Stress - State Modelling of Injection-molded Cylindrical Bosses Reinforced with Short Fibres

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Abstract: An investigation was carried out through a study of the influence of material anisotropy and geometrical parameters of the cylindrical bosses of plastic parts reinforced by short-fibres, on the state of stress. It has been shown that the result of such injection-moulded processes is an anisotropic product, whose mechanical behaviour differs considerably for that of classical types of isotropic solids. Unlike unreinforced plastics, fibre composites exhibit secondary stress phenomena and secondary properties in cases where composite parts are highly curved. These unusual effects of their mechanical properties thus need to be careful consideration in the course of designing a reinforced plastic parts.

Key-Words: Polymers, Modelling, Short Fibress, Anisotropy, Cylindrical Bosses

1 Introduction

Plastic composite parts reinforced by short-fibres are, with increasing frequency, being applied to cases where an emphasis is placed on the level of the utility characteristics value of finished products. However, the choice of short-fibre composites is not only accompanied by the indisputable advantages, but also by certain problems caused by alterations to the superstructure of the injection-moulded part. The outcome of the resultant distribution and orientation of such short-fibres is, generally speaking, an anisotropic and heterogeneous body whose mechanical behaviour may well be significantly different to that of a conventional understanding of the behaviour of isotropic and homogeneous bodies.A certain weak point from the perspective of a potential impairment is represented by type of thick cylindrical injection-moulded components. With isotropic and unreinforced plastic parts the reason lies in the geometric factor. Growing ratios of R/r are accompanied by growing stress components . For anisotropic and heterogeneous structures of injection molded walls the resultant stress state due to curving are further affected by physical factors [1].

2 Analytical solution of cylindrically orthotropic problem

Fig. 1 shows a basic case of a thick cylinder exposed to radial stress. From the analytic solution of the plane stress problem of cylindrical orthotropy of homogeneous case it follows that the mechanical behaviour of cylindrically orthotropic body is, apart from the geometric R/r parameter, also the functional parameter $\eta = E_L/E_T$; where E_L and E_T are modules of the elasticity of short-fibre structure in the longitudinal direction of short-fibre orientation (L) and the transversal direction (T)[2].

3 Idealised model structures of an injection-molded cylindrical part

During the moulding process, the fibres may become oriented in a complex manner. In the component itself, a charakteristic quasi-layered structure is frequently observed. The fibres are oriented in quite different ways according to their location through the thickness of the wall. The polymer melt viscosity and flow rate significantly alter the proportions of the oriented regions. Obviously, for cases of fast injection speeds, the core of the moulding contains fibres mainly aligned perpendicular to the flow direction. Above and below this are regions with the predominant fibre orientation in the flow direction and most of the fibres are lying in planes parallel with the reference plane of the wall.Selected types of idealised wall structures are shown in fig. 2. The wall is divided into three layers of identical thicknesses, with different orientation of short fibres 0°, 90° . Case A - in this case it is considered that the short-fibres in

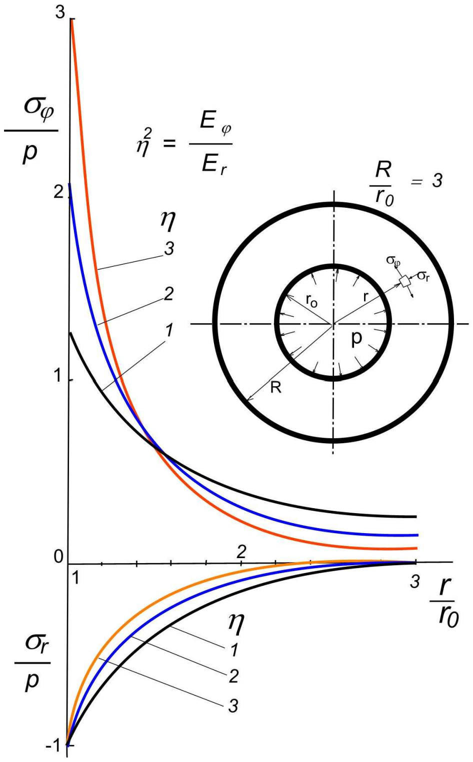

Fig. 1
Analytic solution of cylindrically symmetric problem of thick part loaded with inner pressure. Curvature ratio R / r_0 = 3

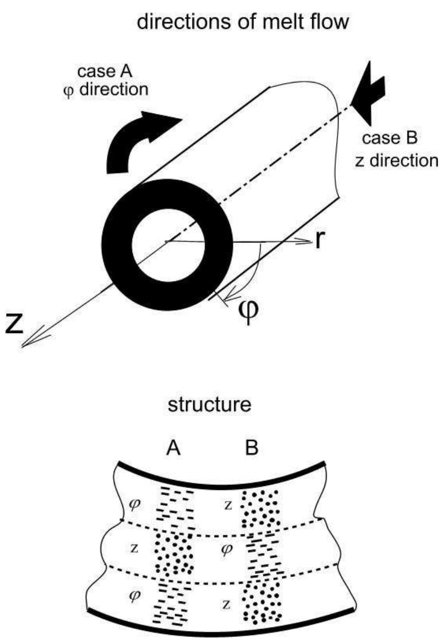

Fig. 2
Idealised model structures of an injection-molded cylindrical part

skin layers are totally oriented in the direction of the periphery. Vice versa, in case B the fibres in core are totally oriented in the axial direction. The direction of orientation of the short-fibres in a totally oriented structure gives the axis of a monotropic material in given area. The material characteristics in case of linear elasticity are given by the set of elastic constants, making up the appropriate matrix of compliance .

