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EXPERIMENTAL AND THEORETICAL ANALYSIS OF THE STRESS STRAIN FIELDS AT BOLDED JOINTS OF TEXTILE WOOD COMPOSITES

Wooden structures with bolded joints and cut-outs can be reinforced with textile composites, which offer a load adapted fibre orientation. Because of the anisotropic material behaviour of the wood and the textile reinforcement complex stress and strain effects occur at bolded joints and cut-outs. Extensive experimental research using modern, optical 3D measurement methods is conducted for the determination of the complex strain fields at bolded joints and cut-outs of reinforced wooden structures. In addition, the finite element method is utilised for selected parameter combinations as a support.

Key words: **textile reinforced wooden strucutres, bolded joints, experimental strain analysis**

EKSPERYMENTALNA I TEORETYCZNA ANALIZA PÓL NAPRĘŻEŃ WOKÓŁ KARBÓW W PŁYTACH DREWNIANYCH WZMOCNIONYCH TEKSTYLNIE

Kierunkowe właściwości kompozytów tekstylnych umożliwiają poprawę wytrzymałości w strukturach drewnianych, szczególnie w obszarach połączeń. W tych strefach drewno jest osłabione różnymi otworami albo metalowymi złączami, które są odpowiedzialne za wystąpienie spiętrzeń naprężeń. Szerokie badania eksperymentalne wzmocnionych struktur drewna z wykorzystaniem zaawansowanych metod optycznych, przeprowadzone w ILK, służyły określeniu niejednorodnego stanu naprężeń oraz dodatkowo zweryfikowano je metodą elementów skończonych.

Słowa kluczowe: **struktury drewna wzmocnione tekstylnie, eksperymentalna analiza naprężeń, połączenia sworzniowe**

INTRODUCTION

Wooden structures are often weakened by required bolded joints or cut-outs. Here, the ultimate load can be significantly increased by a tailored textile reinforcement with a load-adapted pattern in the disturbing notch area [1]. The stress concentration of, for example, textile-reinforced timber structures with a usually orthotropic reinforcement is fundamentally different from that of isotropic engineering materials as the former exhibit a strong dependence on the property characteristic, especially on the degree of anisotropy, of the composite layers as well as on the lay-up of the textile reinforcement. As a result, uncommon, complicated stress and strain effects are observed, so that no universal stress concentration factor can be given to the engineer. Instead, the stress concentration factors have to be determined individually for each lay-up and each load case [2-4].

For the determination of the strain fields of wooden structures with cut-outs and bolded joints extensive experimental tests were performed using optical 3D measuring methods. The experimentally determined strain fields were compared with results from finite element analysis. The material data of the wood and the textile reinforced composite which were needed for the FE analysis were measured in adapted material tests.

DETERMINATION OF DIRECTION DEPENDENT CHARACTERISTIC MATERIAL VALUES

The characteristic material data required for the FE analysis, such as Young's modulus, shear modulus, Poisson's ratio and the strength parameters (interaction coefficients, fracture angles and ultimate strengths) of the individual composite layers have been determined in detailed material tests. For some exemplary timber and glass-fibre textile reinforcement materials, Table 1 shows the essential elastic properties; the direction-dependent elasticity modules are compared in Figure 1.

The characteristic strength values of glass fibre-reinforced plastic (GFRP) have been determined on flat specimens in the tensile tests or compression tests (respectively) as well as on tube specimens in the tension/compression/torsion test (T/C-T test). In the T/C-T tests, the failure-critical stress combinations along pre-stated load paths were introduced with the help of a specially enhanced load-controlled multi-axial testing

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machine with adapted strain-twist extensometer. Normal stress-strain curves as well as shear stress-torsion curves can be prepared with the help of these extensometer measurements.

TABLE 1. **Elastic properties of selected timber and GFRP reinforcement materials**

Material	E_1, E_z GPa	E_2, E_r GPa	ν_{12}, ν_{zr} –	G_{12}, G_{zr} GPa
sprucewood	11,9	0,79	0,323	0,6
glass fibre epoxy:				
UD-reinforcement	42,5	11,0	0,28	4,2
Woven reinforcement	26,9	29,9	0,115	4,2
Multi-axial reinforcement	21,2	21,2	0,3	8,14

