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Numerical analysis of stress state during single point bending in DMTA examinations

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Analysis and modelling

ABSTRACT

Purpose: Determination of stresses at the change of Young's modulus values in temperature function for samples made of PA 6.6 filled with glass fibre, by DMTA method, was the aim of work.
Design/methodology/approach: Investigations were carried out for samples subjected to the one-axial bending. The change in the value of the dynamic Young modulus and the mechanical loss tangent in function of temperature and oscillation frequency by the DMTA method was determined. The computer simulations of changes of the stress and strain distribution within the range of elastic strains and the glass transition phase were done.
Findings: Examinations made possible the determination of dynamic mechanical proprieties PA 6.6 filled with glass fibre and changes in the stress distribution during the dynamic loading of the sample in function of temperature. Higher values of the Young modulus were observed within the range of elasticity and the glass transition phase. The stress increased with the increase in Young's modulus, at the strain generated from push rot oscillation.
Research limitations/implications: The accuracy of used approximate method for computer simulations was not sufficient to indicate the Bielajew point.
Practical implications: Investigated polymeric composite is characterized by viscoelastic properties, so all indicators of the physical and chemical properties depend on not only the time but and also the temperature.
Originality/value: To characterize properties of investigated composite and to estimate the composite usage in particular conditions, dependences of the storage module and the mechanical losses tangent was determined in function of temperature at the one-axial bending.
Keywords: Computer assistance in the engineering tasks and scientific research; Numerical techniques; Computational material science; Methodology of research

1. Introduction

Constructional polymers have good mechanical properties and the resistance on many physical, chemical and biological factors. Properties of constructional polymers allow their wide use in the production of structural components of different machines and devices. The range of their using can be broadening by chemical or physical modification of polymers. The chemical modification of polymers takes place during the polymer production, instead the physical modification of polymers consists in their filling with powder or fiber fillers. The kind of used filler influences moulded part parameters [1-9]. Also during the polymer processing the auxiliary additives are used, which make easier to run the process of polymer processing and in some way permit to control it. All these additives cause changes in polymer properties and the investigations of the range of these changes are necessary to obtain good results of parts production Examinations of the influence of glass fibre addition on mechanical properties of parts made of polyamide 6.6, determined by DMTA method, was the aim of this work. Stress distribution in function of temperature increase during parts dynamic loading was determined. Dynamic mechanical thermal analysis (DMTA) is one of methods which allow to estimate the transformations occurring in polymer during its loading in the broad range of temperature and frequency of load changes (load time). From this analysis one can receive a pattern of changes for dynamic Young modulus and the loss tangent. The knowledge of these changes course enables to establish the relationship between molecular parameters and mechanical properties of polymeric materials [10-21].

The polyamide 6.6 filled with 25% glass fibre and non-flammable agents were used in examinations. The dynamical mechanical properties of moulded parts by DMTA method were determined. Also the results of numerical simulation using the finite elements method in ADINA System were carried out. The numerical simulation permit to calculate the stress, displacement and strain distribution in parts from PA 6.6 filled with glass fibre.

2. Materials and investigation methodology

The polyamide 6.6 filled with 25% glass fibre and the Vampamid 66 2526 V0 Naturale 30 non-flammable agents was used in examinations.

Samples for investigations have been prepared by injection moulding. Injection moulding parameters have been as follows:

- melt temperature 280 °C, mould temperature 40 °C, injection velocity 60mm/s
- holding pressure dependant on injection pressure and equal to 60% of injection pressure value
- holding time 20s
- cooling time 20s
- mould clamping force 650 kN

The examinations by DMTA method were run using the testing device type DMA242 Netzsch. The device allowed to test samples by three-point bending (Fig. 1).