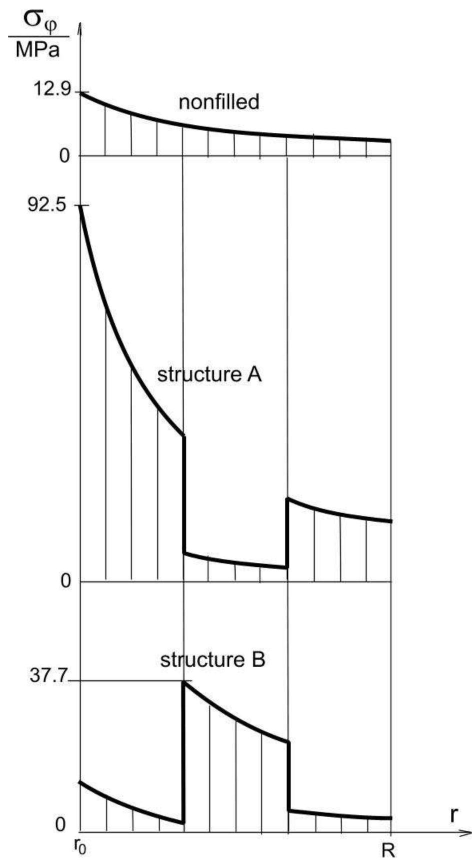

Fig. 3
Distribution of peripheral stress σ_φ for unreinforced and short-fibre reinforced injection-molded cylindrical boss. Curvature ratio R / r_0 = 2.5 , relative radial displacement δ / r_0 = 0,01 .

Making up the set of effective elastic constants of a 3D monotropic structure on the basis of experimental measurement is virtually impossible. For this reason, the theoretical prediction of these elastic constants is irreplaceable. We have already mentioned the outcomes of the modelling of the elastic behaviour of short-fibre plastic composites at the micro-mechanical level . Here, we used the results achieved to establish the macro-mechanical model of the cylindrical bosses of injection-molded part. For the purpose of studying the behaviour of highly orthotropic rounded plastic components,

following values of elastic constants were used for the stress -state analysis:
E_L = 10 560 MPa, E_T = 2340 MPa, ν_{LT} = 0.367, ν_{TT} = 0.576, G_{LT} = 1000 MPa .

4 Stress state of quasilayered thick cylinders under radial loading

In order to illustrate the role of the injection-molded structure in the thick rounded walls like cylindrical bosses , distributions of stress components of idealised structures of injection wall are compared with stresses of unreinforced polymer, i.e. of isotropic and homogeneous case.

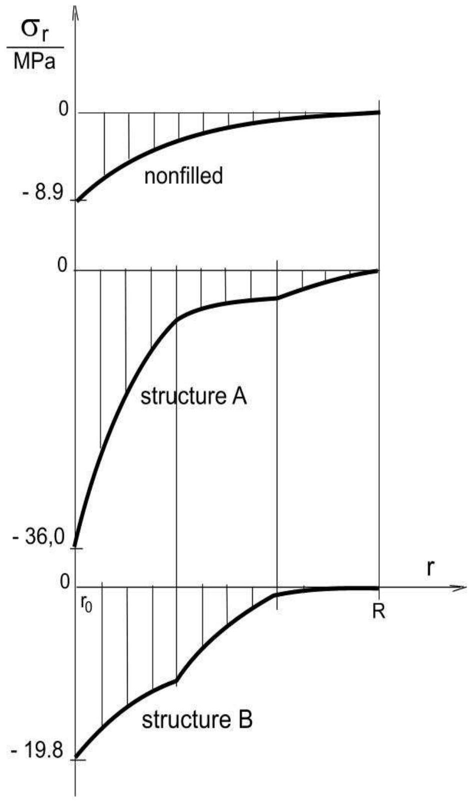

Fig. 4
Distribution of radial stress σ_r for unreinforced and short-fibre reinforced injection-molded cylindrical boss. Curvature ratio R / r_0 = 2.5 , relative radial displacement δ / r_0 = 0,01 .

The results are shown in the fig. 3, 4. Radial displacement of relative value $\delta / r_0 = 0{,}01$ is considered in the inner radius r_0. The values of the maximal peripheral and radial stresses are depicted for cases of structures A, B, and nonfilled that is isotropic and homogenous case.

As it follows from the obtained results, peripheral stresses σ_φ reach diverse values dependently on resultant short-fibre structure. These values considerably differ from isotropic and homogenous - nonreinforced case - Fig. 3.

In case of structure A, the core - transversal material direction T is strained slightly. However, extensive values of peripheral stress in material direction L imply significant disadvantage of this case. Vice versa, structure B shows low values of peripheral stress σ_φ in the direction L, but levels of stress in material direction T must be taken in account, because the transversal strength of fibrous structures is generally low, obviously at levels of unreinforced polymer .

Similarly, the values of the maximal radial stresses σ_r are shown in Fig. 4. As has been demonstrated, there is substantial difference in the values of radial stress . However, in both case A and B, stress components σ_r in r_0 fall into the material direction T and thus it is necessary to consider these values of stresses when considering the mechanical behaviour in view of the generally low levels for transverse strength of fibrous materials.

5 Conclusion

In both case A and B, stress state of short fibre structures substantially differs from a nonfilled case and thus it is necessary to consider these values of stresses when considering the mechanical behaviour of injection moulded parts .

The anisotropy and the heterogenity of mechanical properties caused by short-fibre orientation and distribution in melt flow can influence the macro-mechanical behaviour of injection molded parts. Therefore, it is necessary to pay attention to the design of products exposed to higher mechanical loadings. In such a way failures can be reduced at least.

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