A Dual Stage Model of Anomalous Moisture Diffusion and Desorption in Epoxy Mold Compounds

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Abstract

Absorption and desorption tests were conducted on five distinct commercial epoxy mold compounds (EMCs) used in electronic packaging. For absorption, the samples were subjected to 85°C /85% relative humidity and 60°C /85% relative humidity soaking. Desorption conditions were above glass transition temperature at 140°C and 160°C. A dual stage model is developed in this paper for both absorption andu

materials [10]. The Fickian behavior is superpositioned

where, and are the diffusivity and initial moisture content for Fickian diffusion. is equal to , and is the diffusivity of the non-Fickian behavior. Given the fact that the sample will never lose all the moisture gained by absorption at certain temperature due to the irreversible processes, is taken to be zero in Equation (18). As a result, the second stage term in Equation (18) becomes , representing the amount of residual moisture in the sample after it has reached equilibrium. Fig. 3 visually displays this idea. Equation (18) becomes:

Fig. 4: Fickian absorption fit of Compound A at 85°C /85% RH

Fig: 5: Fickian desorption fit of Compound A at 140°C

5. Dual-Stage Absorption

5.1 Dual-stage Fit

The dual stage model proposed by Equation (16) was developed with the least square-method solving for values of and and and simultaneously. This generated excellent fits for all samples for conditions at 85°C /85% RH and 60°C /85% RH as shown in Fig. 6 and Fig. 7, respectively. Given the fact that the saturated Fickian moisture concentration is independent of temperature, Table 3 summarize the results of the dual stage fits with "forced" same values of , which were obtained by the average at two different temperatures for each compound. The values of , , and were then solved simultaneously with Equation (20). This procedure still generated excellent curve fits that are almost indistinguishable from Fig. 6 and Fig. 7. From Table 3, it can be seen that the diffusivity of the second stage is two orders lower than the first stage at 85°C /85% RH. At 60°C /85% RH, the difference in and is less, but it is still greater than one order. This indicates that the relaxation process is very slow in the beginning of absorption. The diffusivity at both stages increases with temperature as expected. In addition, is always comparable, or greater than , meaning that the non-Fickian behavior plays a major role in moisture uptake.

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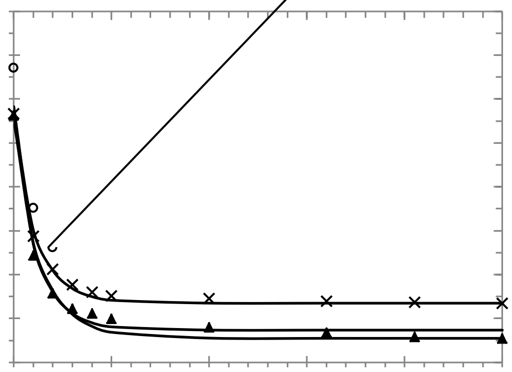

Fig: 10: Dual Stage fit of desorption at 140°C

Fig: 11: Dual Stage fit of desorption at 160°C

6.2 Desorption Thickness Effects

For Compound E with two thicknesses, the initial diffusivities, and , were fitted with Equation (19). Then the averaged values for two thicknesses were forced back into Equation (19) to solve the residual moisture content . The results are displayed in Table 6, and the fitted curves are plotted in Fig. 12 and Fig. 13 for two temperatures, respectively. These two fitted curves are essentially parallel each other with a small shift due to the difference in initial moisture content. This indicates that the dual-stage desorption model of Equation (19) is independent of sample thickness. The variations in Figs. 12 and 13 are more likely due to the lower accuracy of the test more than the desorption mechanisms. All data shows the thickness seemed to matter very little in the final residual moisture percentage.

Table 6: Desorption model parameters for Compound E

Thickness	D (mm^2/hr)		$C_{0,1}/C_0$ (%)		$C_{0,2}/C_0$ (%)	
	140°C	160°C	140°C	160°C	140°C	160°C
3 mm	1.69E-01	2.21E-01	72.4	90.0	27.6	10.0
1.4 mm	1.69E-01	2.21E-01	72.4	90.0	27.6	10.0

Fig: 12: „Modified" Fickian fit of Compound E at 140°C

Fig: 13: „Modified" Fickian fit of Compound E at 160°C

7. Concluding Remarks

Several epoxy mold compounds in absorption and desorption were studied. When the Fickian model produced insufficient results, the anomalous moisture uptake was described with a dual stage model using two Fickian models superpositioned. This idea was extended to the desorption process to account for residual moisture content. These models can describe both Fickian and non-Fickian behavior with Fickian parameters. They can be used to compare the two different mechanisms and produce consistent, fairly accurate results that correlate well with the actual physical processes. The models produced good curve-fits with the experimental data for all five samples. For absorption, non-Fickian behavior was proven to be a great influence on the amount moisture uptake though Fickian diffusion rates were quite larger. Thickness also has a significant role in absorption, indicating the role of anomalous uptake. Relaxation appeared more readily in thinner samples of the same compound which slowed the diffusion rate. In desorption, thickness of the samples does not have nearly as much influence on the amount of residual moisture as the temperature. Residual moisture content decreases significantly as temperature rises. Not only was the desorption model able to generate better curve fits to the data, but it was also able to predict the proper residual moisture content.

For anomalous moisture diffusion, there has been a lack of simulation tools to model the diffusion process in actual packaging systems. In this paper, a dual-stage model is developed to describe both Fickian and non-Fickian diffusions using two sets of Fickian parameters. This work provides a theoretical foundation with experimental validation for a feasible finite element model of anomalous moisture diffusion using currently available finite element software. The results will be reported separately in the future.

Acknowledgement

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