NUMERICAL PREDICTION OF THE ORIENTATION FIELD IN COMPLEX COMPOSITE INJECTION-MOULDED PARTS

Couniot A., Verleye V., Dupret F.,
CESAME, Unité de Mécanique Appliquée
Université Catholique de Louvain, B-1348 - Louvain-La-Neuve, Belgium

ABSTRACT

This paper summarises a method which has been developed in order to simulate the moulding of thin composite parts. Several examples are discussed, which demonstrate the predictive capabilities of our approach.

INTRODUCTION

The interest of resorting to numerical simulation with a view to improving the mechanical properties of composite moulded parts is widely recognised. In particular, designing an optimal feeding system is of the utmost importance, since the location of the gates has a very strong influence on the final orientation of the fibres, which is in turn expected to result in structural reinforcements of the cooled part (Advani et al. [1]).

The best method of representing the random and anisotropic distribution of the fibres in the suspension is to use orientation tensors (Advani and Tucker [2,3]). This approach is the only way to investigate the challenging modelling problems posed by the interaction between the fibres, their influence on the flow rheology (see Rosenberg et al. [4]), and their interaction with the walls of the cavity.

In the present paper, the model has been simplified according to the assumption that fibres are either very short (in a dilute suspension), or very long (in a concentrated suspension). In the former case, fibre-fibre, fibre-flow, and fibre-wall interactions are neglected. In the latter case, fibres are assumed to remain parallel to the midsurface of the cavity, while the velocity profile is flat and a plug flow is assumed. In both situations, the flow is supposed to be governed by the isothermal incompressible Hele-Shaw equations. Detail is given in Henry de Frahan et al. [5], and Verleye et al. [6 to 11]. The complete method is reviewed in Crochet et al. [12].

A particular aspect of our approach is to use a *natural* closure approximation [8 to 11], whose validity has been demonstrated in general situations. This method permits us to model the effect of fountain flow, abrupt changes of thickness, or bifurcations of the midsurface of the part on the orientation field [6 to 8, 10, 12].

DESCRIPTION OF THE METHOD

Decoupled finite element flow calculations are performed following the method of Dupret and Vanderschuren [13], Couniot et al. [14 to 17], Dupret and Dheur [18], and Dheur [19].

On the basis of the approximate velocity field obtained at the successive time steps of the simulation, orientation calculations are performed using the same finite element meshes as for evaluating the pressure field. In the case of very short fibres, the 3D second-order orientation tensor must be calculated in several layers, since orientation depends on the gapwise coordinate [6 to 12]. In the case of long fibres, the 2D second-order orientation tensor does not depend on the gapwise coordinate, and the suspension consists of a single layer [5 to 10, 12]. In both situations, integration by parts must be carried out on the weighted residuals expression of the discrete equations, since velocity space partial derivatives must be removed from the system. Indeed, in Hele-Shaw calculations, velocities are proportional to the pressure gradients and are, therefore, not continuous. A particular upwinding scheme permits us to obtain well-behaved solutions at high flow rates.

In general, we use an Eulerian time-integration technique, which combines accurate front tracking, remeshing over the filled domain [16, 17], and extrapolation of the orientation tensor in the region located between successive fronts. Fountain flow is taken into account at this stage [6 to 13, 18, 19].

RESULTS AND DISCUSSION

Two problems are considered. In the first case (Figs. 1 to 3) we analyse the isothermal filling of a rectangular plate with a dilute suspension of short fibres. Fountain flow is taken into account. A different orientation is obtained in the core and in the layers which are close to the walls. In the former case, the result is very similar to the one which could be obtained with a concentrated suspension of long fibres. In the latter case, we observe that fibres tend to align parallel to the flow velocity, since shearing effects are non-negligible.

