COST 526

"Automatic Process Optimization in Materials Technology"

(APOMAT)

Half-Year Report

1. Reporting Period	**1.7.2002 – 31.12.2002**
Project title	Form Final properties of Components to Mould and process Design in Metal Injection Moulding
Project leader Organization	Prof. Jean-Claude GELIN LMA/ENSMM, 24, chemin de l'Epitaphe 2500 Besançon, FRANCE
Main collaborators involved	Dr T. Barriere LMA/ENSMM, 24, chemin de l'Epitaphe 2500 Besançon, FRANCE Prof. LIU Baosheng, Southwest Jiaotong University, 610031 Chengdu, China

2. Funding Situation	
Amount of money received specifically for COST	0 kEuros
Other resources partially used for the project	30 kEuros

3. International Collaboration (Mentioning the group and type of work done in collaboration in the reporting period)
The development of bi-phasic simulations for Metal Injection Moulding with an effective algorithm is performed in collaboration with Southwest Jiaotong University. Prof. Liu plays a key role in this collaboration with the financial support of invited professor program of Franche-Comte University. A co-tutorial Ph.D. is launched on this research subject under the direction of both French and Chinese tutors.
Participation of the Working Group Meeting in Budapest + project progress report YES

4. Industry participation (Mentioning the name of companies and work done in collaboration in the whole project)

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**
Working Group meeting	Budapest, Nov 28-29, 2002
Exchange of scientists	Mr. CHENG Zhiqiang performed a 6 months period in Besancon under the cotutorial direction of Prof. Gelin and Prof. Liu

6. Progress in the reporting period
(Not exceeding 3 pages, including tables and figures)

HYR2: Project F2: From final properties of components to mould and process design in metal injection molding.

Summary: During the concerned period, the development of a bi-phasic simulation model for the prediction of the powder segregation has been a key aspect of the research project in metal injection moulding

1-Bi-phasic modeling of the MIM injection with mixture theory

The mixture flow in MIM may produce the undesirable powder segregation. It should be controlled at an accepted level. The simulation tool for prediction of the segregation, as well as other characteristics of the injection flow, is necessary for optimization of the process design. See Figure. 1.

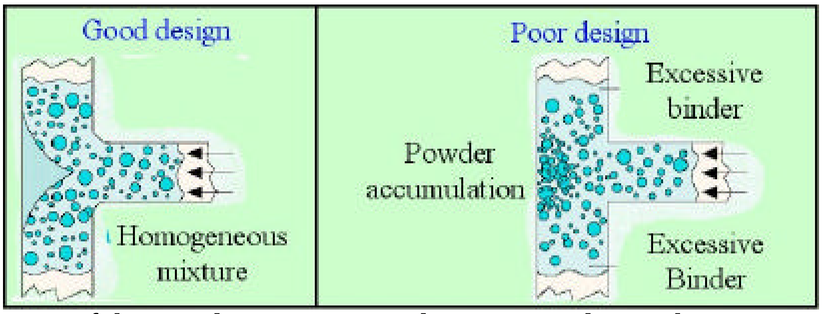

Figure1. Illustration of the powder segregation phenomenon during the injection stage in MIM.

Objectives:

- Determination of velocity and pressure fields during injection
- Determination of the filling state
- Modeling of segregation phenomenon (powder accumulation or dilution)
- Modeling of front movement and welding lines

Two coupled Navier-Stokes Equations have to be solved with high efficiency:

$$\rho_s \frac{\partial \boldsymbol{V}_s}{\partial t} = -\nabla(\phi_s P) + \nabla \bullet \boldsymbol{s}_s' + \rho_s \boldsymbol{g} + \boldsymbol{m}_s$$

$$\rho_f \frac{\partial \boldsymbol{V}_f}{\partial t} = -\nabla(\phi_f P) + \nabla \bullet \boldsymbol{s}_f' + \rho_f \boldsymbol{g} + \boldsymbol{m}_f$$

In which the subscript s indicates the flow of powder phase while f stands for the flow of binder phase. ϕ_s and ϕ_f indicate volume fraction field for each phase, which represents the important segregation effect, $\boldsymbol{m}_s$ and $\boldsymbol{m}_f$ are the interaction terms between the flows of both phases. The viscous behaviors of both phases should be taken into account distinctly though a non Newtonian model. The incompressibility of the mixture should be respected for mixture flow.

2-New algorithm for explicit simulation of the bi-phasic filling flow

An explicit algorithm with high efficiency has been developed for the MIM simulation in optimization procedures. This specific algorithm can be schematically illustrated as shown in Figure 2.

