Materials and Technologies for Rural Engineering: Investigations and Practice

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Abstract. The main research area in Civil Engineering and Technology deals with materials in all aspects starting with raw materials, the analysis and developing of material technology, and ending with reliability and optimization of engineering structures. The developing and investigation of materials and structures with needed properties has become one of the most important sectors in this research area. Reliability of structures – the new research field – was developed depending on the use of different new materials and taking into account environmental effects, especially in agricultural buildings. During the last decade due to support from European funds and financial resources from Latvian Academy of Science, theoretical investigations have been performed and modern equipment has been obtained. In the future, the development of the scientific research activities and results will depend on material resources and international scientific activities of researchers.
Key words: building materials, modification, optimization, reliability.

Introduction

The basic task of the Civil Engineering branch at the Faculty of Rural Engineering is educating of engineers and technologists for building industry, educators and researchers. Real progress in education and building of plants is impossible without research. During the last decades, active scientific work characterizes the Civil Engineering branch at the Faculty of Rural Engineering in respect of the teaching staff as well as of postgraduate, master and bachelor students. Research activities are the basis for new research facilities, for improvement of education quality, and long-term cooperation with international partners. The research in Civil Engineering and Technology is mainly related to the following issues:

- developing of new materials and technologies for thermal isolation and soundproof materials;
- optimisation of wooden, concrete, steel and composite structures;
- reliability analysis of structures;
- investigation of environmental effects on different kinds of materials.

Optimization and Strengthening of Structures

Concrete structures. Because of economic activity, an increase in the processing waste quantity and pollution of the environment is taking place. Very important up-to-date problem is collection, storing, keeping and utilization of aggressive sewage and liquid manure. In the case of wet technology in the process of removing manure in farmhouses, the water content of manure can reach from 95 up to 97%. In order to protect the environment, safe keeping of those liquids is possible by using large containers near to the farmhouses and agricultural factories.

The economic solution of containers is reinforced concrete (RC) cylindrical reservoirs. However, they have several disadvantages. In the case of prefabricated reservoirs very often a leak between elements takes place. Special systems for early detection from small leaks, especially in underground storage tanks, have to be developed. Under action of tension, flexure, temperature gradient as well as concrete shrinkage, cracks can form in the vertical and horizontal direction of reservoir wall. That causes a need of expensive repair techniques for treatment of cracks. In order to assure the impenetrability and durability of the wall it is necessary to check for the material strength and crack formation.

The stress analysis and optimum design of the wall of open aboveground monolithic cylindrical reservoir has been performed, and optimum parameters of reservoir wall taking into account strength and serviceability limit state requirements and discrete material properties have been determined (Brauns, Andersons, 2000; 2002).

In new constructions and especially in renovation of structures, fibre reinforced plastic (FRP) strips are increasingly used as strengthening material of reinforced concrete elements. Immunity to corrosion, low weight, resulting in easier application in confined space, elimination of the need for scaffolding and reducing in labor costs as well as high tensile strength and large deformation capacity are the main positive characteristics of FRP. The addition of externally bonded reinforcement to prefabricated RC beams may be applied to increase structural safety and decrease risk aspects. The behaviour of RC beams with flexural strengthening has been studied. The effect of external FRP reinforcement on failure mode and stress distribution is determined (Brauns et al., 2003).

Basing on the test results and numerical analysis of RC beams with external flexural FRP reinforcement, the following conclusions are drawn:

- application of external flexural reinforcement on structurally balanced beams alters its failure mode;
- unstrengthened beams failed by a collapse of concrete in compressed zone. Beams with external flexural strengthening failed by collapse of concrete in tension at the end of FRP ribbon and following diagonal shear crack;
- the increase of ultimate bending moment for externally strengthened beams is about 7-10% but decrease of maximum deflection – 17-30%.