The effect of the inlet orientation field is also investigated. It is shown that, when the injected suspension has a planar and random orientation at the gate (Fig. 2), fibre reorientation requires some time in the layers where shearing effects are important. This result is in agreement with the conclusions of Crochet et al. [12]. In addition, as demonstrated in [9, 11], the reorientation time is increased when the 3D natural closure is used instead of the classical quadratic closure, since transient effects become more important. However, reorientation is much faster when the injected suspension has a 3D random orientation at the gate (Fig. 3).

The second problem is devoted to analyzing the isothermal filling of a rectangular plate with a hole (Figs. 4 and 5). The injected suspension is concentrated, with long fibres (Fig. 5). The influence of the welding line which is formed downstream of the obstacle is obvious.

ACKNOWLEDGEMENTS

The results presented in this paper have been obtained within the framework of Interuniversity Attraction Poles initiated by the Belgian State, Prime Minister's Office, Science Policy Programming, and within the frame of a Multimateriaux Project initiated by the Walloon Region of Belgium.

REFERENCES

1. Advani S. G., Tucker C.L., Yalvac S., McGee R.L., "Stiffness and Thermal Expansion Predictions for Hybrid Shjort Fiber Composites", Polym. Comp., Vol.11, 229-239 (1990)
2. Advani S. G., Tucker C.L., "The Use of Tensors to Describe and Predict Fibre Orientation in Short Fibre Composites", J. Rheology , 31: 751-784, 1987.
3. Advani S. G., Tucker C.L., "Closure Approximation for Three-dimensional Structure Tensors", *J. Rheology* , 34:367-386, 1990.
4. Rosenberg R., Denn M.M., Keunings R., "Simulation of Non-Recirculating Flows of Dilute Fiber Suspensions, J. Non-Newtonian Fluid Mech., Vol. 37, 317-345 (1990)
5. Henry de Frahan H., Verleye V., Dupret F., Crochet M.J., "Numerical Prediction of Fiber Orientation in Injection Molding", *Polym. Eng. Sci*., 32: 254-266, 1992.
6. Verleye, V., Dupret, F., "Three-dimensional Prediction of Fiber Orientation in Injection Molded Parts", in *Proc. of the 3rd Int. Conf. on Num. Meth. in Industrial Forming Processes* (NUMIFORM '92), Chenot, Wood and Zienkiewicz (eds), Balkema, Rotterdam : 389-393, 1992.
7. Verleye V., Couniot A., Dupret F., "Prediction of Fiber Orientation in Complex Injection Molded Parts", in *Proc. of the 9nth Int. Conf. on Composite Materials* (ICCM/9), A. Miravete (ed), Woodhead Publishing Lim. , Univ. of Zaragoza : 642-650, 1993.
8. Verleye V., Dupret F., "Prediction of Fiber Orientation in Complex Injection Molded Parts", in *Proc. of the ASME'93 Winter Annual Conference*, 28 Nov.-3 Dec. 1993, New Orleans, Louisiana (USA), D. Siginer ed., p. 171-195.
9. V. Verleye, A. Couniot, F. Dupret, "Numerical prediction of fibre orientation in complex injection-moulded parts", in Proc. of the CADCOMP'94 Conference, Southhampton (UK), 1994.
10. Verleye, V., Dupret, F. in preparation, 1994.
11. Verleye V., Couniot A., Dupret F. "Numerical Prediction of the Orientation Field in Complex Composite Injection-Molded Parts", to be presented at the *ASME'94 Winter Annual Conference,* Chicago, Nov. 1994
12. Crochet M. J., Dupret F., Verleye V., in *FLow and Rheology in Polymer Composites*, S. Advani ed., Chapter III : *Simulation of composites processes,* Section III.2 "Injection molding", Elsevier, 1994, p. 415-463.

