Structural Wind Blade Repair Optimization

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Wind turbine blades can undergo in-service damage including lightning strikes, impact and erosion. Depending on the extent of the damage, the repair process can take more than 24 hours to be performed resulting in long and costly turbine downtime. Environmental conditions, such as temperature and humidity, play a key role in the repair process as they could affect the cure kinetics of the resin, affect the adhesion capability of the substrate and degrade composites mechanical performance. Time- and cost-effective repair procedures are fundamental to reduce the turbine downtime and successfully restore the aerodynamic efficiency and structural integrity of the blade. The state-of-the-art curing cycle for repair is not fully optimized which adds to the turbine downtime. The repair process is highly variable, and it depends on several requirements.

The goal of this study is to determine the shortest cure cycle to perform structural repairs understanding the effect of various curing cycle parameters such as, heating rate, hold temperature, hold time and cooling rate for each given configuration. This study will also provide information on the optimum environmental conditions to perform repairs efficiently. First, the cure kinetic of a baseline infusion resin system is determined accounting for different humidity levels and external temperatures. The moisture absorbed by the resin and the curing agent under various environmental conditions and their effect on the curing behavior are investigated performing Differential Scanning Calorimetry (DSC). Then, the repair geometry is modeled within the Finite Element software Abaqus to predict the cure evolution and temperature distribution during repair (See Figure 1). An optimization study for the proposed FE model is performed where all the cure cycle parameters are varied, one at a time, to analyze their effect on degree of cure and temperature distribution within the part (see Figure 2). The optimization study is performed implementing Python scripts. The optimized cure cycle is determined as a result of the FE simulations which account eventual constrains based on the manufacturer's recommendation. Lastly, to learn the state-of-the art of complex repair procedures pristine laminate panels are damaged and repaired in collaboration with TPI Composites. More repairs will be performed in the lab at UML to assess the quality of the part cured using the temperature cycle from the optimization study. Next, specimens will be cut from repaired panels and tested under various loading conditions to compare their strength with that of pristine specimens.

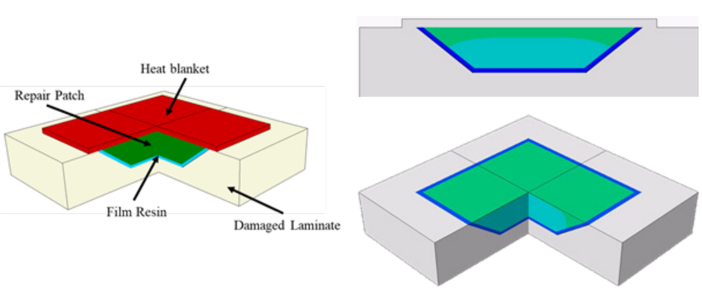

Figure 1: FE modeling of single side scarf geometry to predict degree of cure and temperature (different colors represent different temperatures within the patch and the adhesive).

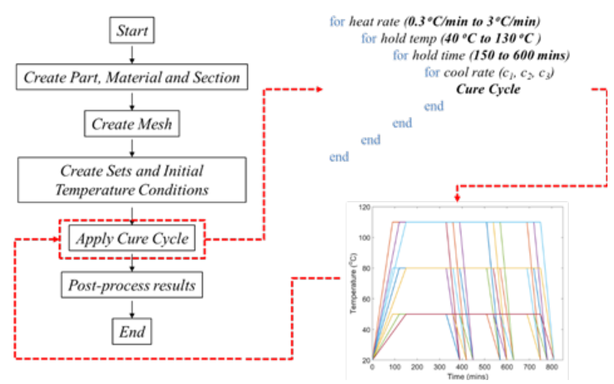

Figure 2: Flowchart showing the automated model generation, pre-processing and post-processing procedure developed in Abaqus, Python and MATLAB.

Reducing the blade downtime, while restoring the structural integrity and aerodynamic efficiency means longer blade life, higher revenues and lower cost of energy. This study benefits owners and operators as well as repair & manufacturing and resin companies. High fidelity FE modeling will provide guidelines to define optimized repair processes under various environmental conditions. Results from this project will be used to establish better practices for specific kinds of repairs. Additionally, this study is setting the basis for an onsite tool that can be used to provide the shortest cure cycle to evenly cured laminates for specific repair configurations.

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