TLM at the University of Hull.

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Abstract

Some of the recent work carried out at the University of Hull on the TLM algorithm is described. Attention is focused on modelling heat transfer and stress wave propagation and on the implementation of models in distributed computer architectures.

1 Introduction

The numerical dynamics group at Hull is concerned with fundamental aspects of the development and implementation of the TLM algorithm as well as with its application for a range of purposes in which the technique offers advantages over more traditional approaches. Previous work on the modelling of heat transfer in ceramic pieces during firing is being extended to represent microwave assisted firing, and the recently acquired ability to represent equations involving cross derivatives is enabling us to model heat transfer in anisotropic materials. The treatment of cross derivatives is also being used, in a modified form, to model stress wave propagation in 2- and 3- dimensions. In terms of implementation, collaboration with the Department of Computer Science is concerned with the development of a systematic approach to implementation of TLM models in distributed and parallel computer architectures.

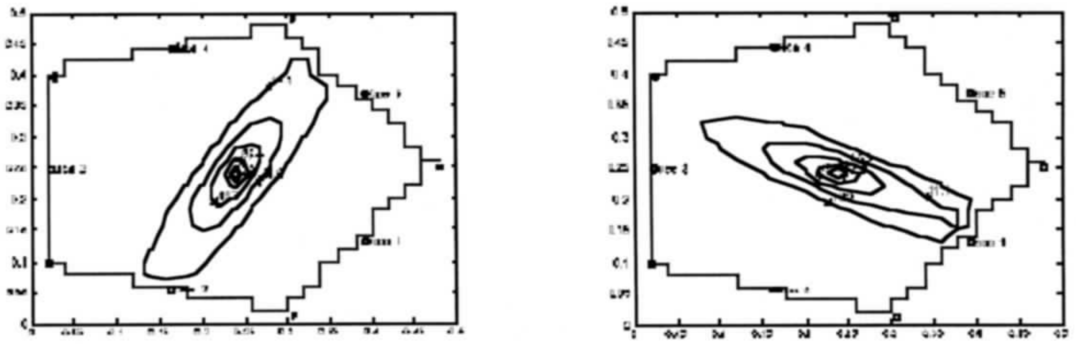
2 Heat Transfer

Earlier work was concerned with modelling the thermal experience of pieces of vitreous china ware during firing in a conventional tunnel kiln [1]. Pieces of ware are loaded onto kiln cars which then travel through the kiln. In the model heat is transferred to the ware via convection from ambient air, the temperature of which is specified as an input to the model, by radiation from burners, kiln walls and remote kiln car furniture, and via conduction from furniture contacting the piece of ware. The model differs from many kiln models in so far as the focus of attention is on thermal effects within each piece of ceramic rather than on prediction of air temperatures and total heat transferred to the ware. Microwave assisted firing is currently a topic of considerable interest , the objective being to reduce energy consumption and firing time while maintaining or enhancing product yield and quality. Maintenance of product yield and quality requires that the temperature gradients within pieces of ware, and the variation of those profiles in time, should not become sufficient to cause excessive differential thermal expansion which is associated with the generation of local defects. In this industrially funded work the original model is being extended to incorporate heat generation within the ceramic via microwave absorption. In the first instance a uniform microwave field is considered in those zones of the kiln in which microwave heating is applied. In future generations of the model it is likely that treatments of field attenuation due to absorption and diffraction around obstacles will be desirable.

