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Estimation of kinetic parameters of composite materials during the cure process by using wavelet transform and mollification method ☆

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ABSTRACT

In some inverse problem, the convergence of the inverse algorithm is impossible due to the correlation of the involving parameters. Several different approaches have been used to address this problem. This paper proposes a procedure to smooth the temperature data by wavelet transform and mollification method prior to utilizing the Levenberg–Marquart method. Comparison of the two filtering methods shows that a comparable improvement in performance can be achieved specially using the mollification method. In order to examine this technique, a highly ill-posed problem was considered as a test case; that is the estimation of the composite kinetic parameters during the cure process.

1. Introduction

Inverse heat conduction problems are mathematically ill-posed; being highly sensitive to random errors (noise) that inherently exist in measured temperature data. In order to alleviate this problem regularization techniques are utilized [1]. Mulcahy et al. [2] used the steepest descent method in order to determine the waste heat flux from a helicon plasma discharge using transient surface temperature measurements obtained from infrared thermo graphy. Chen et al. [3] proposed an on-line inverse method based on the input estimation method combined with the finite element scheme to inversely estimate the unknown heat flux on the nozzle throat-insert inner contour and the inner wall temperature by applying the temperature measurements of the nozzle throat-insert. Su et al. [4] used inverse process method combined with gray prediction model to estimate the inner surface geometry of a cylindrical furnace wall. Fieberg et al. [5] used the inverse method for the calculation of thermal contact resistance in combustion engine that is based on the analytical solution for a semi-infinite body and a step response to a Neumann boundary condition. This method provides an algorithm that is used in a sequential manner. Inverse methods are commonly used for thermo physical parameter estimation problems. Beck [6] estimated the thermal conductivity simultaneously with the volumetric heat capacity of nickel from one-dimensional transient temperature measurements. Scott and Beck [7] estimated these thermal properties for carbon/epoxy composites as function of temperature and fiber orientation. They also developed a methodology for the estimation of these two properties in the same composite materials during curing [8]. The researches done by Jurkowski et al. [9] and Garnier et al. [10] showed that small sensitivity coefficients or the unbalance of the sensitivity matrix results in the instability of the estimation procedure. This particular remark goes along with the fact that both the Gauss and modified Box–Kanemasu methods [11] have been found to show that resulting instabilities cause the divergence of the method when used with models that contain correlated or nearly correlated thermal properties.

Several different approaches have been used to address this problem. One approach is to modify the experimental design. For example, Loh and Beck [12] were able to simultaneously estimate both thermal conductivities and the volumetric heat capacity of an anisotropic carbon/epoxy composite through the use of nine thermocouples embedded at various locations within the sample. Correlation may still have been present but the use of multiple sensors alleviated the problem. Nevertheless, modifications of the experimental design, such as the use of internal sensors, are not always feasible, especially when nondestructive testing is required. In addition, the use of embedded thermocouples can be a source of important bias. Another approach is applying regularization methods, which can be employed in two ways. Although the regularization methods introduce a bias into the estimation but significantly stabilize the solution. One type of regularization known as the "Tikhonov Regularization" adds a penalty term to the objective function. Additional comments on this type of regularization can be found in chapter 2 of the book by Woodbury [13]. The Levenberg–Marquardt (LM) method regularizes the Gauss method applying this procedure. The iterative regularization is another type of regularization method. The main idea in iterative regularization method is to stop the

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