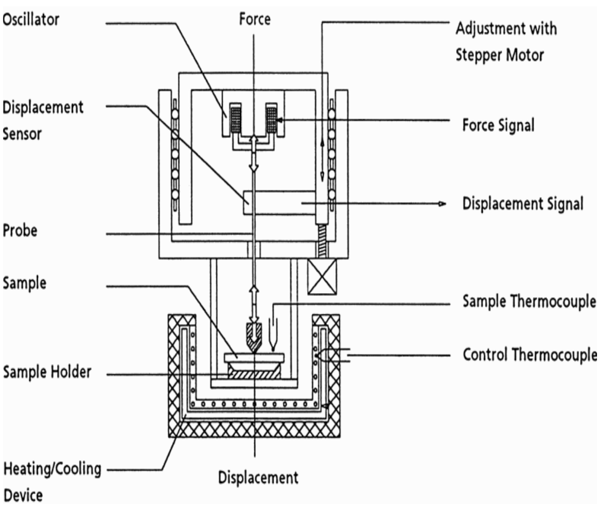

Fig. 1. The scheme of the device for the three-point bending of sample

On the sample placed in the holder, the sinusoidal variable load with the frequency 1Hz and 10Hz and constant amplitude, at simultaneous heating from the temperature -50°C to 200°C, was applied through the push rot. The results were presented in the form of graph showing the course of changes of storage modulus E' and loss tangent tgδ in the function of temperature (Figs. 2). Examinations were done in accordance with obligatory standards.

3. Results of investigation and discussion

The results of DMTA investigations of polyamide filled with glass fibre were presented in the form of graph showing the course of storage modulus E' and mechanical loss tangent tgδ in function of temperature (Fig. 2).

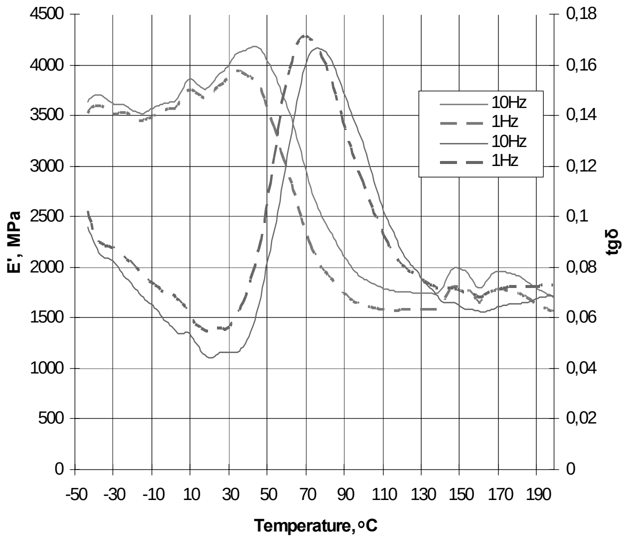

Fig. 2. Courses of changes of storage modulus and mechanical loss tangent vs. temperature for PA/glass fibre composite

In the range of higher strain frequencies or within the area of temperature lower than the glass temperature, the composite is in glassy state, it is hard and fragile. In the glassy range the thermal energy is not sufficient to overcome the potential barrier for dislocation and rotational movements of the particle segments. The system remains in a state of thermodynamic imbalance. With the temperature increase or with the deformation time extension the quite rapid decrease in modulus occurs and the mechanical loss tangent curve goes to its maximum. The composite is in the area of glassy transition, where mechanical loss tangent reaches its maximum at the given deformation frequency 1 and 10 Hz. In mechanical interpretation the value of loss tangent may be treated as a stress relaxation indicator. The maximal value of this coefficient appears when $\omega\tau_r = 1$ (ω - angular frequency, τ_r – relaxation time). In the area of glassy transition the initiation of the Brownian movements inside the molecular chain occurs. The thermal energy becomes comparable with the barrier of the potential energy for the chain rotation. Near the temperature of the glassy transition the polymer viscoelastic properties change very quickly both with time, as well as with the changing temperature. A lot of changes in polymer mechanical and physical properties are observed here. Relaxation modulus decreases significantly, the creep compliance increases, the coefficient of thermal expansion and internal friction change in a very big range. The glass temperature depends on the chemical and molecular structures. After the glassy transition, the changes in the modulus are comparatively independent on time and temperature and the composite properties are highly elastic. During further temperature or time increase, modulus is temperature and time dependent again and the component of the viscous flow appears. In the last area the modulus is very low, material is characterized by very low strain recovery and remains in a flow state. The highest values of the storage modulus were obtained within the range of elastic strains at the temperature 29 °C - 49 °C. The maximum of the storage modulus was obtained at the temperature 42°C and its value was 4179 MPa. The maximum value of the mechanical loss tangent was obtained at the temperature 75°C. The investigation was finished within the range of high-plasticity phase, at decreasing values of the storage modulus and mechanical loss tangent.

