крутости комплексног ламината у коначним елементима чини посебан допринос истраживања, затим верификација мерењем реалних померања на изабраним моделима, потврђује нумерички прорачун и омогућава пројектовање, конструисање и димензионисање столица, као и било ког гредног или површинског система на бази ламината, уз могућност варирања врсте и комбиновања различитих материјала, дебљине слојева и оријентације влакана.

С обзиром на све израженији значај ламината у производњи намештаја, посебно столица, ауторка се нада да ће ова монографија побудити пажњу истраживача у циљу унапређења пројектовања, припреме и производње предмета од ламината на бази дрвета.