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MODEL TO PREDICT SHRINKAGE AND EJECTION FORCES OF INJECTION MOULDED TUBULAR PARTS OF SHORT GLASS FIBER REINFORCED THERMOPLASTICS

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Summary *This work presents a model to predict shrinkage and ejection forces for glass fiber reinforced thermoplastics of tubular geometry. This mathematical model was based in Jansen's Model to predict shrinkage and residual stresses in fiber reinforced injection molded products and Pontes's Model to predict ejection forces for tubular parts of pure PP. The model used the modified classical laminate theory applied to injection moulding and it uses the fiber orientation state, temperature and pressure field as input and which predicts the shrinkage and ejection forces. The fiber orientation state was determined experimentally and the temperature and pressure fields were obtained by MOLDFLOW simulations. The model to predict ejection forces considers also the fiber orientation state, friction coefficient between steel and polymer, elastic modulus of polymer, both in the ejection temperature and diametrical shrinkage. The model is validated by experimental results.*

1 INTRODUCTION

Reinforced glass fiber polymers have a great application in several industrial areas. The designers have problems when need to design parts and tools that use this kind of materials due the anisotropic shrinkage, mainly in complex parts. The determination of ejection forces is important to design the optimized ejection systems in injection moulds.

Several models to predict shrinkage in fiber reinforced injection molded products were developed. A relevant study was realized by Jansen [1] that developed a model to predict the shrinkage and internal stresses for fiber reinforced injection molded products. After, Pontes [2] developed a model to predict shrinkage and ejection forces in injection molded tubular part.

2 ANALYTICAL MODEL

The unidirectional ply properties are calculated from those of the constituent materials.

The molded product will be considered as a laminate consisting of a finite number of plies with known fiber orientation. The average orientation of each ply determines the ply properties.

In this model was used the thermo-mechanical model to predict the shrinkage and ejection forces in injection moulded tubular parts, moulded over a cylindrical core.

The expression to obtain radial shrinkage that is the same radial deformation is

$$Sh_3 = \varepsilon_3(r,t) = -\sum_{i=1}^{2} Q_{i3}^{P}\,[\varepsilon_i - \alpha_i(T-T_s)] + \alpha_3(T-T_s) - \frac{\beta_3(P-P_s)}{\sum_{j=1}^{2} Q_{3j}\beta_j}\Big|_{t_{ss}}^{t_e} \qquad (1)$$

where the index $1=\theta$, $2=x$ *and* $3=r$, *Sh* shrinkage, ε deformation, Q is the stiffness matrix, divided by Q_{33} is Q^P, α coefficient of thermal expansion, T temperature and T_s solidification temperature of composite, β linear compressibility, P pressure and P_s solidification pressure, t_e ejection time and t_{ss} onset solidification time.

The material is considered orthotropic and transversely isotropic in 2-3 plane. In consequence of that $Q_{22}=Q_{33}$, $Q_{12}=Q_{13}$.

The coefficients of stiffness matrix are

$$Q_{13}^{P} = \frac{Q_{13}}{Q_{33}} = \frac{\nu_{13}+\nu_{12}\nu_{23}}{1-\nu_{12}\nu_{21}} \qquad Q_{23}^{P} = \frac{Q_{23}}{Q_{33}} = \frac{\nu_{23}+\nu_{21}\nu_{13}}{1-\nu_{12}\nu_{21}} \qquad (2)$$

and

$$Q_{11} = \frac{E_1}{1-\nu_{12}\nu_{21}} \qquad Q_{12} = Q_{21} = \frac{\nu_{21}E_1}{1-\nu_{12}\nu_{21}} \qquad Q_{22} = \frac{E_2}{1-\nu_{12}\nu_{21}} \qquad (3)$$

v is the Poisson ratio and E is the elastic modulus in different directions.

The ejection force is calculated by

$$F_e = 2\pi\mu e_{part}\left\{-\sum_{j=1}^{2} Q_{2j}\int_0^L\left[\sum_{j=1}^{2}\tilde{a}_{1j}\sum_{k=1}^{2}\overline{Q_{jk}\alpha_k(T-T_s)} + \sum_{j=1}^{2}\tilde{a}_{1j}\sum_{k=1}^{2}\overline{Q_{jk}\beta_k(P-P_s)}\right]dx + Q_{22}\int_0^L\left[\frac{H}{2R_m}Sh_3\right]dx\right\} \qquad (4)$$

μ is the friction coefficient between steel of mould and polymer in the ejection temperature, e_{part} part thickness, R_m is average radius.

3 CONCLUSIONS

The results of analytical model to predict shrinkage and ejection forces in tubular parts with short glass fiber reinforced thermoplastic agree with experimental results.

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