Composite structures. In many cases very effective is the use of concrete steel composite structures. According to Eurocodes implemented in Latvia, the plastic resistance of a concrete-filled column is given as a sum of the components and taking into account the effect of confinement in the case of circular sections. In investigations performed, the stress state in composite column has been determined by taking into account the non-linear relationship of modulus of elasticity and Poisson's ratio on the stress level in the concrete core. It is determined that the effect of confinement occurs at a high stress level when structural steel acts in tension and concrete in lateral compression. The stress state and load bearing capacity of a section in bending is determined by taking into account non-linear dependence on the position of neutral axis. Because the ultimate limit state of material is not attained for all parts simultaneously, to improve the stress state of a composite element and to prevent the possibility of a failure the appropriate strength of concrete and steel should be used. The safety of high-stressed composite structures can be improved by using ultra-high-performance concrete (UHPC).

Taking into account the design strength of steel and concrete as well as limit ratios of the circular hollow sections, the analysis of load bearing capacity of the composite column is performed (Brauns, Kreilis, 1998). It is shown that the load limiting factors are concrete design strength and diameter thickness ratio. Using concrete with strength class C35/45 and steel with grade Fe235 the load bearing capacity of the composite column increases by 20% in comparison with concrete of class C30/37. For a thin wall hollow section instead of thick wall the steel economy can be 50% (Brauns, Rocens, 2004b).

The optimization of working conditions and cross section area of a composite structure as well as the prevention of a failure in the case of small thickness of structural steel and fire can be realized by using appropriate strength of concrete and steel. By using UHPC as steel element filling the increase of load carrying capacity can be significant.

The stability of steel-face sandwich panels under bending and axial loading is studed, and the effect of core material stiffness is determined (Brauns et al., 2005).

Investigation and Optimization of Laminated and Short Fibre Materials

Modification of wood in wooden composites. Hot pressing is one of the important stages during the production of wood-based composites when mats of resinated wood fibers, particles, flakes or veneers are consolidated under heat and pressure to create close contact and form bonds between the wood constituents. Mat deformation is, however, not uniform across the material thickness resulting in a density profile in pressed composite boards. This in turn has significant effects on the physical and mechanical properties of the final product. The initial mat structure and the mechanical properties of its components govern the overall mat stress–strain relationship. Due to the viscoelasticity of wood, some elements exhibit time-dependent creep behavior and they may undergo stress relaxation.

As resin in wooden composites is employed in limited amount, bond efficiency relies on the degree of mat densification, which should be high. Increasing mat density, however, causes detrimental effects such as increased weight and wood consumption, and excessive thickness swelling in service when the product is subjected to high humidity conditions.

Mechanically modified wood by compression, to flatten its cavities, and by cavity filling with other materials improves wood strength and stiffness. The mechanical and hygromechanical quality of wood composite boards depends on the properties of layers and on the alignment of these (Brauns, Rocens, 2007a, 2007b).

Structural changes in technological pressing of wooden composites. Studies on wooden composites have focused on the relationships between processing parameters and material properties caused by densification. In manufacturing of a composite board the basic function of the pressing operation is the development of an adhesive bond between individual flakes or veneer sheets while minimal glue spread is utilized.

The structure of a mat made of fibres exhibits a double cellularity. Void space among the strands results from the inherent randomness of the deposition process, and the flakes include the cell lumen. It is thus possible to distinguish not only two different voids, but also two different densities: the density of the mat, and the average density of the fibres. During the first stage of pressing, voids space between flakes is eliminated from the mat structure and the flakes get into contact. Further pressurization enhances the collapse of cell walls and the lumen volume is decreased. The volume of the mat is the sum of the volume of the flakes and of the void space. At this stage, both the density of the mat and that of constituent flakes increase.

Viscoelastic behaviour of wooden composite. Viscoelasticity influences wood modification when wood flakes or veneers are under static pressure and subjected to changes in temperature and moisture content. In these situations, wood can be adequately treated as a linear viscoelastic material.

The high pressure applied during the manufacture of wood composites, coupled with the random mat structure, results in a non-linear and non-uniform mechanical response of the wood constituents. Time-dependent stress-strain relationships, instantaneous and delayed strain recovery, permanent deformation, and temperature and moisture-dependent stress relaxation may intervene during the pressing process.

Influence of composite structure on hygromechanical behaviour. The distribution and properties of densified flakes determine the load carrying capacity of the board. Oriented strand boards can increase the strength and the stiffness of wooden composites. Nevertheless, the warping of panels is very high. As a result, the quality of wood composite boards depends on the properties and alignment of flakes.

