Two-scale characterization of fiber-reinforced polymers with self-heating effect

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ABSTRACT

With a view to application to thermomechanical coupled two-scale analysis of fiber-reinforced thermoplastics (FRTP), we propose a viscoelastic-viscoplastic combined constitutive model for of thermoplastic resins, which is capable of representing the complex inelastic behaviour with self-heating effect. The generalized Maxwell model is employed to characterize the viscoelastic behaviour at small or moderate strain regime, while a finite strain viscoplastic model is employed to represent transient creep deformations due to frictional resistance of molecular chains along with the hardening due to orientation of molecular chains. Within the framework of de-coupled computational homogenization [1] for FRTP, we are concerned with the effect of self-heating behaviour due to large strains distributed locally in periodic microstructures (unit cells) on the macroscopic thermomechanical behaviour that inevitably become extremely complex.

The thermodynamics-based formulation adopted here enables us to naturally derive a set of coupled governing equations for heat conduction, thermo-mechanics and self-heating phenomena. As the self-heating plays a role of heat sources in the microstructure of FRTP, the unsteady heat conduction problem has to be solved at a micro-scale to obtain the time-variation of temperature distribution that causes the transition from the glassy state to the rubbery one. As a result, the macroscopic self-heating effect is supposed to be delayed according to the unit cell size. In order to strictly consider this kind of temperature effects in homogenization analyses and reflect them in the macroscopic responses, we employ the incremental variational formulation [2] to formulate a coupled thermomechanical problem.

After the fundamental performance of the proposed constitutive model is verified in representing typical material behaviour of typical thermoplastic resins, representative numerical examples are presented to demonstrate the capability of the proposed model in reproducing the stress-softening, non-homogeneous creep, stress-build-up and self-heating phenomenon due to large inelastic deformations as well as the deformation-rate dependency. It is also confirmed that the model is capable of properly representing the transition between glassy and rubbery states, which may be caused by the self-heating phenomena especially under the condition of relatively high deformation rates. Then, the proposed constitutive model is applied to the numerical material testing (NMT) [2] for unit cells of FRTP to characterize the overall anisotropic inelastic behaviour along with micro-macro self-heating effects.

REFERENCES

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