ANALYZING THE STRESS – DEFORMATION MECHANISM OF LAMINATED POLYMER COMPOSITE PLATES FOCUSING ON THE SIZE AND STRUCTURAL EFFECTS

PHD DISSERTATION
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THESES

1. I developed and realized an injection technology, which is applicable for RTM, VIM and VARTM technologies with different reinforcing materials, structures and fiber contents and it uses two rigid mold halves. Using this technology the standard deviation of the mechanical properties (tensile, bending and compressive modulus and strength) of the produced samples can be kept <10%, the standard deviation for the physical properties can be kept <2%, and the standard deviation of the thickness as a geometrical property can be kept <5%, which is almost one order better than can be achieved by the conventional hand lamination technology.

2. Analyzing the tensile test results of samples containing 16 layers of woven reinforcement – all layers having the same alignment – with different width (b = 10, 15, 20, 25, 35 and 50 mm), but with the same thickness (h = 4 mm) I derived that:
   a) The tensile modulus of the samples cut out in three directions (parallel to the warp direction of the reinforcing structure, in 22.5° and 45° to the warp direction) does not depend on the sample width. I evinced that the strain velocities, calculated from the results of videoextensometer strain measurement, and the arising stress velocities are not constant during tensile testing. I analyzed the effect of sample width on this phenomena in the standardized strain range (ε = 0.0005-0.0025) for determining the tensile modulus, and derived the undermentioned relationship depending on sample width:

   \[ \dot{\varepsilon} = Ab^B, \dot{\sigma} = Cb^D \]

   If B = D, the fraction of A and C is constant, and shows agrees well with the measured tensile modulus at different sample widths. The parameters for samples parallel to the warp direction are: A = 2.62x10⁻⁴ 1/(s*mm^3), C = 5.70 MPa/(s*mm^3); for the 22.5° samples: A = 2.93x10⁻⁴ 1/(s*mm^3), C = 4.40 MPa/(s*mm^3); for 45° samples: A = 3.34x10⁻⁴ 1/(s*mm^3), C = 3.56 MPa/(s*mm^3), in case B = D = -1.25.
b) I proved that there is a clear relationship between the damage process and the sample width. The tensile strength of the 22.5° and 45° specimens is increasing in the width range of 10..50 mm. The damage process is fiber pull out, fiber breakage with fiber pull out followed by fiber breakage. In case of 10..25 mm wide samples the fracture is matrix material dominant, where rising times of the acoustic events are in the range of >200 μs and the duration times are >500 μs, the 35 and 50 mm wide samples showed fiber breakage dominant failure with <200 μs rising times and <500 μs duration times. Analyzing the transversal modulus during the damage process (from the tensile tests) I concluded that detecting its deviation from the linear nature is capable to determine the start of the failure process. Thus, the initiation of the damage process can be defined by the follow up of the transverse modulus (e.g. by strain gauge measurements).

3. Analyzing the bending test results of samples with 0, 22.5, 45, 67.5 and 90° to the warp direction of the woven reinforcement – all the 16 layers having the same alignment – and with the same sample thickness (h = 4 mm), I derived that:

a) In case of three point bending, with increasing support length – sample thickness ratio (L/h = 5, 10, 16, 20, 25, 30, 40 and 50), the bending modulus of the samples with the same width (b = 15 mm) is monotonously increasing and tends to a constant value when L/h ≥ 25. This asymptotic behavior is valid for the bending stresses at different strain levels in the linear elastic range. If the span length is kept constant (L / h = 25) and the sample widths are different (b = 10, 20, 40, 60 and 80 mm), the arising bending stresses in the 22.5 and 45° samples are monotonously increasing with the specimen width, and they can be considered to be constant when the floating fibers disappear.

b) The span length – specimen thickness ratio and the specimen width had a big influence on the failure type of the specimens under three point bending. The catastrophe-like failure was delamination at L/h ≤ 10 on every tested specimen, thus this configuration is capable of determining the interlaminar strength of the samples. At larger L/h ratios the fiber break type failure appears only in specimens cut out parallel to the warp or weft direction of the woven reinforcement. In case of 22.5 and 45° specimens fiber break type failure dominates with increasing specimen width at L/h = 25.
4. Analyzing the four point bending test \((L/h = 25\) and \(L_2/L = 0, 0.2, 0.33, 0.5\) and 0.66) results of samples with 0, 22.5, 45, 67.5 and 90° alignment to the warp direction of the woven reinforcement – all the 16 layers having the same alignment – and with the same sample thickness and width \((h = 4\ mm, b = 15\ mm)\) I derived that the bending modulus is not sensitive to the loading point distance – support span ratio. \(L_2/L\) has no effect on the bending modulus of the samples, in case of 22.5 and 67.5° specimens there was a 5-7% modulus increase (with increasing standard deviation) between the two end points of the measured range, the modulus of the 45° samples showed 10% decrease over the tested range. I showed that the loading point distance – support span ratio had no effect on the failure type.

5. Analyzing the interlaminar shear stress distributions derived from the finite element modeling of the three point bending tests \((L/h = 5..50)\) of the composite specimens with all layers having the same alignment I evinced that:

a) The classical beam theory gives good results only when calculating the shear stress distributions at halfway of the loading nose and support nose distance at the mid-width of the fiber dominant specimens (cut out parallel to the warp of weft direction of the reinforcing structure). In case of 22.5 and 45º samples the classical beam theory gives appropriate result only for the mean value of the maximum shear stress arising in the whole specimen width.

b) At large \(L/h\) ratios the interlaminar shear stress distribution at the vicinity of the loading nose is greatly distorted both in specimen width and thickness direction. I showed that the shear stress distribution in the 22.5º specimen is the sum of the shear stress coming from bending and the asymmetric structure generated torsion shear stress, which has an asymmetric distribution over the specimen width. With the help of finite element analysis I proved that the distortional effect is the greatest at the specimen edges, at \(L/h = 50\) it can cause a two times strengthening or weakening effect on the local shear stress distribution coming from the shear force.

6. I developed a new type, image processing based measuring method for determining the bending modulus. The contours of the curved specimen with a known geometry can be identified by analyzing the contrast (or intensity) differences of pixels on a digital image. By determining the symmetry axis at the minimum point of the contour, and symmetrizing the data the asymmetric error of the image can be corrected. The curvature, so the bending modulus can be derived from the second derivative of the fitted \(m\)-grade \((m \geq 2)\) polynomial function, and the fitting takes place at the vicinity
of the minimum place of the contours. According to my test results I proved that fitting a polynomial function of sixth-grade gives the same modulus result as calculating it from the known bending force – deflection characteristics.