13. Dupret F., Vanderschuren L., "Calculation of the Temperature Field in Injection Molding", *AIChE*, 34:1959-1972, 1988.
14. Couniot A., Dheur L., Hansen O., Dupret F., "A Finite Element Method for Simulating Injection Molding of Thermoplastics", in *Proc. of the 3rd Int. Conf. on Num. Meth. in Industrial Forming Processes* (NUMIFORM'89), Thompson E.G., Wood R.D., Zienkiewicz O.C. & Samuelsson A. (eds), Balkema, Rotterdam:235-241, 1989.
15. Couniot A., Dheur L., Dupret F., "Numerical Simulation of Injection Molding: Non-isothermal Filling of Complex Thin Parts, Including Abrupt Changes of Thickness or Bifurcations of the Midsurface", in Proc. of the IMA conference on *Mathematical modelling for materials processing*, Bristol 1991, Mark Cross, J.F.T. Pittman and Richard D. Wood (eds.), Clarendon Press Oxford: 381-398, 1993.
16. Couniot A., "Développement d'un algorithme de remaillage automatique pour la simulation du moulage par injection", Ph.D. Thesis, Université Catholique de Louvain, 1991.
17. Couniot A., Dupret F., "A General Method for Simulating 2.5D Problems Involving Moving Boundaries", in preparation, 1994.
18. Dupret F., Dheur L., "Modelling and Numerical Simulation of Heat Transfer during the Filling Stage of Injection Molding", in Proc. of the *Oji International Seminar on Advanced Heat Transfer in Manufacturing and Processing of New Materials*, Tomakomai (Japan) 1990, Tanasawa I. & Lior N. editors, Hemisphere Publishing Corporation : 583-591, 1992.
19. Dheur L., "Simulation Numérique des Echanges Thermiques en Moulage par Injection", Ph.D. Thesis, Université Catholique de Louvain, 1992.