In general, wooden composites do not display symmetry with respect to the midplane; their properties can be either asymmetric or antisymmetric. The composite has been analyzed as a system of parallel elementary layers. The local co-ordinate system has been associated with the principal directions of the elementary layers. In order to approximate the stress state, stress-gradient-dependent force-stresses and couple-stresses are used in the model.

The multilayer model and model based on the laminate analogy was used to determine the behavior of layered and fiber composites. Non-symmetric moisture distribution causes linear expansion and hygromechanical warping. Curvatures resulting from hygrodeformation of wood were computed using the method developed in (Brauns and Rocens, 2004a).

The midplane strains and curvatures of wooden composites depend on the content and distribution of moisture. The hygroscopic deformation model contains seven veneers with equal thickness of 1.4 mm. The partial density of plywood (birch) is 660 kg m^{-3}. The results, which compare the properties of densified and of customary wood, showed the effect on curvature of an asymmetric non-linear distribution of moisture and antisymmetric structure at uniform moisture content.

Estimation of fibre length effect. Short fibres can offer advantages of economy and ease of processing (Brauns, Rocens, 1998; Brauns, Andersons, 1998). However, when the fibres are not long enough, the equal strain condition no longer holds under axial loading, since the stress in the fibres tends to fall off towards their ends. This lower stress in the fibre, and correspondingly higher average stress in the matrix compared with the long fibre case, depresses both the stiffness and strength of the composite. It is therefore necessary to quantify the change in stress distribution as the fibres are shortened.

Several models, ranging from fairly simple analytical methods to complex numerical packages, are commonly available. The simplest is the so-called shear lag model, which is based on the assumption, that all of the load transfer from matrix to fibre occurs via shear stresses acting on the interface between the two constituents.

The method developed gives possibility of examining the predicted stiffness as a function of fibre aspect ratio, fibre/matrix stiffness ratio and fibre volume fraction, and other effects on the distribution stresses as well as predict whether fibres of the specified aspect ratio can be loaded up enough to cause them to fracture.

Determination of elastic characteristics and strength of materials. The mechanistic approach is adaptable to the computation of composite material properties that characterize the material averaged responses, such as the prediction of composite compliances from micro-mechanical analysis. For a general composite laminate loaded in an arbitrary direction, a systematic approach is needed in order to predict the stiffness and the stress distribution. Simple cross ply and angle-ply laminates are not balanced for a general loading angle. If the plies vary in thickness, or in the volume fractions or type of reinforcing fibres, then even symmetric laminate is prone to tensile-shear distortions (Brauns, Rocens, 2008b). Computation is necessary to determine the lay-up sequence required to construct a balanced laminate. The fibre aspect ratio, fibre to matrix stiffness ratio, and fibre volume fraction affects the stress distribution as well as the elastic properties of short-fibred material. The fabric function of spatially reinforced composite can be fixed experimentally and used for the determination of elastic properties. By using the properties of unidirectionally reinforced structural elements, the orientational averaging allows determining the lower and the upper bond of elastic characteristics (Brauns, Rocens, 2006).

On the basis of the strength analysis the form of material failure can be predicted. A phenomenological failure criterion provides feedback for material improvement via structural changes and supplies quantitative strength characteristics of material that reveals pivotal to rational engineering design.

The method developed permits determining the stresses in a thin laminated structure by means of an experimental deflection function. It is established that the fracture occurs at maximum couple-stresses. For some laminates the delaminating takes place under action of interlayer shear stresses. The failure criterion permits predicting the sites of a fracture and possible load-carrying capacity of a shell upon loss of the stability. For strength-related properties, a failure criterion can provide feedback for material improvement via structural changes.

Investigation of materials with adaptive properties. Laminates can be designed to provide the desired strength and stiffness characteristics required for specific applications. The bend-twist coupling results in twisting of a structure, when a pure bending is applied but stretching twisting coupling can occur when a tensile load is applied. This behaviour is influenced both by the material characteristics of the laminate and geometric properties of the structure to which it is assigned.