For the purpose of presentation the reduced stress, strain and displacement distribution, the numerical analysis using the finite elements method, in ADINA System 8.3 program, was carried out. The mathematical model was created, in which into the test sample (the beam of rectangular cross-section situated on two supports) the moving push rot penetrates in cycles with the frequency 10 Hz and the constant value of displacement (0.24 mm). Dimensions and the locations of restrains (arcs R2) and the push rot (R1,5) in the mathematical model are shown in Fig. 3.

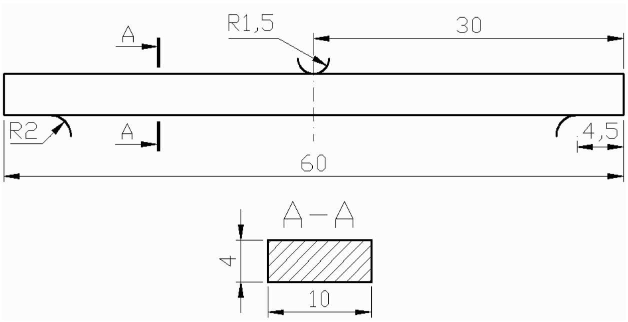

Fig. 3. The schema of the sample load

In simulation the stress, strain and displacement were examined in the range of the elastic strains phase for two extreme Young's modulus values: 3520 MPa and 4179 MPa and at the constant value of the Poisson's ratio υ = 0.4. The exemplary results of numerical calculations: reduced stress, strain and displacement for the parts made of PA 6.6 filled with glass fibre used in DMTA tests, at maximum push rot penetration (0.24 mm), obtained using ADINA System are presented in Figs. 4 - 7.

4. Conclusions

Examinations allowed determination of dynamical properties of PA 6.6 filled with the glass fibre.

Mechanical characteristics received as a result of the tests carried out under the static load, in room temperature are not sufficient for prediction of material behavior in given usage conditions and longer times. To fully characterize proprieties of examined composite and to

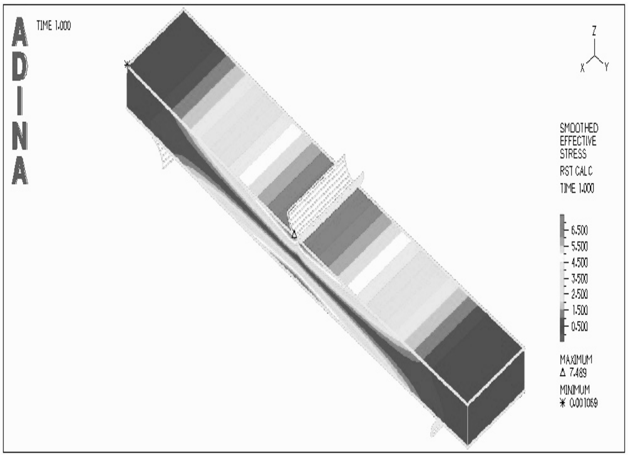

Fig. 4. The reduced stress distribution in sample for the Young's modulus E = 3520 MPa

