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IMPLEMENTATION OF 3D NONLINEAR MATERIAL MODEL IN FINITE ELEMENT CODE

L. Pupure[1], I. Ruiz Cozar[2], L. Pakrastins[1] and J. Varna[1,3]

[1]Institute of Structural Engineering,
Riga Technical University Kipsalas 6A, LV-1048 Riga, Latvia
Email: Liva.Pupure@rtu.lv, web page: www.rtu.lv

[2]AMADE Research Group
Polytechnic School, University of Girona, Campus Montilivi s/n, E-17003 Girona, Spain
Email: ivan.ruiz@udg.edu, web page: www.amade.udg.edu

[3] Laboratory of experimental Mechanics of materials
Riga Technical University Kipsalas 6B, LV-1048 Riga, Latvia

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ABSTRACT

In certain applications, there is a growing need to use a nonlinear material model that could account for viscoplasticity, viscoelasticity and damage. Bio-based composites, composites used in demanding environments, and manufacturing process optimization are just a few examples of such fields. On top of that, composite structures are becoming more complex. Thus, using widely used simplistic 1D material models is not sufficient anymore for these applications. Even for relatively simple conditions, 3D material models show significantly higher stresses than typically used 1D models. Figure 1 shows thermal stresses during the cooling process within a mold. The plate is cooled down in two steps – first, the "fast" cooling process, where the plate is cooled down from 120°C to 70°C in 600s, followed by the "slow" cooling process until 20°C in 1200s. Often, the 1D models are used with the assumption that the plate in the lateral direction can move freely. However, in reality, the mold will constrain the movement in the lateral direction. Thus, the 1D models will significantly underestimate the stresses within the material. Simulations using experimentally determined master curves are performed for two different cases using two different assumptions: a) the time-temperature shift factor is temperature independent (notation a=1) and b) the shift factor is temperature dependent (notation a(T)) and it changes following the temperature change. Although only a part of the nonlinearity expected within the material is included in the shift factor, there is a significant difference in the modeling curves. With temperature-dependent shift factors, stresses are lower than with the other assumption.

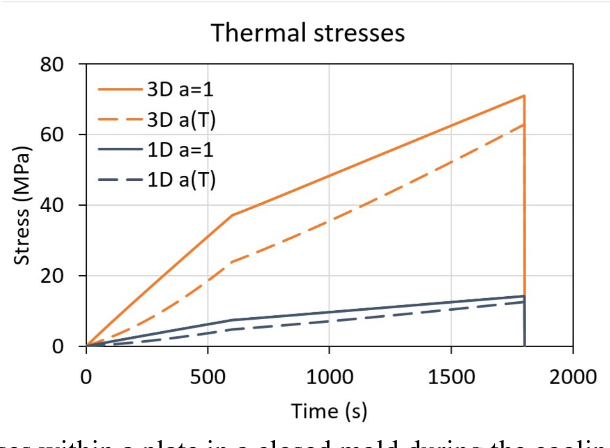

Figure 1: Thermal stresses within a plate in a closed mold during the cooling down process with 1D and 3D models and two nonlinear assumptions: a) shift factor is constant (notation a=1) and b) shift factor is temperature dependent (notation a(T)).

This simple simulation shows a clear need for 3D nonlinear material models that could capture the complex internal stress-strain state within the material and how different conditions affect these properties. The overall objective of this work is to implement a code of nonlinear material model that could capture viscoelasticity, viscoplasticity and how different environmental conditions or internal states affect these phenomena within finite elements. The implemented model will allow more accurate simulation of complex structures, loading cases, and materials in more demanding environments and different internal states. In addition, such models would allow using the multi-scale approach for composites with complex reinforcement, thus significantly simplifying the nonlinear modeling and the computational time required.

It has been demonstrated that the Schapery type of nonlinear viscoelastic model with the Zapas model for viscoplasticity and damage parameters can be used to predict the 1D behavior of nonlinear materials [1]. This model was adjusted for 3D cases and two options with significantly different complexity were developed [2]. In the first case, the nonlinearity reflecting functions used in the model are the same for all strain components. For this model, the experimental parameter identification is very similar to the one used for 1D materials models. However, for anisotropic materials, these functions are most probably different for different strain components. Thus, the second, more complex material model should be used. In this case, the experimental parameter identification for the model is rather complex and at least one bi-axial relaxation test needs to be performed.

Analysis of experimental data on viscoplasticity revealed that for isotropic materials, the differences in different VP strain components could be attributed to only one parameter [3]. The functions may be describing time and stress dependence were the same for axial and lateral (contraction) direction, thus significantly reducing the complexity of viscoplastic modeling in 3D. This somewhat supports the assumptions on which the first viscoelastic model was developed. Similarly, the nonlinear viscoelasticity has to be analyzed and based on the results, the model can be simplified for 3D cases. Each simplification can significantly reduce the complexity of the developed model and, thus, the required time for experimental parameter identification and computational time for implemented model.

For the first implementation stage, the simplest model, where nonlinearity functions do not depend on strain components, was rewritten in the incremental form [4]. This form will be used to implement the model within the finite element code. The simplified model will also allow the model to be validated in relatively straightforward cases. In the future, it will be possible to incorporate nonlinearities that can be attributed to different environmental conditions or internal states or generalize the model to obtain the more complex nonlinearity model, where nonlinearity functions are strain component dependent.

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