A method for predicting thermal conductivity in fiber-reinforced thermoplastic parts produced by injection molding

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Prediction of thermal conductivity in fiber-reinforced thermoplastics is made difficult from the flow-dependent, heterogeneous fiber orientation observed within the part. In the frame of this study, fiber orientation in injection molded parts is calculated using commercial fluid dynamic simulation software. Simulation results are compared with metallographic images to confirm prediction accuracy. Later, numerically obtained fiber orientation is used in a new method to predict thermal conductivity of the part. Comparison of the predicted thermal conductivity with experimental data showed a good agreement.

Keywords: thermal conductivity, fiber-reinforced materials, injection molding

1. Introduction

Fiber-reinforced thermoplastics are widely used as case materials to cover electronic appliances. Their use in such applications is justified by the increase in mechanical and thermal properties brought by the addition of fillers such as carbon or glass fiber etc. to the thermoplastic base material. Injection molding is a common process widely used in electronic industry to manufacture plastic-made parts.

When fiber-reinforced materials are used within injection molding machine a heterogeneous fiber orientation will result in the manufactured part. This heterogeneity will lead to location-dependent mechanical and thermal properties and, if model predicting local properties are not used, design accuracy may be reduced.

Fiber orientation in injection molded parts can be predicted using commercial numerical software computing plastic flow pattern inside the mold cavity. If fiber orientation is known, thermal conductivity can be computed using existing theoretical models 1).

In the past, several studies 2)3) used those models to predict thermal conductivity, but, in most of the cases, experimentally obtained fiber orientation was used.

In this study a fully numerical method for the prediction of thermal conductivity in injection molded parts will be presented and obtained results will be compared with experimental measurements.

2. Experimental

Square plate samples with an edge length of 100 mm and a thickness of 2 mm were produced using an injection molding machine. Glass fiber (with an average length of 200 µm and 11µm in diameter) has been used as filler material with a 50% weight fraction. Polyamide (PA) was used as matrix material.

Metallographic images were taken along the thickness in the central part of the sample and, to experimentally measure fiber orientation, an image processing method was implemented.

From the 100 mm square plate sample, smaller subsamples (edge length 10 mm) have been cut in different positions (see Fig 1.).

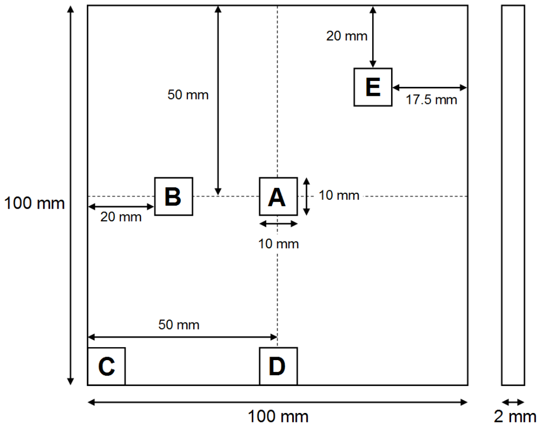

Fig. 1 Selected regions for subsamples

For each subsample thermal conductivity along the thickness has been obtained by measuring thermal diffusivity (α), density (ρ) and heat capacity (c_p), related by the following equation:

$$K_{composite} = \alpha \; c_p \; \rho \qquad (1)$$

Thermal conductivity of glass fiber and polyamide

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matrix were, respectively, 1.000 and 0.271 W m^{-1} K^{-1}.

3. Numerical simulation

Fiber orientation in the injection molded square plate has been computed by using commercial fluid dynamic software. Later, using the dimensions given in Fig. 1, computational model used for simulation has been divided into the region corresponding to subsamples A-E.

In each region cumulative fiber orientation distribution in the thickness direction was computed using fiber orientation data contained in each computational cell (Fig 2.).

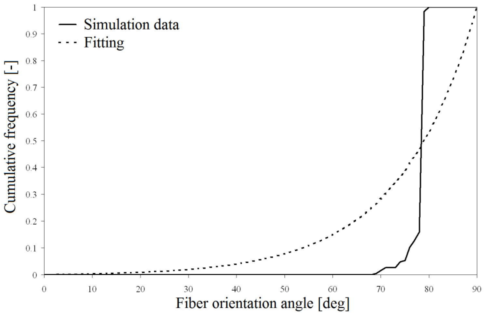

Fig. 2 Cumulative fiber orientation distribution

Cumulative fiber orientation distribution obtained from simulation was fitted with the theoretical model given as[3)]:

$$G(\theta)=\frac{1-e^{-b\theta}}{1-e^{-b\pi/2}} \qquad (2)$$

and fitting parameter *b* was subsequently obtained. This fitting parameter was later used to compute thermal conductivity in the thickness direction using following equation[3)]:

$$K_{composite}=\tfrac{1}{2}(K_1+K_2)+\tfrac{1}{2}V(K_1-K_2) \qquad (3)$$

where *V*, K_1 and K_2 are given by:

$$V=\frac{b^2(1+e^{-b\pi/2})}{(b^2+4)\,(1-e^{-b\pi/2})} \qquad (4)$$

$$K_1=\frac{1+2\cdot a\cdot\mu_1\cdot V_f}{1-\mu_1\cdot V_f}K_m \qquad K_2=\frac{1+0.5\cdot\mu_2\cdot V_f}{1-\mu_2\cdot V_f}K_m \qquad (5)$$

with V_f being the filler (volume) fraction, K_m the matrix thermal conductivity and μ_1 and μ_2 are material dependent parameters given by:

$$\mu_1=\frac{(K_{f1}/K_m)-1}{(K_{f1}/K_m)+2\cdot a} \qquad \mu_2=\frac{(K_{f2}/K_m)-1}{(K_{f2}/K_m)+0.5} \qquad (6)$$

with K_{f1}, K_{f2} being the fiber parallel and perpendicular thermal conductivity, and *a* the fiber aspect ratio.

4. Results and discussion

Comparison of experimentally observed fiber orientation with numerical data is shown in Fig. 3.

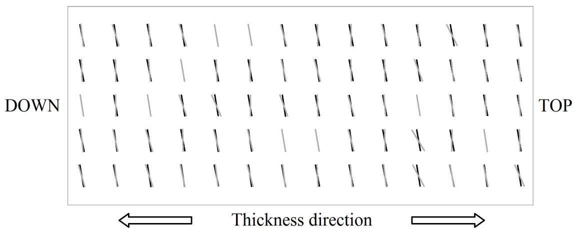

Fig. 3 Comparison between numerically obtained fiber orientation (black) and experimental data (gray)

In general a good agreement was found between experimental and numerical fiber orientation, confirming numerical simulation a successful method for predicting fiber orientation.

Predicted and measured thermal conductivity in each location (A-E) is given in Table 1.

Table 1 Comparison between predicted and experimental thermal conductivity

[W m^{-1} K^{-1}]	A	B	C	D	E
Experiment	0.390	0.371	0.406	0.424	0.397
Prediction	0.393	0.394	0.404	0.400	0.394

In general good agreement is found between experimental data and numerical prediction.

5. Conclusions

In this study, a fully numerical method for predicting thermal conductivity in injection molded parts was presented. Fiber orientation obtained by commercial software showed good agreement with experimental metallographic images. The use of thermal conductivity theoretical model applied on fiber orientation data obtained from simulation showed good agreement with experimental data.

References

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