Computational models for parallel computing of composites reinforced by short fibres

Vladimír Kompiš[1], Zuzana Murčinková[2]*, Miloš Očkay[3] and Miroslav Kelemen[3]

[1]*DSSI, j.s.c., Wolkrova 4, 851 05 Bratislava, Slovakia,*
e-mail: vladimir.kompis@aos.sk

[2] *Faculty of Manufacturing Technologies, Technical University in Košice, Štúrova 31,080 01 Prešov, Slovakia,*
e-mail: zuzana.murcinkova@tuke.sk

[3]*Academy of Armed Forces, Demänovská 393, 031 19 Liptovský Mikuláš, Slovakia*
e-mail: milos.ockay@aos.sk, miroslav.kelemen@aos.sk

Abstract

Method of Continuous Source Functions (MCSF) developed by authors using 1D continuous source functions distributed along the fibre axis enables to simulate the interaction of fibre with the matrix and also with other fibres. 1D source functions satisfy the governing equations inside the domain (matrix) and boundary conditions on the fibre-matrix boundaries are satisfied in collocation points in the least square (LS) sense along the fibre boundaries. The source functions are defined by Non-Uniform Rational B-Splines (NURBS). In our model, only the interactions of each two fibres is solved by elimination and then the complex interaction of all fibres in a patch of fibres and the matrix is completed by iteration steps in order to increase efficiency of computations. For heat problem, material of fibres is supposed to be super-conductive in the first steps. The energy balance condition in each fibre enables to find temperature change of each fibre by the interaction with the other fibre in the first iteration steps. The next iteration steps enable to correct the temperature changes of the fibres by complex interaction of all fibres and the matrix and distribution of the source functions inside the fibres are obtained.

Keywords: method continuous source function, meshless formulation, composite reinforced by short fibres

1. Introduction

Composites reinforced by short fibres/tubes are often defined to be materials of future with excellent electro-thermo-mechanical (ETM) properties. The aspect ratio of the short fibres is often 10^3:1-10^6:1, or even more. Very large gradients are localized in all ETM fields along the fibres and in the matrix. 1D source functions localized along fibre axis serve as Trefftz (T-) functions, which satisfy the governing equations inside the domain (matrix). Boundary (continuity) conditions on the fibre-matrix boundaries are satisfied in collocation points in the least square (LS) sense along the fibre boundaries. The source functions are defined by Non-Uniform Rational B-Splines (NURBS). Because of large gradients, large number of collocation points and many NURBS shape functions are necessary to simulate the interaction. These fields define the interaction of the fibres with the matrix, with the other fibres and with the boundaries of the domain/structure. Method of Continuous Source Functions (MCSF) developed by authors [4, 5] using 1D continuous source functions distributed along the fibre axis enables to simulate the interaction similar to the Method of Fundamental Solutions (MFS [1, 2]), however, because of large aspect ratio huge number of all, collocation points and fundamental solutions in source points would be necessary to satisfy accuracy and numerical stability would be bad. Continuous source functions enable to master these problems.

The source functions are forces and their derivatives (dipoles and couples) for deformation fields and temperature and temperature dipoles for heat transfer problem. The largest gradients of fields in the ends of fibres require both the high density of collocation points and fine points defining the B-splines in these parts of the fibre in order to receive good accuracy and numerical stability of the model. More details about the model can be found in [3, 4 and 5] and will be presented by the conference. Here we will present strategy of parallel computations for the model for heat problem.

2. Model description

Usually less few hundred of equations are enough to simulate the inter-domain continuity for one fibre. However, if the model contains large number of fibres, the model would be large, the system of equations full and the computation time very consuming. Assuming that the thermal conductivity of the fibre is much larger than that of the matrix, it is possible to obtain temperature increments for each fibre by the interaction of the fibres with the matrix. Resulting temperature of fibres in the control volume (CV) is obtained as a result of interaction of all pairs fibres in the model.

In MCSF model, only the interactions of each two fibres is solved by elimination and then the complex interaction of all fibres in a patch of fibres and the matrix is completed by iteration steps in order to increase efficiency of computations. If there are n fibres in the model (CV), then it is necessary to solve the interaction of (n-1)(n-2) pairs of fibres. The model is very suitable for parallelization and the computations of each two fibres can run in a parfor loop parallel (we use parallel MATLAB for the numerical simulations).

Materials of all matrix and fibres are supposed to be homogeneous and isotropic with infinite dimensions. All fields are split into homogeneous part (matrix without fibres) and local part (interaction of fibres with the matrix). Usually the conductivity, stiffness, strain and strength of fibres is much higher (by several orders) than that of the matrix.

