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Computational Homogenization for Elasticity and Stationary Heat Conduction in Composite Materials Reinforced by Short Fibers

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Abstract

This paper presents Method of Continuous Source Functions (MCSF) for homogenization of material properties both elasticity and heat conduction in composite material reinforced by finite length regularly distributed, parallel, overlapping fibres. Stiffness/conductivity is incrementally reduced starting with rigid/super-conductive material properties of fibres and the fibre-matrix interface boundary conditions are satisfied by iterative procedure. Computational examples have to show: (1) the possibilities and difficulties connected with present numerical models and suggested ways for further developments, (2) similarities and differences in composite behaviour in heat flow and elasticity and (3) the way of choosing control volume for homogenization of composite materials reinforced by finite length fibres with large aspect ratio. Parallel MATLAB computational models increase computational efficiency. The results indicate that the proposed method is efficient and accurate in analysing the micromechanical elasticity and thermal behaviour of short fibre-composites.

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Keywords: Fiber-reinforced composite; finite length fibers; large aspect ratio; method of continuous sorce function; homogenization; thermal conductivity

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1. Introduction

Composite materials are characterized by the complexity of mechanical properties determining their behaviour. A material having two or more distinct constituent materials or phases may be considered the composite material when the volume fraction is greater than 10% and when the physical property of one constituent is much greater (≥5 times) than the other [1,2]. The composite properties are improved comparing with individual constituent properties. The combination of different properties materials provides exceptional properties of the composite, but it is one of the major problems in the simulation. The discontinuous fibres are made of materials whose strength, stiffness, thermal and electrical conductivity is much larger than that of continuous matrix material. In micro-scale, the composites are characterized by large gradients of physical fields in the fibres, as well as in the matrix caused by very different electro-magneto-thermo-mechanical properties of both the fibres and matrix materials [3]. The high gradients of physical fields characterize the interaction of the fibres with the matrix and with the other fibres and with the boundaries of the domain/structure and thus the reliable computer simulation is important to determine the behaviour of the whole structure.

Another effective method based on integral equation is method of fundamental solutions (MFS) [4]. MFS is recognized as boundary meshless method that does not need any mesh. In linear problems, the boundary conditions are necessary to satisfy only in nodes (collocation points) on the domain boundaries and by a set of source functions (fundamental solutions) in points outside the domain. However, if the shape of the domain is complex, the large numbers of both collocation points and source functions are necessary to use. Furthermore, the resulting system of equations is bad conditioned in some problems. MFS has specific advantages comparing to BEM, as it completely avoids the need for any integral evaluation and it results in very simple formulations in some problems. The source functions must be placed outside the domain and act as the trial functions. The location of the source functions is of fundamental importance to both the numerical stability and accuracy of the solution. The MFS can be also classified as Trefftz-type methods because the functions used there are Trefftz functions and interpolate the whole domain of solution [5]. Any of Trefftz functions can be used for this purpose.

This paper presents models for simulation both elasticity and heat conduction in composite material reinforced by finite length regularly distributed and overlapping fibres and homogenization of material properties. Computational examples have to show: (1) the possibilities and difficulties connected with present numerical models and suggested ways for further developments, (2) similarities and differences in composite behaviour in heat flow and by mechanical loading and (3) the way of choosing control volume for homogenization of composite materials reinforced by fibres with large aspect ratio. The computational models are especially appropriate for parallel algorithms and present models are in parallel MATLAB. Presented examples contain up to 63 interacting fibres.

2. Model description and homogenization

2.1. Model description

The source functions of MCSF belong to Trefftz functions are also called Trefftz Radial Basis Functions (TRBF). Trefftz functions are RBFs fulfilling the governing equations inside domain (matrix) except the source point itself in which they act. RBFs can be used as interpolating functions of various fields (displacement, stress, strains, temperature, heat flow etc. fields in elastic body i.e. the body with linear material properties) mainly in boundary-type methods. The source points are situated outside domain of solution (matrix in our problems) and the TRBF are:

- for structural analysis: Kelvin fundamental solutions (unit force acting in infinite continuum), its derivations (force dipole and force couple acting in point, Fig. 1) in corresponding direction,
- for thermal analysis: unit heat source and heat dipole.

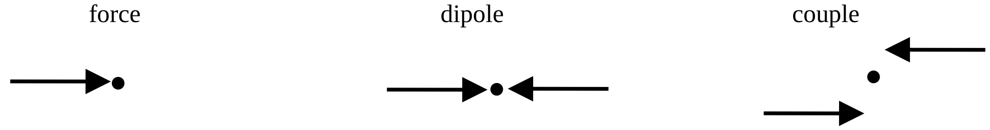

Fig. 1 Unit force, force dipole, force couple.