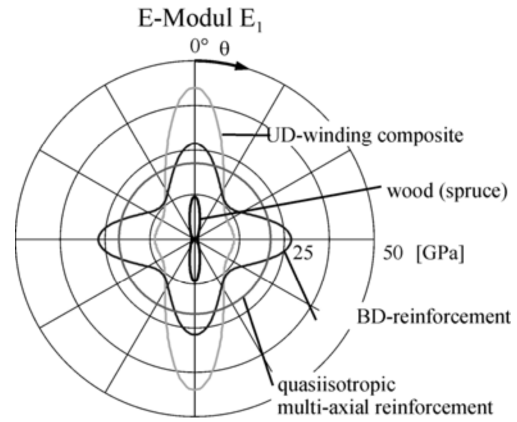


Fig. 1. Comparison of direction-dependent elasticity modules (θ = 0° : fibre direction)

In addition, the experiments conducted on filament-wound tube specimens served for the determination of ultimate stresses as well as corresponding fracture angles on the one hand, and on the other hand for the characterisation of elementary types of failure. Furthermore, the additionally obtained information with regard to fracture angle and fracture mode enable a detailed description of the complicated failure phenomena in fibre-reinforced composites. The failure curve in the (σ_2, τ_{21}) stress plane for uni-directionally reinforced fibre composite materials comprises for example the types of failure: transverse normal failure, transverse-transverse shear failure and transverse-longitudinal shear failure. The considerable amount of information which the T/C-T test supplies allows explaining the initial, essential physical failure phenomena, and on top of that also enables displaying the inadequacies of the general failure criteria, which are quite frequently utilised at present.

The experimental results of the T/C-T tests in tangentially wound fibre/epoxy resin specimens (GFRP: E-Glass/LY556/HT976) for the (σ_2, τ_{21}) planes are presented in Figure 2. The load is increased uniformly until failure along pre-determined load paths, for which a constant stress ratio σ_2 to τ_{21} is maintained. The measured strengths exhibit a very marginal variance, which indicates a good reproducibility of the experiments. Based on the key strengths $R_{\perp}^{-}$, $R_{\perp}^{+}$ and $R_{\perp\parallel}$ determined from flat specimens, the failure curve was calculated according to the failure criterion of Hashin/Puck [5-7]. This theoretical curve shows a very good congruence with the failure values measured under superimposed loads.

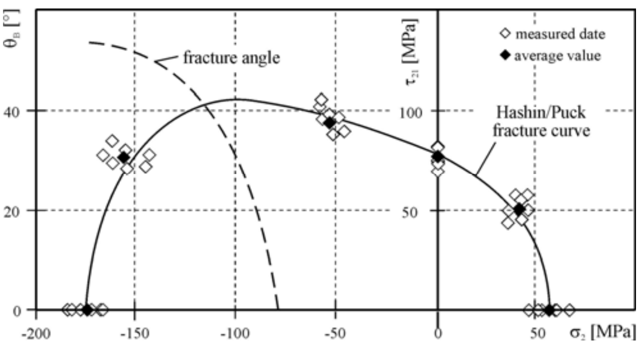


Fig. 2. Strengths, failure curve and fracture angle for tangentially wound GFRP tube specimens

The slope of the failure curve in the compression/torsion range, which is caused by „internal material friction" according to the hypothesis of Coulomb, is clearly recognisable. Thus it can indisputably be proven that with increasing compressive stress, the shear failure as a consequence of τ_{21} is increasingly inhibited in the beginning. The gain in compressive stresses thus leads to a change in the relevant failure planes from parallel to the fibre direction to perpendicular to the fibre direction. This results in a relatively strong drop of the failure curve for high compression loads.

EXPERIMENTAL TESTS TO DETERMINE THE STRAIN FIELDS OF NOTCHED TEXTILE REINFORCED WOODEN STRUCTURES

Extensive load tests are conducted for experimental verification of the developed calculation methods. In particular, the decaying behaviour of the peak stress concentrations is measured and the notched failure is observed with the help of modern 3D field measurement methods such as ESPI (Electronic Speckle Pattern Interferometry) and the grey-value correlation method. The tried and tested strain-gauge technique is applied for reference measurements. Certainly the field measurement methods necessitate a relatively high effort during the implementation and evaluation of the experiment; however, in comparison to the strain-gauge technique they provide not only local values, but details concerning the displacement or strain distribution in the entire field of measurement.

The composite specimens necessary for the bending and tension tests are produced at the ILK on the one hand by means of hand-laminating technique, and on the other hand by the autoclaving method, whereby multi-axial textiles, which have been produced at the Institut für Textil- und Bekleidungstechnik of the Technische Universität Dresden, as well as commercial GFRP plates are utilised as GFRP reinforcement.