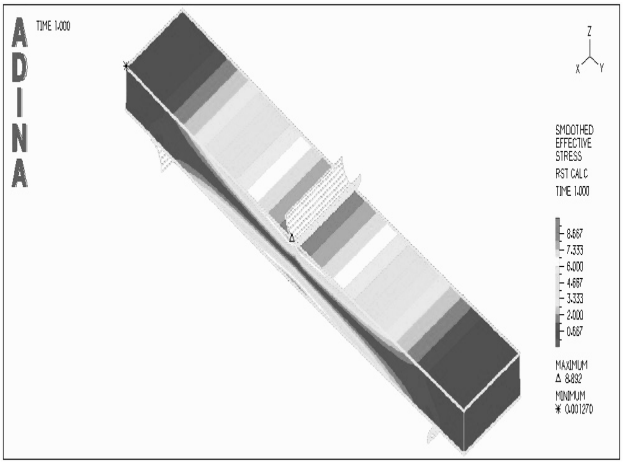

Fig. 5. The reduced stress distribution in sample for the Young's module E = 4179 MPa

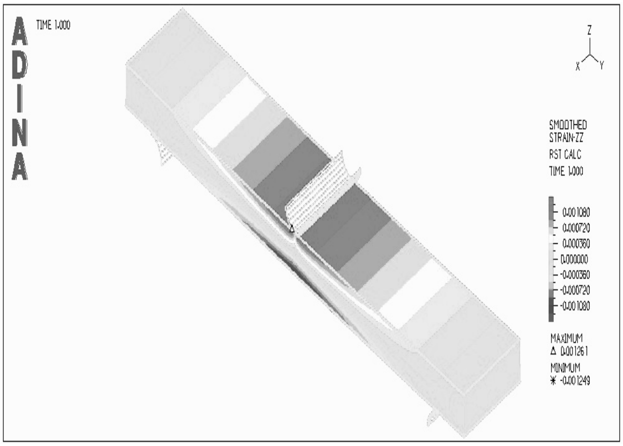

Fig. 6. The Z-axis strain distribution in sample, for the Young's modules E = 3520 MPa and E = 4179 MPa

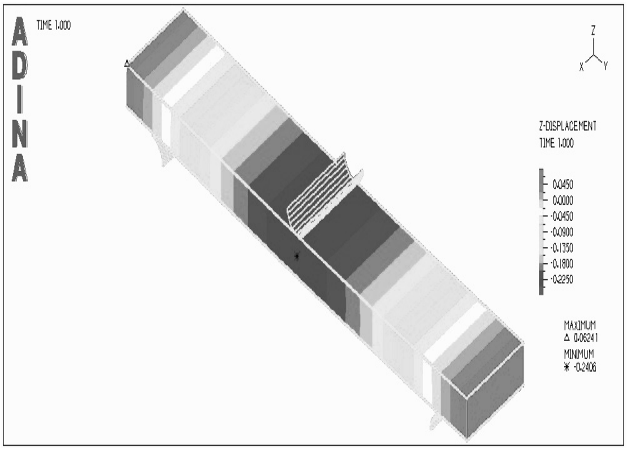

Fig. 7. The displacement distribution in sample for the Young's module E = 3520 MPa and E = 4179 MPa

estimate its behavior in conditions expected for this composite using, temperature dependence of the module and mechanical loss tangent were determined. Examined polymeric composite is characterized by viscoelastic proprieties, so all coefficients describing physicochemical properties depend significantly not only on time, but also temperature. The DMTA method takes into account these dependences.

Analyzing results of calculations the following conclusions can be formulate:

- in the phase of elastic strains at two extreme Young's modulus values not large changes in reduced stress values were obtained,
- strains and displacements in the whole range of the elastic phase are constants,
- using finite elements methodology it was not possible to indicate the Bielajew point, that is the area of the greatest effort of material, which is located under the sample surface in the contact area with the push rot; not sufficient accuracy of used approximate method is a reason of it.

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