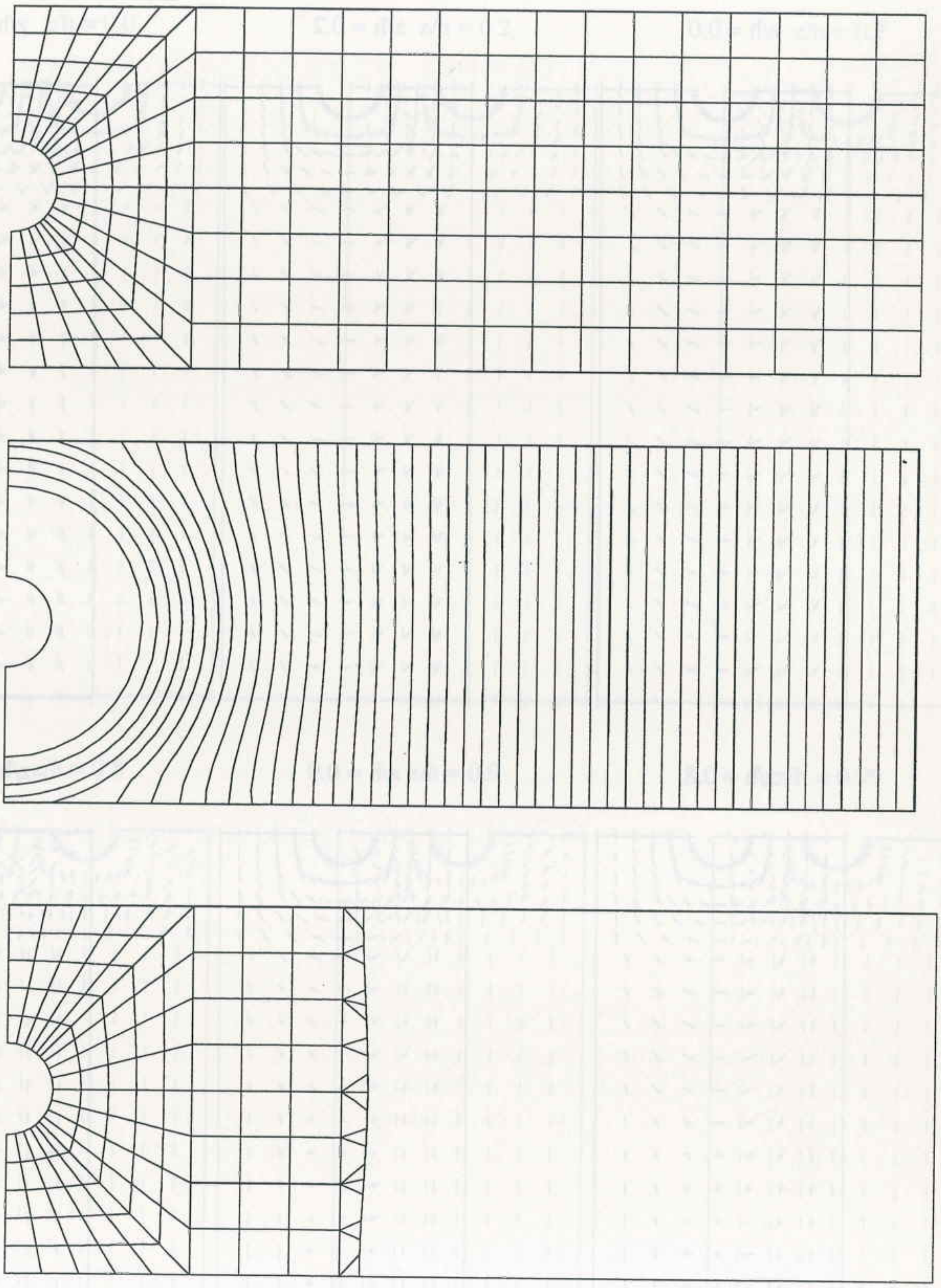

Fig.1. Isothermal filling of a rectangular plate
with a dilute suspension of very short fibres :
fixed mesh, successive flow fronts and example of temporary mesh