Anisotropic heat transfer problems described by equations of the form

$$K_h \frac{\partial^2 T}{\partial x^2} + K_v \frac{\partial^2 T}{\partial y^2} + \left(K_{hv} + K_{vh}\right) \frac{\partial^2 T}{\partial x \partial y} = \rho S \frac{\partial T}{\partial t} \tag{1}$$

where ρ is the material density, S is the specific heat capacity, and K_h, K_v and K_{hv} are the thermal conductivities are also being addressed [2]. The application of interest is monodirectional carbon fibre composite material. Here carbon fibres are laid parallel to each other and are embedded in a resin. The thermal conductivities are calculated from the thermal conductivity of the fibre along its length and across its width, the volume fraction occupied by fibre, the conductivity of the matrix resin which is assumed to be isotropic and the angle of the fibre to the TLM mesh. Current work is concerned with modelling of sandwich structures in which layers of composite are each associated with a different in plane fibre angle, and with the development of 3- dimensional models. Figure 1 shows two simple examples of heat diffusing from a hot spot in a shaped single layer structure towards its insulated boundaries. In one case, 1(a), the fibre angle is 60 ° and in the other, 1(b), the fibre angle is 150 ° .



1(a)

1(b)

Figure 1 Predicted temperature contours in anisotropic material.

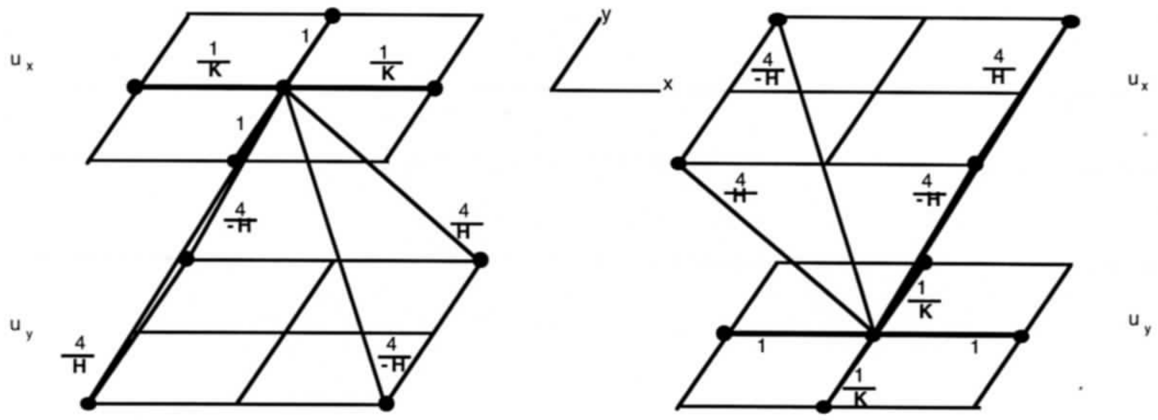
3 Stress Wave Propagation

The equations describing inplane deformation of a material and can be written

$$\frac{\partial^2 u_x}{\partial t^2} = \frac{(2G+\lambda)}{\rho}\frac{\partial^2 u_x}{\partial x^2} + \frac{G}{\rho}\frac{\partial^2 u_x}{\partial y^2} + \frac{(G+\lambda)}{\rho}\frac{\partial^2 u_y}{\partial x\,\partial y} \qquad (2)$$

$$\frac{\partial^2 u_y}{\partial t^2} = \frac{G}{\rho}\frac{\partial^2 u_y}{\partial x^2} + \frac{(2G+\lambda)}{\rho}\frac{\partial^2 u_y}{\partial y^2} + \frac{(G+\lambda)}{\rho}\frac{\partial^2 u_x}{\partial y\,\partial x} \qquad (3)$$

$\sqrt{\frac{G}{\rho}}$ is identified as the velocity of the transverse or rotational wave, and $\sqrt{\frac{(2G+\lambda)}{\rho}}$ as the velocity of the dilatational or irrotational wave. In order to represent equations 2 and 3 requires two resistance free TLM networks, one representing u_x and one representing u_y. It is significant that the u_x modelling network involves a cross derivative of u_y, and the u_y network involves a cross derivative of u_x. Hence, the networks are linked by transmission lines which represent the cross derivatives. The arrangement is illustrated in figure 2. Space and timestep are linked to the wave velocity via the stub impedance in a manner very similar to other wave modelling networks. A two dimensional model of in plane stress propagation has been devised [3] and results produced shown to be in good agreement with those obtained using finite difference analysis and reported in the literature [4]. Figure 3 illustrates a typical comparison of results.



u x node

u y node

Figure 2 Coupled networks used to model stress wave propagation.

