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Influence of thermal boundary conditions on the parameter identification in thermodynamics

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Finite-Element based identification schemes, such as the FEMU-method, are a powerful tool for the (quantitative) adjustment of material models to an observed material behaviour. A relative sparingly explored segment of this field, however, is the identification of thermal material parameters based on full field temperature measurements. Hence, the focus of this contribution lies on the influence of thermal boundary conditions on the result of such an identification. More precisely, the impact of the convection and conduction coefficient is analysed by simply performing several identifications, each with different values prescribed. Results suggest that some parameters are indeed very sensitive to the choice of coefficients.

1 Introduction

The FEMU-method has already thoroughly been tested for mechanical material models and requires the definition of an associated boundary value problem. This is often intuitively done for purely mechanical models, but a thermal coupling requires the definition of thermal boundary conditions also. The latter are quite often of the Robin-type and therefore necessitate the use of a convection or conduction coefficient. Those coefficients, however, are in general unknown for a specific boundary value problem, since they depend on variables like geometry, material, surface, temperature and many more. In a first step, physically sensible values for the convection and the conduction coefficient are assumed, enabling an identification of the mechanical and thermal material parameters based on full field displacement and temperature field measurements. The obtained material parameters lead to a very good match of the experimental data and are presented in Section 2. In this work and as a second step, the sensitivity of the solution w.r.t. the assumed values is analysed to get an impression of the required precision, since it might not be possible to accurately deduce physically meaningful values for other setups. To do so, different values for the two coefficients are prescribed and the resulting thermal material parameters are compared. At last a short outlook is given.

2 Identification

Basis for the identification process are experimental values obtained from a simple tension test using a dog bone shaped specimen made of the aluminium alloy AW-6016. The specimen is observed by a Digital-Image-Correlation (DIC) and a thermography system to obtain temperature and displacement field in parallel. Only a very small increase in temperature of about three Kelvin is detected for the experiment at hand. Before an identification can be performed, the boundary value problem must be defined. The discretised body is modelled using the measured dimensions of the utilised specimen and the chosen material model leads to an increase in temperature due to plastic dissipation. Regarding the boundary conditions for the mechanical field, these are directly derived from the experimental setup. Thus, displacements are clamped at one side and the experimental force is applied to the other side of the discretised specimen. A definition of the temperature boundary conditions appears less intuitive. In general, one can only say that heat is exchanged with the environment which is usually modelled by means of surface elements. Those elements yield to Newton's law of cooling

$$q_0 = \boldsymbol{n} \cdot \boldsymbol{q} = \alpha_{\text{con}} \left[\theta - \theta^{\text{M}} \right] \tag{1}$$

introducing the heat flow normal to the current surface q_0, the temperature of the surrounding medium θ^{M} as well as the convection or conduction coefficient α_{con} to the material model. Accurate values for this coefficient are in general unknown, but for the experiment considered, reasonable values can be deduced. Local temperature measurements of the specimen show an almost isothermal state within the clamping jaws. Together with the high conductivity of aluminium and the low rise of three Kelvin over ambient temperature, data suggest that heat conduction is the main effect of heat exchange. Therefore, heat exchange with the surrounding air is neglected by setting the convection coefficient to zero whereas the conduction coefficient is given a value over 10^8 $(\approx \infty)$ W/[m^2 K]. With the defined boundary value problem at hand a first identification is performed and the obtained material parameters lead to a very good match of the experimental data, as is depicted in Figures 1 - 4. Still, the chosen values for the convection and conduction coefficient are nothing more than an educated guess and for other setups it might not even be possible to deduce physically meaningful values. Hence, the sensitivity of the solution w.r.t. the assumed values is of interest to get a first impression of the required precision.

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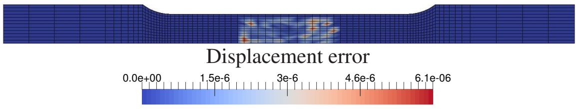

Fig. 1: Remaining squared error of displacement per node at last time step.

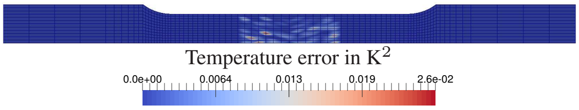

Fig. 3: Remaining squared error of temperature per node at last time step.

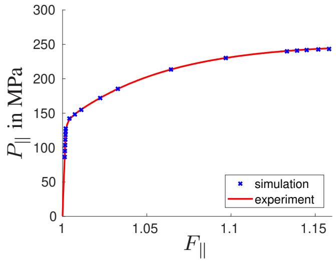

Fig. 2: Local stress-strain relation for optimal plastic parameter set, evaluated at the midpoint of the specimen.

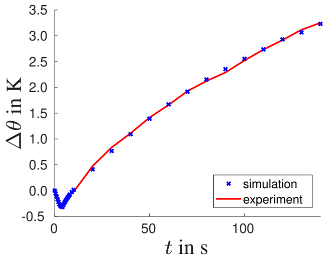

Fig. 4: Local temperature-time relation evaluated at the midpoint of the specimen.

3 Sensitivity of results

Several parameter identification based on the full field measurements are performed to get an idea about the influence of the two coefficients which define thermal boundary conditions. The convection coefficient $\alpha_{\rm con}^{\rm air}$ is modified in the first set of optimisations, keeping the conduction coefficient constant. In the second set of optimisations, the conduction coefficient $\alpha_{\rm con}^{\rm clamp}$ is modified while the convection coefficient is constant. Figures 5 and 6 show the resulting parameters normalised with respect to the set which leads to the smallest remaining error between experimental and simulated data. Varying the convection coefficient within the range usually associated with free convection of air at room temperature, the optimal value for the thermal expansion coefficient and the heat capacity change only very little, but the optimal value for the thermal conduction coefficient differs by almost 20%, cf. Figure 5. The impact of the conduction coefficient, Figure 6, is less pronounced and only shows for very low values of $\alpha_{\rm con}^{\rm clamp}$. Regarding the quality of each fit, the value of the objective function at the obtained optimum does not vary much, but clearly descends in the direction of low convection and high conduction.

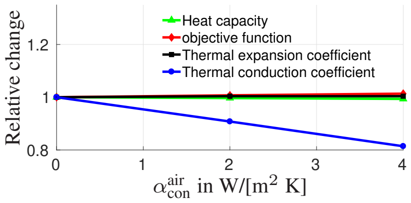

Fig. 5: Optimal thermal material parameters and remaining error for different prescribed convection coefficients $\alpha_{\rm con}^{\rm air}$. Relative change with respect to the values obtained by the identification with the least remaining error.

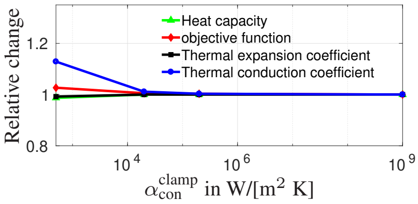

Fig. 6: Optimal thermal material parameters and remaining error for different prescribed conduction coefficients $\alpha_{\rm con}^{\rm clamp}$. Relative change with respect to the values obtained by the identification with the least remaining error.

4 Conclusion

The presented results show that especially the convection coefficient should be defined with high precision. Furthermore, the remaining error associated with each prescribed coefficient suggests that an optimal value for the convection and conduction coefficient exists and can be identified alongside the thermal material parameters. Future research will concentrate on such an identification.

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Correction added on 26 October 2020, after first online publication: Projekt Deal funding statement has been added.

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