Analysis of a Thermomechanically Coupled Forming Process Using Enhanced Design and Analysis of Computer Experiments

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Keywords

Kriging, Design and Analysis of Computer Experiments (DACE), non-stationary covariance, functionally graded material, Finite-Element (FE) simulation, thermomechanical coupling

Abstract

A differential thermal process control provides the possibility of establishing different functional zones within a workpiece made of a single material. The localised induction of heat within the mechanical forming process, also denoted as thermomechanical coupling, allows the reduction of additional process steps without losing flexibility in the design of the product. In contrast to composite materials, the resulting workpieces are economical and easy to recycle. Thus, this technology offers a novel potential for an innovative production.

Nevertheless, comprehensive knowledge about the process, which is crucial for an appropriate adjustment, can only be achieved by combining extensive experimental investigations and powerful statistical methods with a detailed thermomechanically coupled numerical simulation of the process. Thus, both measurements obtained from real-world experiments as well as the output of a finite-element simulation of the process variables are modelled using *Design and Analysis of Computer Experiments* (DACE). The resulting models assist in understanding the process by allowing the calculation of response surfaces, which describe the effect of the modelled parameters as well as their interactions.

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In this paper, a thermomechanically coupled process consisting of an inductive heating, an automated workpiece transfer and positioning, and a forming step with integrated cooling is analysed. The workpiece, a shaft with a flange, is made of CrV-alloyed steel (51CrV4). The process-integrated introduction of different functional zones in the workpiece necessitates the consideration of the measured properties, such as temperature, stress, strain, and hardness, over the whole workpiece geometry and over the whole duration of the process. The resulting dimension of the modelled parameter space leads to two problems. While the density of sampling points is relatively low for the experimentally obtained results, the finite-element simulation provides a higher number of samples than the number that can be included in the model calculation. Thus, point-selection techniques are proposed in order to find a meaningful subset of the whole sample for this case.

The obtained models are also to be used to optimize the process with respect to defined functional requirements of the workpiece. Therefore, a statistical validation of the models is performed. Specific problems, which are observed in the validation, are identified and enhancements to overcome these problems are proposed. In particular, the assumptions of deterministic output and stationary covariance made in the traditional DACE do not hold for all modelled process variables.

Finally, the predictions of the resulting empirical models are compared to the ones of the finite-element simulation. Thereby, differences between the results of the experiments and the ones of the simulation can be detected. These differences can occur due to a not completely adequate simulation model, but also indicate inaccuracies of the empirical models due to a low sampling density. Thus, the consideration of these differences provides a method to determine parameter vectors for additional real-world experiments.