Residual Stresses in Thick Paste Adhesive Bondlines

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Bondline failure is a key critical failure mode in wind turbine blades. Substantial variation in bondline thickness can result in different thermal histories for the adhesive layer due to the exothermic curing of common adhesives. Predictive guidance regarding the impact of this variability in adhesive cure temperature cycles is extremely limited. Without guidelines of acceptable variability, excess resources may be placed into avoiding damage by processing at excessively low temperatures and longer processing cycles, which produce no discernible benefits. This project focuses on the characterization of adhesive bonded joints as a function of the curing temperature and adhesive thickness. In order to take into account the thickness influence, a series of experiments are conducted in a bonded joint configuration. Two sets of specimens for each thickness (10/20/30 mm) have been manufactured using recommended cure cycles and an elevated temperature cure cycle. A series of tensile tests is performed on the joint specimens to determine the mechanical properties and the thickness-temperature influence on the bonded joint performance. Moreover, due to the exothermic nature of the cure of most adhesives, thicker regions result in elevated temperatures during curing which can lead to higher residual stresses in the bondline. Little research has been conducted to characterize the effect of temperatures and exothermic reaction levels on adhesive quality for thick joints. Additionally, the effect of bondline thickness on curing temperatures is also poorly understood, and predictive capabilities in this field are presently unavailable. Therefore, a finite element model capable of tracing the thermal, conversion and residual stress histories in thick adhesive bondlines is presented. The cure kinetics of the bonding paste has been successfully characterized using non-isothermal DSC analysis and validated with temperature readings from the curing process of an adhesive bead of variable thickness from 5mm to 30mm. Residual stress predictions were compared with experimental results from tensile test on bonded specimens. Finally, cure cycle optimization strategies for a representative section of a wind turbine blade were proposed using active heating and active cooling and compared with a baseline cure cycle.

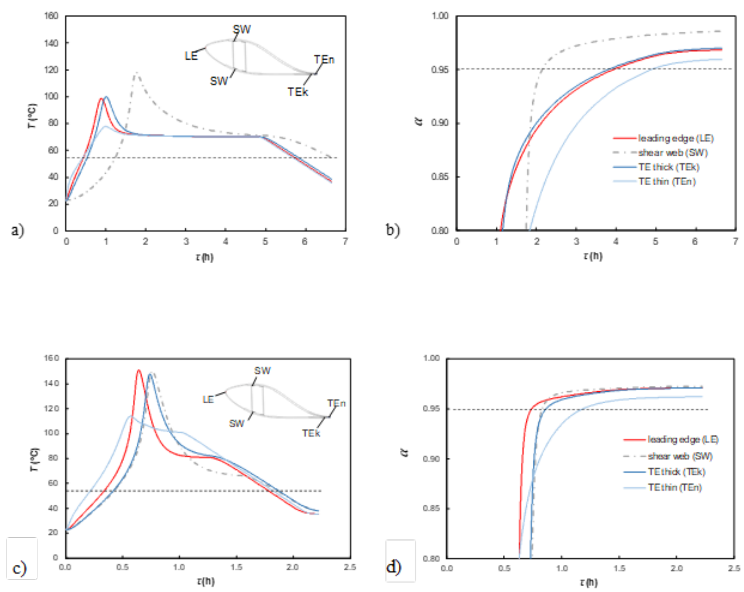

Figure 1. Simulated curing cycles for the baseline model: a) Adhesive temperature vs time b) Degree of cure α vs. time and Improved Spar Cap Heating: c) Adhesive temperature vs. time d) Degree of cure α vs. time.

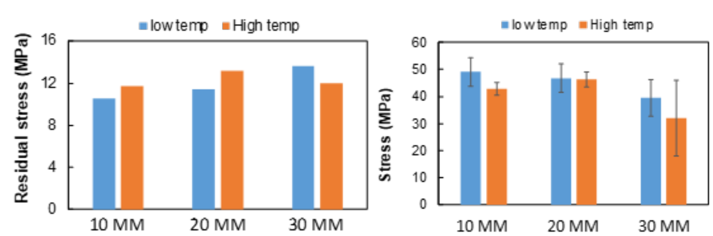

Figure 2. Comparison of a) residual stresses predicted by FE model and b) stress to failure from tensile testing on thick adhesive bondlines (10, 20 and 30 mm).

PROJECT ID: A4-18