DEVELOPMENT OF NATURAL FIBER REINFORCED POLYMER COMPOSITES

PHD DISSERTATION
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THESES

Theses 1:
Hemp fibers from all steps of the processing chain have been evaluated, and two of them have been selected as the best reinforcement for plastics. For heavy loaded, high performance composites, the retted, drawing sliver showed the best properties combined with thermosetting matrix, and for medium loaded parts, the retted, morefold carded tow was selected combined with thermoplastic matrix.

Theses 2:
A measurement method was worked out for more accurate determination of non-circular fiber cross sectional area and perimeter, based on contour width measurements using optical microscopic pictures taken from fiber cross sections.

a. The cross sectional area of the fiber can be calculated using the formula $\overline{A_{szám}} = \frac{\left(s \times c \times \overline{ProjX,Y}\right)^2 \pi}{4}$, where s shape factor is $s = \overline{ECD} / \overline{ProjX,Y}$, c correction factor is $c = \sqrt{\frac{\overline{A_{sz}}}{\frac{\left(s \times \overline{ProjX,Y}\right)^2 \pi}{4}}}$. $A_{szám}$ is the calculated corrected cross sectional area, $\overline{ECD}$ is the mean equivalent circle diameter, $\overline{ProjX,Y}$ is the mean projected length of fiber cross sections to X and a Y axes, $\overline{A_{sz}}$ is the average area of the examined fiber cross sections.

b. The mean perimeter of fiber cross sections can be calculated using the formula $\overline{K_{szám}} = \frac{\sum_{i=1}^{n} z\,ProjX,Y\pi}{n}$, where z shape factor is determined by dividing the mean fiber perimeters ($\overline{K_{sz}}$) with the average perimeters calculated from *ProjX,Y*, supposing they have circular cross sections.

Theses 3:

Prediction of tensile strength and Young's modulus of unidirectional hemp fiber reinforced unsaturated polyester resin composites based on the rule of mixture (ROM) and the matrix failure controlled version of ROM have been investigated, if the fibers' cross sections are being considered as non circular, and:

a. the fiber strength is determined as the strength at the critical fiber length from the curve based on the Vas-Halász modified weak chain theory fitted on the measured fiber strengths at different clamping lengths. The critical fiber strength can be determined based on microdroplet tests, and when calculating the fiber perimeter, the fiber's cross section needs to be considered as non-circular.
b. when calculating the fiber's Young's modulus, the elastic fiber pull-out needs to be eliminated. The Young's modulus can be corrected for the elastic fiber pull-out based on the measurement results of fiber tensile tests, using a correction factor *e*, $e = \Delta l_{átl} / \Delta l_{korr}$, where $\Delta l_{átl}$ is the mean displacement, Δl_{korr} is the mean displacement diminished by the permanent fiber pull-out. The permanent fiber pull-out is the value of linear function at $x=0$, where the linear function is fitted on the measured mean displacements at different clamping lenths.

Theses 4:

It was investigated, that prediction of Young's modulus of hemp/PP composites hot pressed from hybride mat can be estimated based on the Hirsch model, if the fiber's Young's modulus is corrected for elastic fiber pull-out, and during the calculations the fibers are considered as having non-circular cross sections.

The Young's modulus can be corrected for the elastic fiber pull-out based on the measurement results of fiber tensile tests, using a correction factor *e*, $e = \Delta l_{átl} / \Delta l_{korr}$, where $\Delta l_{átl}$ is the mean displacement, Δl_{korr} is the mean displacement diminished by the permanent fiber pull-out. The permanent fiber pull-out is the value of linear function at $x=0$, where the linear function is fitted on the measured mean displacements at different clamping lenths. The value of the *x* stress-transfer ratio is 0.68 and 0.46 paralell and perpendicular to carding direction.

Theses 5:

The formula of the β_C parameter in the Nairn-modified Cox model has been modified, which makes it suitable for calculation of Young's modulus of natural fiber reinforced composites containing low and medium fiber volume fraction. β_C can be calculated using the following formula:

$$\beta_C = \left[\frac{2}{s^2 c^2 (D_{sz}/2)^2 E_{sz} E_m} \left[\frac{E_{sz} v_{sz} + E_m v_m}{\frac{v_m}{4G_{sz}} + \frac{1}{2G_m} \left[\frac{1}{v_m} ln\left(\frac{1}{v_{sz} + \chi} \right) - 1 - \frac{v_m}{2} \right] + \frac{1}{sc(D_{sz}/2)D_s}} \right] \right]^{0,5}$$

This formula already contains the non circular cross sectional area correction of natural fibers. *s* is the shape factor based on the cross sectional investigations, *c* is the correction factor, D_{sz} is the fiber diameter, E_{sz}, G_{sz} and E_m, G_m are the Young's modulus and shear modulus of the fibers and matrix, and χ parameter is introduced in order not to get infinity for $ln\ (1/v_{sz})$ when $v_{sz}=0$, D_s parameter stands for the not perfect interface between fiber and matrix.

Theses 6:

a. It was investigated, that both fiber length (*L*) and fiber contour width (D_{sz}) decreases at injection molding; the reduction of fiber contour width (increasing of it's fineness due to longitudinal cracking) can be described using the $\overline{D_{sz}} = D_0 \left(1 - \frac{v_{sz}}{v_{sz1}} \right)$ linear function fitted to the measurement results in the $0<v_{sz}<39.82$ vol% domain, where $\overline{D_{sz}}$ is the mean fiber contour width, D_0 is the mean initial fiber contour width, v_{sz} is the fiber volume fraction, v_{sz1} is the theoretical maximum fiber volume fraction determined by the fitted curve (the x value of the line at $y=0$).

b. A statistical fiber breaking model was worked out for the $0<v_{sz}<39.82$ vol% domain, that is suitable for calculating the average fiber length after processing using the $\overline{L_T} = \frac{1}{\overline{L}} + B\left(\frac{v_{sz}^{\ f}}{1-\frac{v_{sz}}{v_{sz1}}}\right)$ formula, where $\overline{L_T}$ is the mean broken fiber length, $\overline{L}$ is the mean initial fiber length, v_{sz} is the fiber volume fraction, v_{sz1} is the theoretical maximum fiber volume fraction determined by the fitted curve. The value of index f was $f=1,067$ at retted, more fold carded hemp tow and polypropylene (TVK, H116F), which gave a fitting with the correlation factor of R^2=0.998. Parameter B can be written in formula $B = \frac{8\Omega}{\pi D_0}$, where Ω is the crossing factor of fibers, D_0 is the mean fiber contour width. The average value of the crossing factor in the examined case was 0.1856 from the regression fitting in the 0-39.82 vol% fiber volume fraction range.

Theses 7:

It was investigated, that in case of retted, morefold carded hemp tow reinforced PP (TVK, H116F), the reduction of the technological- and post shrinkage due to the increasing in fiber content is mostly dominated by the presence of the fibers and not by the needed changes of the technological parameters (increase of injection pressure at higher fiber contents), which is negligible. It was pointed out, that when neglecting the effects of injection pressure changes, the shrinkage of composites can be described as a function of time using the formula $S(t)=m\ ln(\ t)+S_{t,}$ in between the $t_1=0.083$ and $t_2=216$ hours time frame. Based on measurement results the parameters are: $m=0.0287,$ $S_{t,}=1.3128.$