Using COMSOL to Estimate the Heat Losses of Composite Panels Undergoing Repairs Using Bayesian Inference

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Abstract

A method for repairing composite panels involves inserting a patch into a kerfed opening with a resin interface, then heating the patch such that the resin causes the patch to bond to the undamaged structure. The amount of heat must be controlled; if it is insufficient the patch will not correctly bond, if it is excessive the material will be damaged. The heat can be applied by an infrared source or a heating blanket, but the heat applied to the bond is reduced by losses from both the heated and unheated surfaces of the composite. In the former case, estimating the heat loss is difficult because it is a function of emissivity, surface temperature, and the surrounding conditions. In the latter case, the insulating properties of the blanket are temperature dependent. In both cases, there will be heat loss from the backside of the patch and possibly conduction laterally through the patch to a region of the undamaged material that loses heat easily to a supporting structure. Estimating these heat losses is critical to determining the correct amount of heat to be supplied to the patch. The paper describes the use of COMSOL to estimate the heat losses based upon measured temperatures. Since the backside thermal conditions are not known, measured surface temperatures using both thermocouples and infrared thermography are used as the input to an inverse solution from which the losses can be determined. The method as usually employed is based upon the model sensitivities (S) to each of the parameters being sought. For complex models simulated by partial differential equation, these sensitivities are usually determined by finite differencing the model responses using S=(R(p+dp)-R(p))/dp, where R is the model response and p is the parameter value. Choosing a large value of dp can give erroneous values, particularly when the heating is discontinuous in time, but choosing too small a value leads to imprecision because of numerical noise. By using the PDE features of COMSOL we are able to solve directly for S, eliminating the errors due to finite differencing. The sensitivities are then used in conjunction with Bayesian Inference to compute the maximum a posterior probable values of the heat flux along with estimates of the confidence intervals. The Bayesian approach involves integration over a range of parameter values and thus requires significant computer resources since the sensitivities (S) must be evaluated for a range of values of p. The ability to compute S accurately and with minimal expense is critical to this approach in determining correct estimates of the confidence intervals associated with the different parameters and thus of the adequacy of the repair. This is particularly true for the composite repair because the properties, e.g., the thermal conductivity, density, and thermal specific heat, are temperature dependent. Figure 1 illustrates the smooth nature of S derived from the PDE capability of COMSOL as compared to Figure 2 where the sensitivity is normalized to highlight the effect of

finite differencing.

Figures used in the abstract

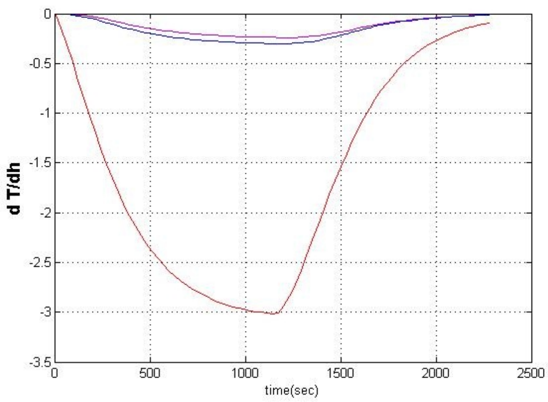

Figure 1: S based on solving the PDE.

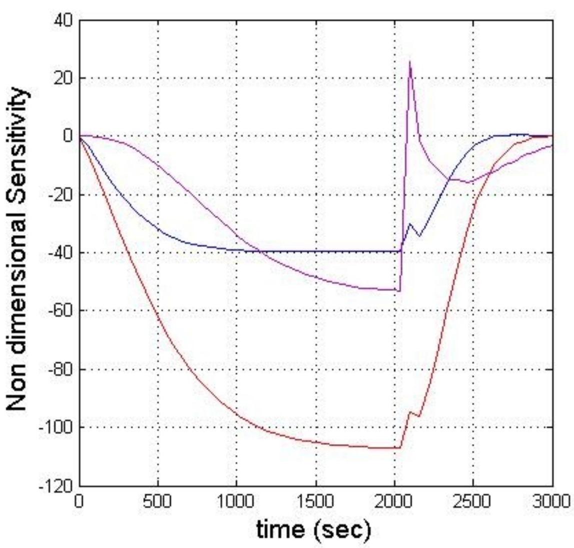

Figure 2: S based on finite differencing.