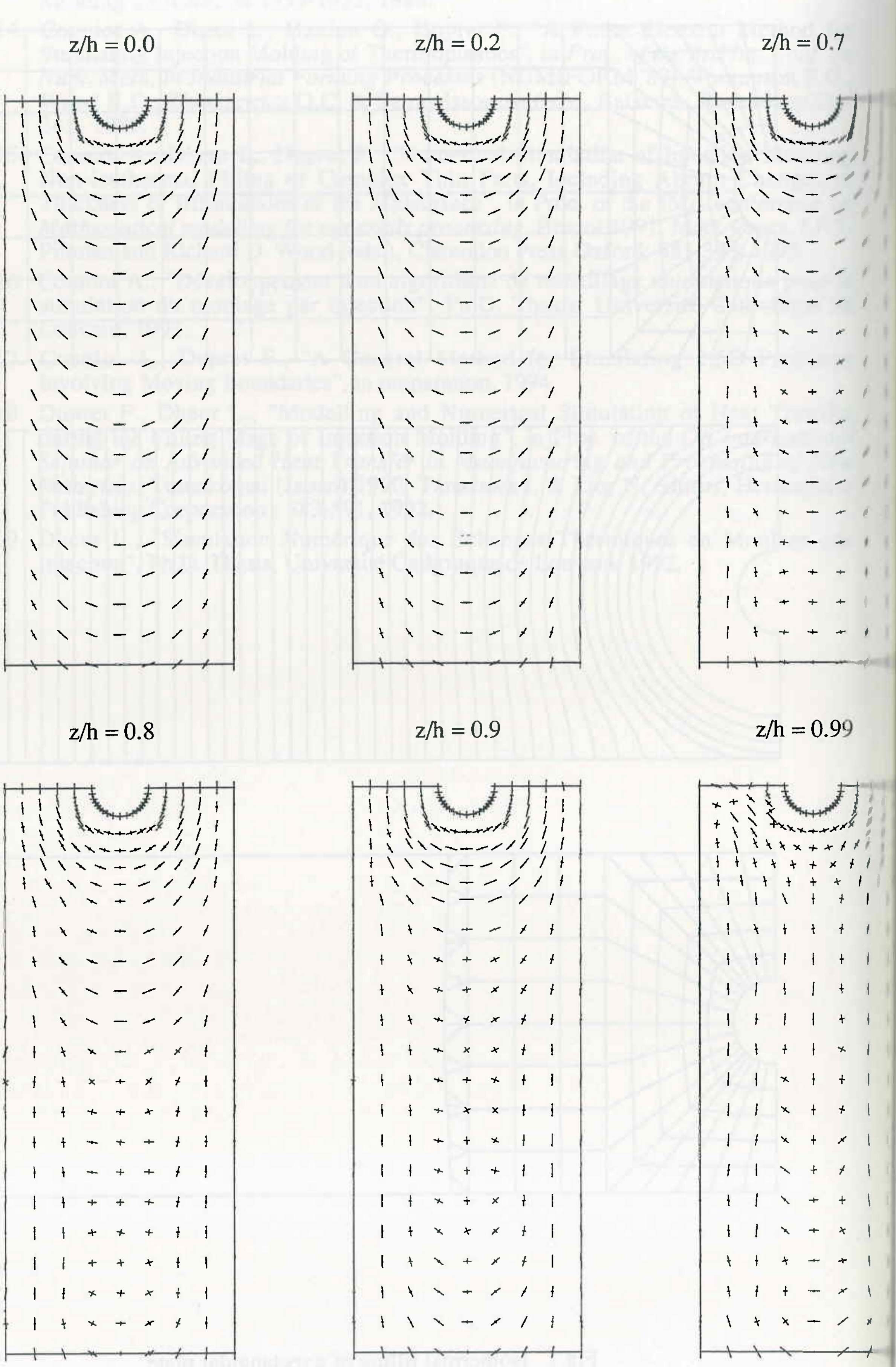

Fig. 2. Same problem as in Fig. 1 :
final orientation field at layers z/h = 0.0 , 0.2 , 0.7 , 0.8 , 0.9 and 0.99
for an isotropic planar inlet orientation