The GFRP/timber structures examined here are equipped with strain gauges at four positions: on the top and bottom surface of the plate, respectively on the x- and y-axis, in 3 mm distance from the edge of the notch (see Fig. 3). Usually, 2-axis rosette strain gauges are utilised. 2 × 5-point strain gauge chains are also applied on a few selected specimens. Figure 4 shows the ε_x and ε_y strain fields of a textile reinforced wooden structure loaded by a metallic bold, which were determined using the grey value analysis.

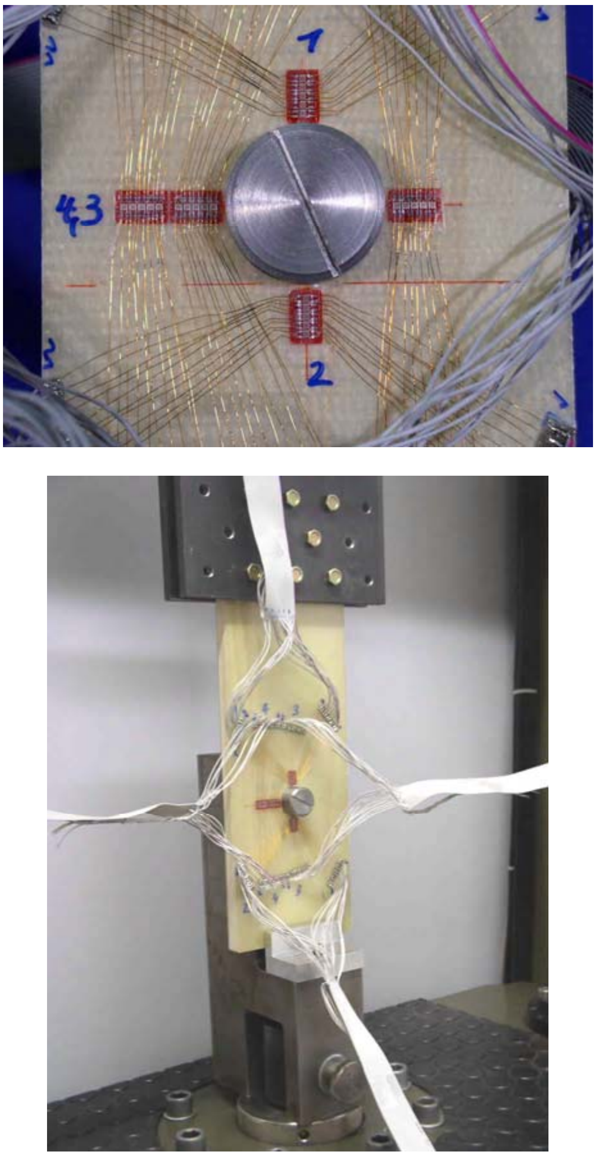


Fig. 3. Strain gauge positioning on the timber GFRP structures and testing fixture