In the first steps it is supposed that fibres are superconductors and so, the temperature of each is constant, From the interaction of each two fibres with the matrix the temperature in each fibre is obtained from the condition of energy balance in each fibre (the local temperature is linearly distributed along fibres with opposite gradient to that of the homogeneous field). In the example a patch of regularly distributed overlapped 23 fibres with aspect ratio 1000:1 were computed in a PC. The interaction of two fibres was described by system of 480 x 138 equations. As the temperatures of the

*presenting author

fibres are not known, it is necessary to solve the system of equation with 3 rhs. The one, with the constant gradient along fibre axis and the other two with constant temperature equal one, in one fibre and zero in the other fibre. Integrating the heat flow along each fibre the temperatures in each fibre are found from the energy balance in both fibres.

Solution for two fibres in the matrix is obtained by computing of subsystem for corresponding two fibres. The interaction of all fibres are obtained iteratively: first considering the source functions obtain by interaction of all pairs of fibres the temperatures in all fibres are found in four steps, then taking these fibre temperatures more accurate source functions are find in other two steps. Convergent solution of heat flow in all fibres is shown in the Figure 1.

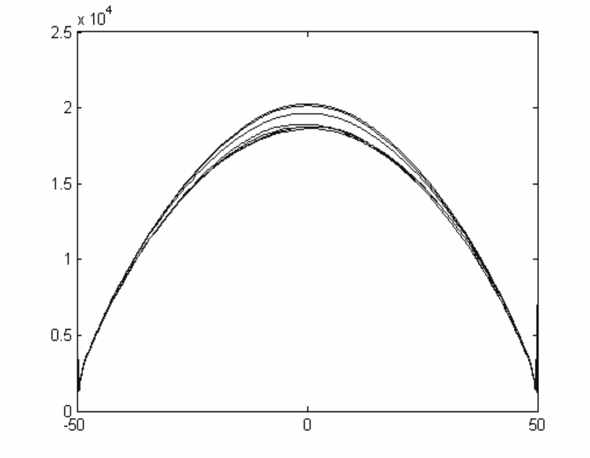

Figure 1: Heat flow in fibres

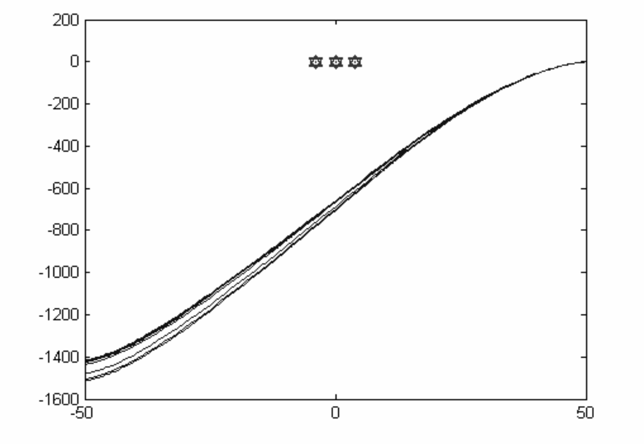

Figure 2: Temperature for finite conductivity of fibres

The source functions obtained for conditions of superconducting fibres would provide very different distribution of temperature along fibre for finite conductivity. Figure 2 shows the temperatures in fibres for conductivity of fibre 1000 times larger than that of the matrix. Further iteration steps have to be included to correct both temperatures in fibres and the intensities of source functions in order to fit the interdomain boundary conditions along fibres. More details and results will be presented in the conference and will be published later.

3. Conclusions

The present model use solution of subproblems and iterative steps to obtain complete solution of interaction of many fibres reinforcing composite material increases efficiency of the MCSF. Moreover, it is very suitable for parallel computing. This is even more important in elasticity problems, as the number of equations to solve similar problem to that of the heat transfer is three times larger and computer time increases then by nearly one order.

References

[1] Chen C. S., Karageorhis A., Smyrlis Z. S., *The method of fundamental solutions – A meshless method*, Dynamic Publishers, Atlanta, 2008.

[2] Golberg M. A. and Chen C. S., The Method of Fundamental Solutions for Potential, Helmholtz and Diffusion Problems, *Boundary Integral Methods – Numerical and Mathematical Aspect*, Golberg M. A. ed., Computational Mechanics Publications, Southampton, pp. 103-176, 1998.

[3] Kompiš V., Murčinková Z., Heat flow in composites reinforced by short fibres, *Proceedings 18th International Conference on Computer Methods in Mechanics*, eds. M. Kuczma, K. Wilmanski, W. Szajna, Zielona Gora, 2009, pp. 243-244, The University of Zielona Gora Press, 2009.

[4] Kompiš V., Murčinková Z., Očkay M., *Temperature fields in short fibre composites*, *Computational modelling and advanced simulations*, to be published in Springer.

[5] Kompiš V., Štiavnický M., Kompiš M., Murčinková Z., Qin, Q.-H., *Method of continuous source functions for modeling of matrix reinforced by finite fibres*, V. Kompiš, ed. *Composites with micro- and nanostructure*, Springer, Dordrecht, 2008.