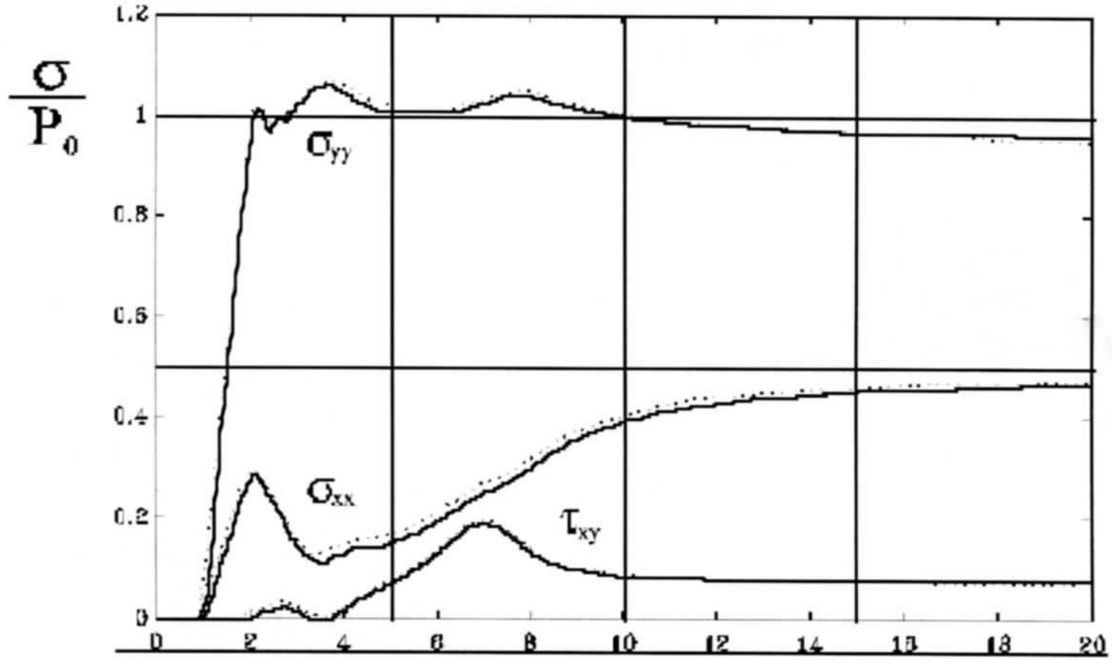


Figure 3 Comparison of results. The dotted lines represent finite difference results and the solid lines correspond to the TLM results.

This fundamental work is now being extended and applied to the modelling of acoustic wave propagation in cancellous bone. The ultimate objective of this is to produce a model which can be used in conjunction with measurement equipment to improve the diagnosis of osteoporosis.

4 Implementation in Distributed Computer Architectures

Implementation of TLM on parallel and distributed systems is a particularly attractive concept in the light of the inherent parallelism of the 'scatter- connect' process. Although large parallel computers remain something of a luxury computer networks are commonplace. Fundamental work on implementation of TLM models across a distributed workstation system has recently been undertaken [5]. A simple 2- dimensional model was chosen for the preliminary work, and PVM (parallel virtual machine) software was used to investigate various modes of distribution of the TLM nodal array across up to twelve Sun SPARCstations workstations connected via a single ethernet. The speed up associated with a particular arrangement is calculated by dividing the run time for the model on a single processor by that associated with the arrangement. High levels of speedup ware found, but this was very much dependent on the distribution chosen. The performance associated with a distribution is related to the number of messages passed and the volume of data contained in each message. Although the exact relationship involves a number of parameters, the fact that only one pulse value is passed in each direction per peripheral element associated with a processor eases prediction of advantageous arrangements. Planned future work is concerned with derivation of generally applicable guidelines and a metric to predict performance of parallel TLM implementations.

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