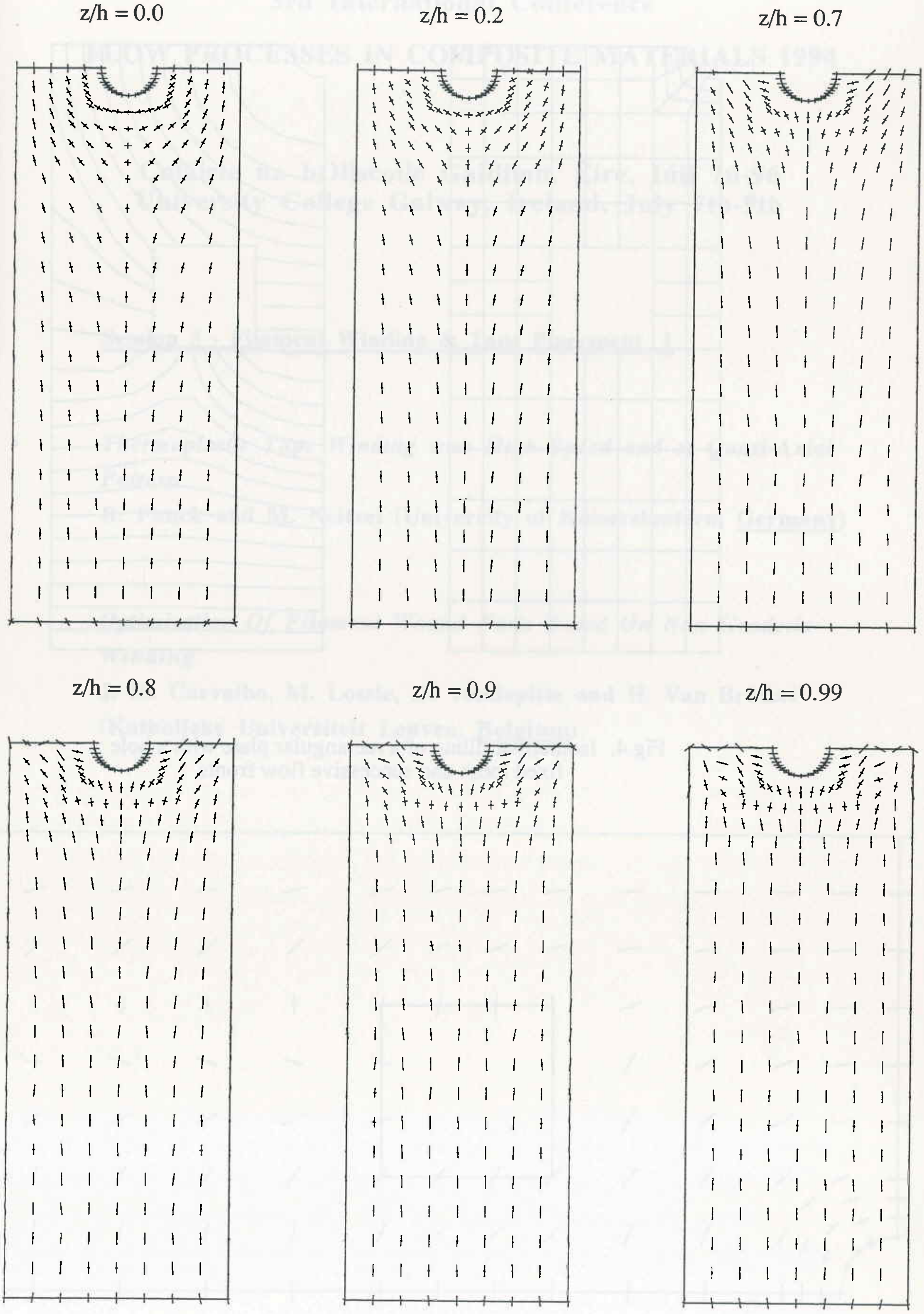

Fig. 3. Same problem as in Fig. 1 :
final orientation field at layers z/h = 0.0 , 0.2 , 0.7 , 0.8 , 0.9 and 0.99
for a 3D isotropic inlet orientation