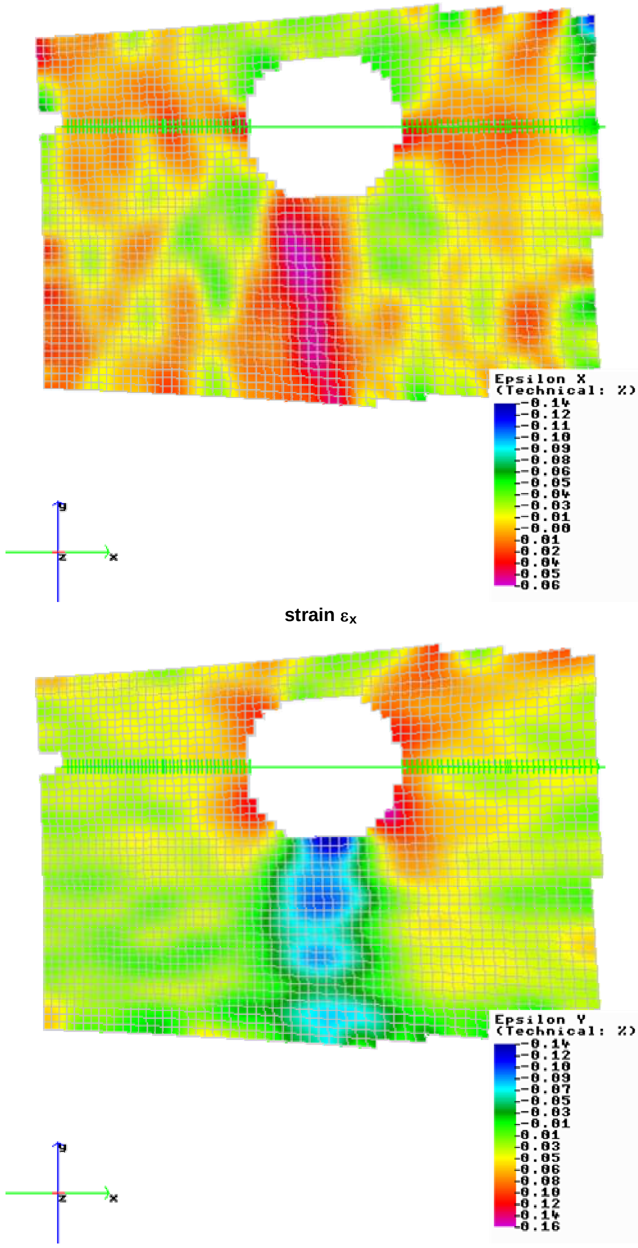


Fig. 4. Strain fields of a pin loaded textile reinforced wooden structure

FE-SIMULATION

For selected textile reinforced wooden structures with cut-outs and bolded joints the finite element analysis were applied to determine the stress and strain fields. Especially in the case of bolded joints great efforts have to be made to choose the right boundary conditions. The FEA simulation were performed using the software system I-DEAS Master Series. Figure 5 shows exemplarily the quarter model using the structural and material symmetry.

For the stress strain analysis especially the area close to the metallic insert is considered. The outer areas are needed for the FE model as well as for the specimen to reduce the influences of gripping effects. In Figure 6 the strain fields of a tensile loaded reinforced wooden plate with steel insert is shown.

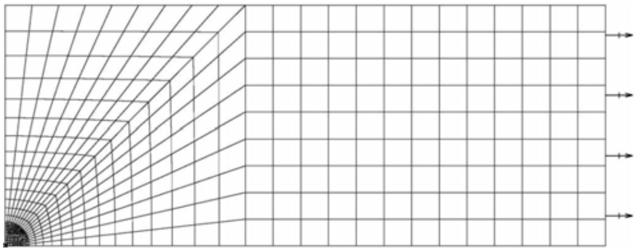
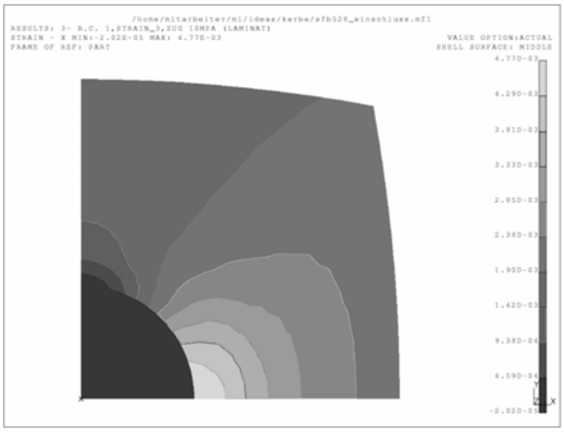
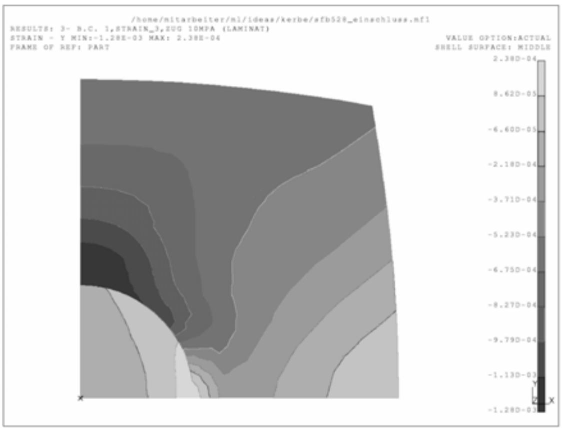


Fig. 5. Meshing of the finite element model, here with tensile loads



strain ε_x



strain ε_y

Fig. 6. Strain fields of a textile reinforced timber structures with insert under tensile load in x direction

CONCLUSIONS

Measurements conducted at the ILK indicate the complexity of the design especially of wooden structures with bolded joints. Besides the direction dependent characteristics of the textile composite and the wood as well as on the lay-up of the textile reinforcement the interface of metallic bold and textile wood have to be considered intensely.

Extensive research with regard to develop analytical models which describe the stress strain behaviour of bolded joints for textile reinforced wooden structures is currently being conducted at the Institut für Leichtbau und Kunststofftechnik. The results will subsequently be published in engineer-usable, tabular and graphic form, whereby engineers concerned with notch problems in hybrid composites will be provided with an efficient design tool.

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Recenzent
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