Non-Isothermal Curing Kinetics of EVA, POE, and EPE Encapsulants for PV Applications

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This work presents a method to determine the non-isothermal curing kinetics of peroxide-crosslinking ethylene vinyl acetate copolymer (EVA), polyolefin elastomer (POE) and coextruded multilayer EVA/POE/EVA (EPE) encapsulants. The curing kinetics were derived from dynamic mechanical analysis (DMA) in plate-plate configuration under isothermal conditions, following ICTAC recommendations [1]. DMA was performed from 125 to 150°C for EVA and POE, and from 140 to 160°C for EPE due to its higher curing onset. Measurements were performed in 5°C increments. Conversion curves were obtained from viscosity changes, and curing rates by numerical differentiation (s. Fig. 1, left). The kinetics were modelled using a temperature dependent Arrhenius rate coefficient (s. Fig. 1, middle) and a rate model based on a form of the Sestak-Berggren equation (s. Fig. 1, right). To evaluate the accuracy of the model, the initial isothermal DMA data was fitted and a non-isothermal validation routine was performed. The curing model showed a very high accuracy under both conditions. Using an integration-by-summation approach, the non-isothermal curing process can be calculated by solely tracking temperature (Eq. 1).
All encapsulants followed a similar reaction model, with peak curing rates near 30% conversion. While activation energies were comparable, pre-exponential factors varied notably. EVA cured fastest, POE slowest and EPE was intermediate. Additionally, the model was further applied to predict the crosslinking homogeneity in mini PV modules. Therefore, temperature was monitored at seven positions during vacuum lamination. The fastest crosslinking was observed at the bottom glass, which was in direct contact with the heated plate of the laminator. Interestingly, the slowest conversion was observed in the module center and not at the topside glass. Presumably, this was related to the heat flux through the silicone membrane.

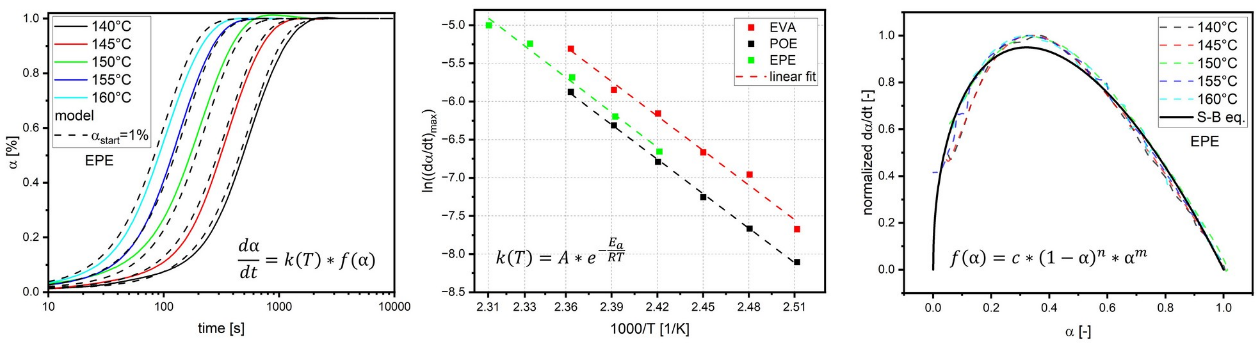

Fig. 1: **Conversion curves at and model fit at different temperatures (left), Fit of the Arrhenius rate model for EVA, POE and EPE (middle) and the fitted reaction model (right)**

$$\alpha_n = \alpha_0 + \sum_{k=1}^{n} \dot{\alpha}\,(T_k, \alpha_{k-1}) * \Delta t_k \qquad (1)$$

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References
[1] S. Vyazovkin, A.K. Burnham, L. Favergeon, N. Koga, E. Moukhina, L.A. Pérez-Maqueda, N. Sbirrazzuoli, ICTAC Kinetics Committee recommendations for analysis of multi-step kinetics. Thermochimica Acta **2020**, 689, 178597