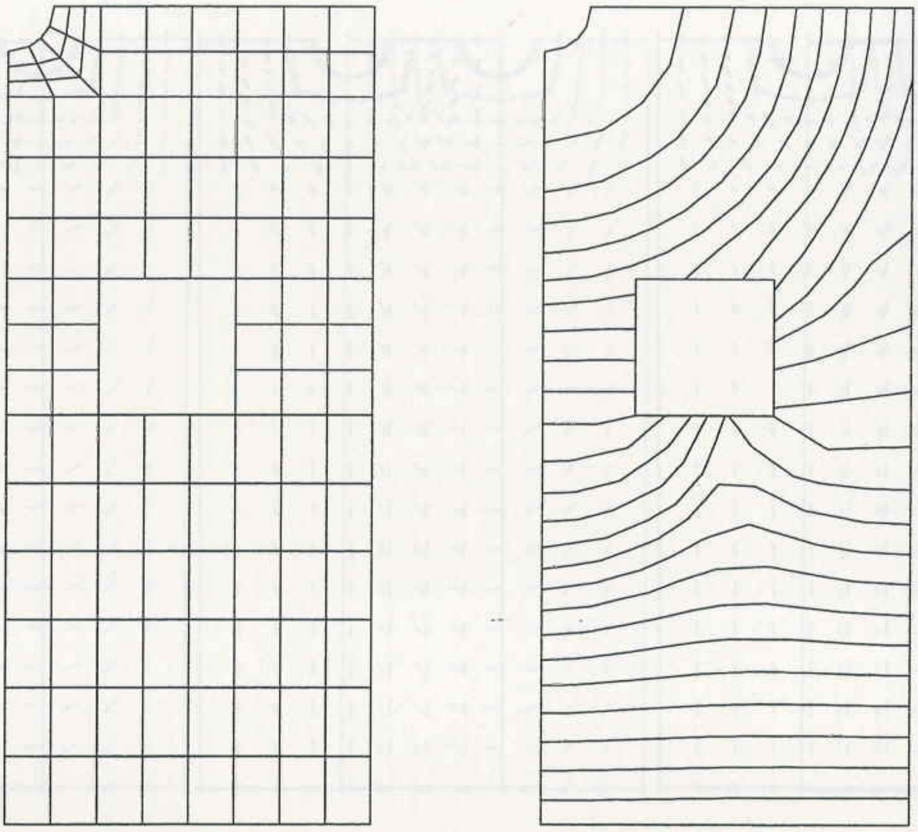

Fig.4. Isothermal filling of a rectangular plate with a hole :
fixed mesh and successive flow fronts

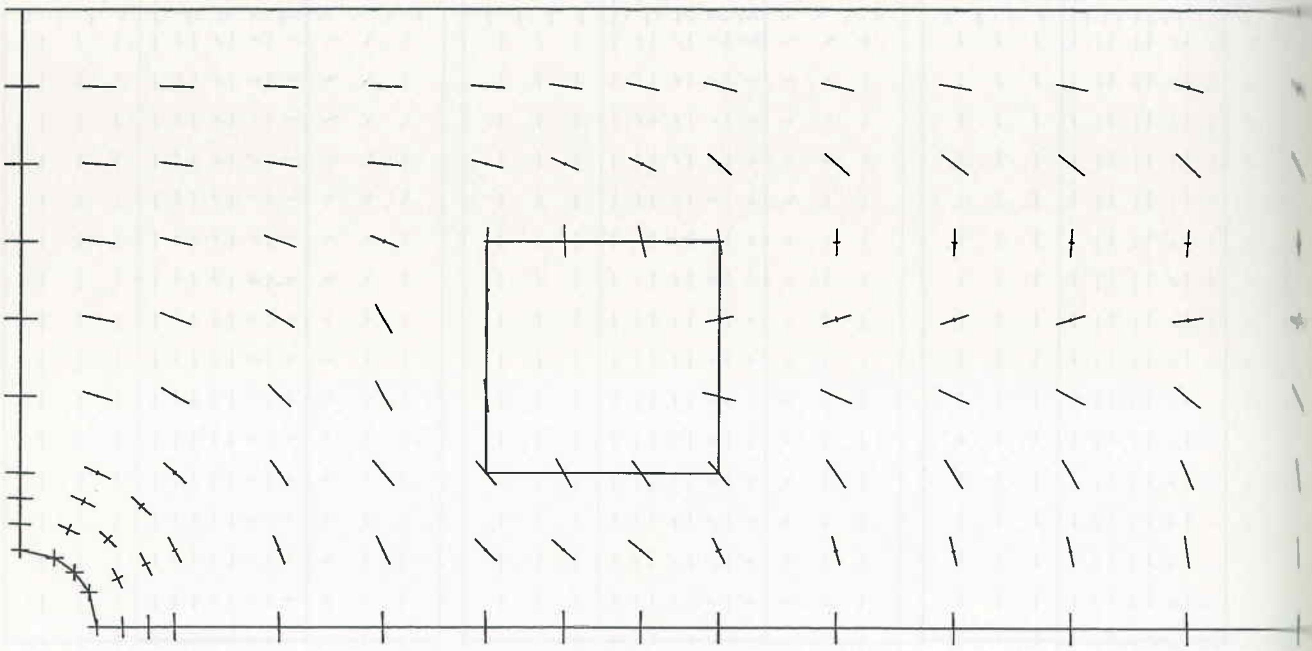

Fig.5. Same geometry as in Fig. 4 :
final orientation field in the case of a concentrated suspension of long fibres