The use of fibre-reinforced composite rotor blades enables a number of possible passive aerodynamic control options. The investigation of coupled deformation effects of laminated composite materials to obtain the necessary twist and strength of material is an important up-today problem. However, considering the membrane-bending stiffness coupling effects, not only the complexity of the design process increases, but also the risk of introducing effects that are difficult for designers to detect and account for.

The rotor blades are usually made using fibreglass mats, which are impregnated with polyester or epoxy. The blades may be made wholly or partially from carbon fibre, which is a lighter, but costlier material with high strength. Wood–epoxy laminates are also being used for large rotor blades. Experimental results indicate that wood is both a viable and advantageous material for use in wind turbine blades. This material is reasonably priced, domestically available, ecologically sound, and easily fabricated with low energy consumption.

Anisotropic properties of fiber-reinforced materials provide that the blade twists into stronger winds to reduce transient loading. By using adaptive blades with twist coupling there is a possibility of keeping good, steady power-production and smooth out unwanted peaks in loading. On the basis of investigations it is determined that in the case of in-plane balanced laminate anti-symmetric orientation of skin layers can be used to ensure the necessary adaptive warping and strength of the laminate under action of radial force in the rotor blade (Brauns, Rocens, 2008b).

Developing of New Materials and Technologies for Thermal Isolation and Soundproof Materials

The foam gypsum production technology and the acquired material (density – 200-700 kg m^{-3}) quality investigation is the main research field. The objective of the research is to develop a construction material to be used for heat and sound isolation. Along with this, a research has been initiated to develop a foam gypsum mixture by using various organic fillers.

Theoretical and experimental research on foam gypsum drying process. The world technical progress in construction of buildings is nowadays aimed at the use of materials with desirable properties where in multilayer constructions each layer carries out the functions it is assigned to. Gypsum binders are widely used in manufacturing gypsum paperboard, sound and heat isolation material in building monolithic one-to-two storey houses. The drying of gypsum products is an obligatory requirement for the technological process that significantly influences both its physical qualities such as density and heat conductivity coefficient and its mechanical qualities. For example, the strength indicators in dried gypsum are several times higher than in a wet sample. The authors have made experiments where the drying of foam gypsum can be researched by electrical methods, which do not destroy the material during the experimental process (Iljins et al., 2009)

Measurements of heat transfer of multi-layered wall construction with foam gypsum. A new wall structure and its manufacturing technique have been developed by the authors (Skujans et al., 2007). An experimental wall fragment has been manufactured. It consists of the following layers: internal finishing layer (gypsum boards and vapour insulation), foam gypsum, thermal insulation (polystyrene), and a plaster outer layer. The construction element's heat transfer coefficient U was determined by applying specially developed equipment and software. According to the experimental test, the coefficient's U value for the multi-layer construction with the foam polystyrene thermal insulation is 0.36±0.10 W m^{-2} K. The manufacturing technology with foam gypsum is used for quick building of one and two storey houses. With the foam gypsum apparent density it is possible to regulate the heat inertia of the wall construction.

Experimental research of foam gypsum acoustic absorption and heat flow qualities. It is well known that acoustic absorption and heat flow indices of materials of open or closed pores are different. It is expected that the research will allow developing a material for which it is possible to acquire the preferable pore structure depending on application. Up to know the research has been made on foam gypsum acoustic absorption qualities, modifying the foam gypsum material density, layer thickness as well as production technology. It has been stated that all these parameters influence the qualities of foam gypsum acoustic absorption, which enables to develop such foam gypsum structure that can be used for production of acoustic absorption layers and acoustic insulation panels. Because of acoustic parameters' conformity with normative regulations, the use of different acoustic materials in modern civil engineering will continue to increase (Iljins et al., 2009).

Conclusions

The investigations in the Civil Engineering science are based both on theory and experimental research work. The development tendencies in the Civil Engineering science are linked with the applied engineering problems and development tendencies of Latvia. The major areas of research activities in the future are:

- elaboration and investigation of building materials incorporated by particular properties of considerable industrial interest and competitiveness, the use of the local and recyclable raw materials in production;
- economy of energy and environmental resources;
- integrated development of strategy and technology of construction production with the progressing activities in European Union.

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