Development of a Finite Strain Weakly Coupled Electro-Magneto-Thermo-Mechanical Model for Shape Memory Polymer Composites

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ABSTRACT

Shape memory behaviour refers to the ability of the material to shift from a temporary configuration to the permanent/original configuration under the influence of an external stimulus, such as temperature, electromagnetism, or light. Triggering the shape change in polymer composites through contactless temperature control induced through the losses incurred by the alternating electromagnetic fields is the primary focus of this work. Shape memory polymer composite (SMPC) synthesized with electrically conductive fillers and magnetic particles in a polymer matrix are considered here.

A coupled Electro-Thermo-Mechanical (E-TM) model for SMPC was recently developed in [1]. The present work extends the existing E-TM model by introducing the magnetic field, thus leading to a strongly coupled Electro-Magneto-Thermo-Mechanical (EM-TM) model. A finite strain phenomenological model for shape memory behaviour of semi-crystalline polymers under thermo-mechanical loading was developed in-house [2]. The viscoelasto-plastic constitutive model for the thermo-mechanics of SMP is extended considering i) the heat sources arising from the losses incurred by the alternating EM fields in the SMPC ii) the Maxwell stress contributions in the SMPC arising from the EM fields permeating in the SMPC and the surrounding air.

First, a strong coupling EM-TM model with heating of the SMPC through EM sources in the non-linear finite deformations regime is demonstrated. Due to the considered frequency of the EM sources, the timescale of the EM problem is relatively small (ms or μs) compared to the heating and deformations observed in the SMPC (in s). Secondly, the large deformations in the elements belonging to the air domain surrounding the deforming SMPC lead to skewed elements which cause convergence issues. To circumvent these issues of the strong coupling, a novel multi-timescale scheme weakly coupling the dynamic EM and quasi-static TM problem was developed. The weak coupling employs a total Lagrangian formulation with only the SMPC domain for the TM problem. Whereas an updated Lagrangian formulation after a remeshing step, using the deformed SMPC and added inductor coil and air domains, is employed for the EM problem. The computational efficiency of the weak coupling is highlighted along with the validated results against the strong coupling. Finally, a test depicting the shape memory effects with shape recovery by temperature control in the SMPC will be demonstrated.

REFERENCES

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