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Multiphysics Simulation of Microwave Processing using a Multidomain Coupled Solver Approach

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ABSTRACT

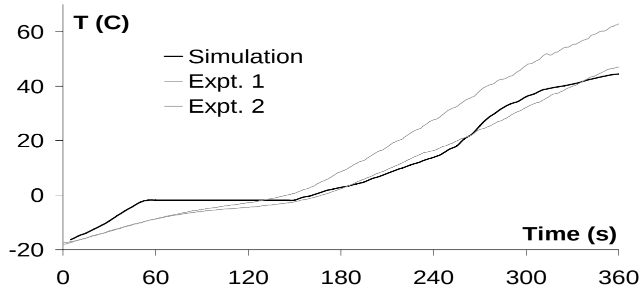
Microwave processing of materials is numerically simulated using a coupled solver approach. Microwave heating is a complex coupled process due to the variation in dielectric properties during heating. The effects of heating an object in a electromagnetic field directly influence the manner in which it interacts with the field. Simplifying assumptions and empirical solutions do not capture the fundamental physics involved and, in general, do not provide usefully accurate solutions in a number of practical problems. In order to capture the underlying processes involved in microwave heating, the problem must be looked at in a holistic manner rather than a number of discrete processes. This contribution outlines a coupled-solver multiphysics analysis approach to the solution of practical microwave heating problems.

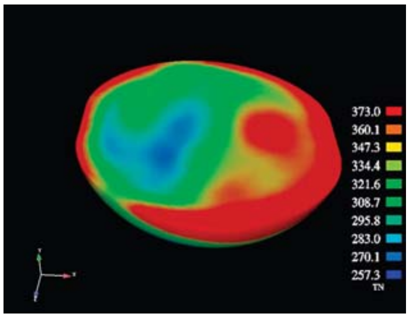
The approach utilises a dedicated electromagnetic Yee scheme [1] Finite-Difference Time-Domain (FDTD) solver which is closely coupled to an unstructured Finite Volume Method (UFVM) multi-physics package [2]. Two overlapping numerical domains are defined; the microwave oven cavity and waveguide are meshed for analysis of electric field distribution, whilst the object being processed is meshed for thermophysical analysis. The two solution domains are linked using a cross-mapping routine which uses a spatial sampling approach to link the domains. The implementation of the numerical model is fully described by Tilford et al [3]. The analysis process is expedited through parallelisation of the code using both MPI and OpenMP techniques.

The coupled solver approach has a number of advantages over traditional co-incident cell coupling methods. The two solution meshes are completely independent of each other, allowing thermophysical analysis to be confined to the volume enclosed by object being processed. The meshes can be moved independently of each other enabling rotation and/or translation of the load to be considered. Additionally the discretisation of the FDTD can be varied throughout the heating process to maintain numerical accuracy whilst minimising computational expense.

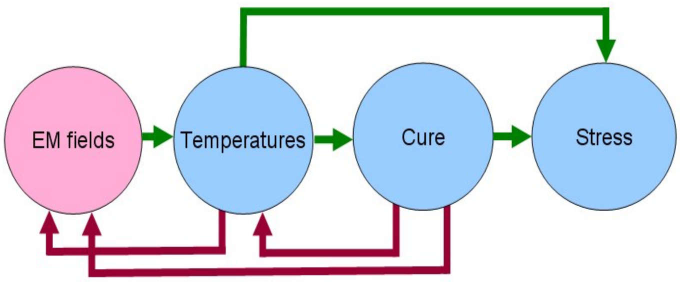
Two examples of application of the approach are outlined in this contribution. Both are complex multi-physics problems involving coupling between disparate physical processes. Firstly, numerical analysis of microwave thawing of a frozen food product in a domestic microwave oven is performed. The load is rotated on the oven turntable throughout the heating time. The bowl is not rotationally symmetrical and is placed a small distance from the centre of the turntable. Throughout the heating period the food

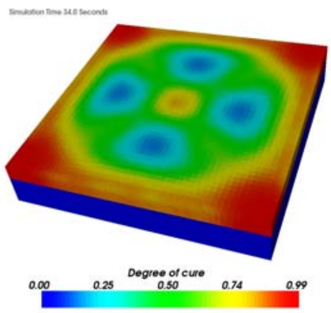
load undergoes thawing and evaporation while loosing energy to surroundings through convective and radiative boundary losses. Developing temperature fields predicted by the numerical solution are validated against experimentally obtained data. Presented results indicate the feasibility of fully coupled simulations of the microwave heating of a frozen product.





Additionally, microwave processing of thermosetting polymer materials utilised in microelectronics applications is considered. A novel variable frequency microwave system [4] is used to induce a cure process within polymer encapsulant covering a silicon semiconductor device. Fully coupled analysis of electromagnetic fields, dielectric heating, polymer curing and thermally induced stresses is presented.





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