WindSTAR
Wind-Energy Science, Technology, and Research
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Cure Cycle Optimization of Wind Turbine Blades Adhesive Bondlines

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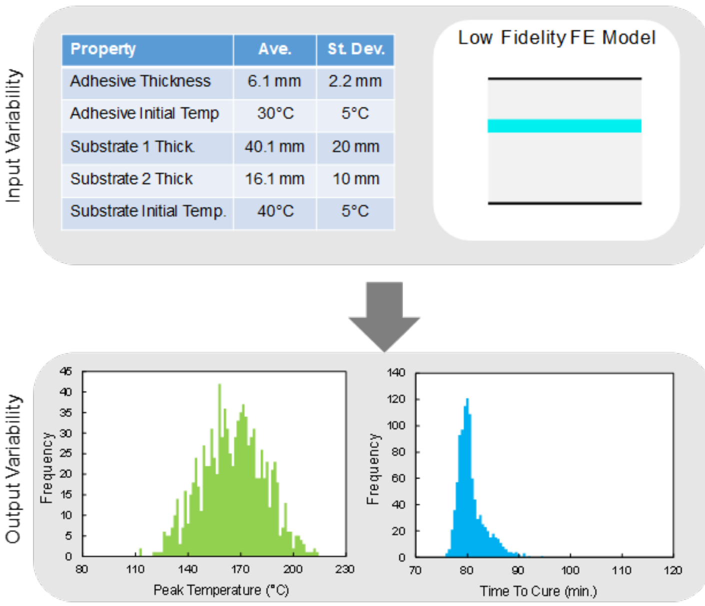
Adhesive bondlines in wind turbine blades are crucial to maintaining the operation and safety of wind farms. Therefore, manufacturers are very careful to ensure that bonds are fully cured and as pristine as possible during manufacturing. To ensure the quality of bonds, conservative approaches to bondline curing are taken to ensure the bondlines are fully cured and do not reach high temperatures during cure. However, bonding of blades can be a manufacturing bottleneck, tying up molds and space in factories while waiting for cure. Since manufacturing time is directly related to the cost of production, manufacturers would like to reduce this curing time as much as possible. To reduce the cure time, heaters are utilized to speed up cure, but they must be careful not to cause the highly exothermic reaction of thick adhesives to carry temperatures into ranges where heat damage may occur. Therefore, manufacturers are have two competing goals: a conservative cure and a quick cure.

To help find the balance between these goals and achieve a cure that is optimized for speed but avoids excessively high temperatures, cure kinetics simulations have been developed. Past work has been done to characterize materials and show the accuracy of such models by comparing with laboratory experiments. While this is a good first step, the shop floor of manufacturing facilities contains many unknowns, and comparisons with highly controlled experiments may not be sufficient to predict actual curing of wind turbine blade bondlines. Therefore, in this project, the model was "taken to the shop floor". Researchers traveled to manufacturing facilities and took measurements about different uncertainties found on the shop floor. Small, instrumented experiments were conducted within wind turbine blades using shop-floor conditions and materials and compared with models. Furthermore, a low-fidelity finite element model was created and a study was made to see how all of the uncertainties in geometric and environmental conditions propagate out and influence the time to cure and the peak temperature. Using this approach, manufacturers can input their uncertainties for a certain material system and cure cycle and ensure that it not only the "nominal" cure will stay within acceptable temperatures, but can give probabilities of proper temperatures and full cure using output statistics.



Property	Ave.	St. Dev.
Adhesive Thickness	6.1 mm	2.2 mm
Adhesive Initial Temp	30°C	5°C
Substrate 1 Thick.	40.1 mm	20 mm
Substrate 2 Thick	16.1 mm	10 mm
Substrate Initial Temp.	40°C	5°C

Figure 1: A low fidelity finite element model with cure kinetics was created, and a random selection of substrate and adhesive temperatures and thicknesses within a normal distribution were selected and virtually cured to get a distribution of outputs such as time to cure and peak temperature.