Fractional steps	Solid phase	Fluid phase
(1) Interaction between two phases (LR)	$\rho_s \frac{\partial [V_s^* - (V_s)_n]}{\partial t} = k\,(V_f - V_s)_n$	$\rho_f \frac{\partial [V_f^* - (V_f)_n]}{\partial t} = k\,(V_s - V_f)_n$
(2) Viscous diffusion (LR)	$\rho_s \frac{\partial (V_s^{**} - V_s^*)}{\partial t} = \nabla \cdot \sigma'_s + \rho_s g$	$\rho_f \frac{\partial (V_f^{**} - V_f^*)}{\partial t} = \nabla \cdot \sigma'_f + \rho_f g$
(3) Pressure field (GR)	$\left(\underset{\Omega^E}{A} C^T \left[\frac{\phi_f}{M_{f0}} + \frac{\phi_s}{M_{s0}} \right] C \right) P = \frac{1}{\Delta t} \left(\underset{\Omega^E}{A} \left[\phi_s C^T V_s^{**} + \phi_f C^T V_f^{**} \right] \right)$	
(4)Velocity field (LR)	$V_s^{n+1} = V_s^{**} - \Delta t\, M_s^{-1} C\, P$	$V_f^{n+1} = V_f^{**} - \Delta t\, M_f^{-1} C\, P$
Volume fraction (LR)	$\frac{\partial \phi_s}{\partial t} + \nabla \bullet (\phi_s V_s) = 0$	$\frac{\partial \phi_f}{\partial t} + \nabla \bullet (\phi_f V_f) = 0$
Filling field (LR)	$\frac{\partial F}{\partial t} + V_{eff} \cdot \nabla F = 0$	$V_{eff} = \phi_s V_s + \phi_f V_f$

Figure 2. Explicit algorithm in fractional steps (LR: Local resolution, GR: Global resolution).

In such an algorithm, only one global solution for pressure field is required at each time step. Other operations are uncoupled and explicit with low computational cost.

3-The results of bi-phasic simulation for MIM injection

Various examples concerning MIM cases have been treated with the developed simulation tool. The simulation by finite elements method provide the detail information on different physic fields of the injection process, such as the segregation, the evolution of filling state, the velocities of different phases and their effective velocity, the front welding phenomenon, etc.

The injection of a mobile phone shell is taken as an example. The following parameters are used:

$P_{imposed}$= 50 MPa or 5 MPa	k = 10^{11} Pa.s.m^{-2}
Sticking wall for the two phases	f_{s_o} = 45% or 75%
r_s = 7500 kg.m^{-3} r_f = 7500 kg.m^{-3}	Element type: 2D MINI-Element
m_s = 200 Pa.s m_f = 20 Pa.s	Element nb. 3340, Nodes Nb. 5495

Figure 3. Parameters used in simulation for MIM injection of a mobile phone shell

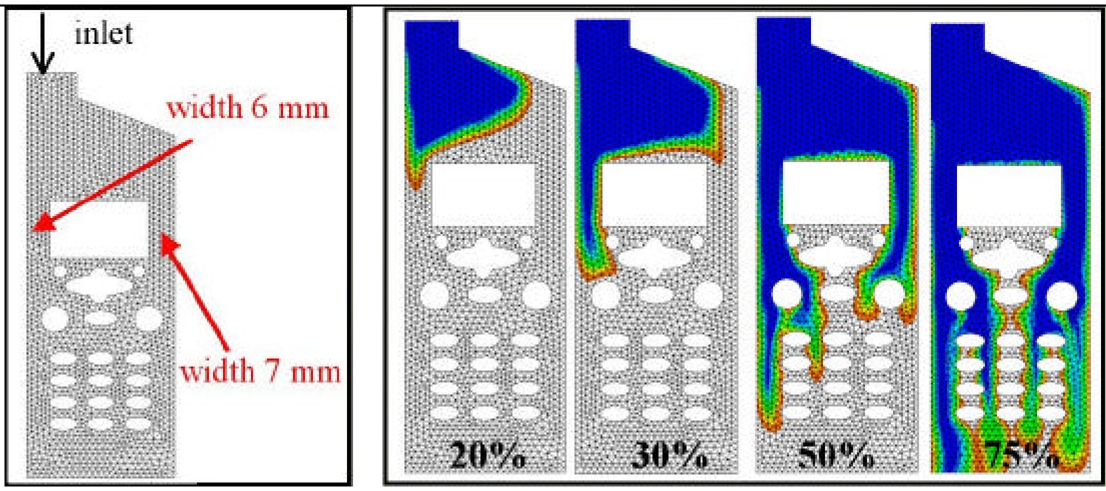

Figure 4. Filling patterns at different values for mould filling.

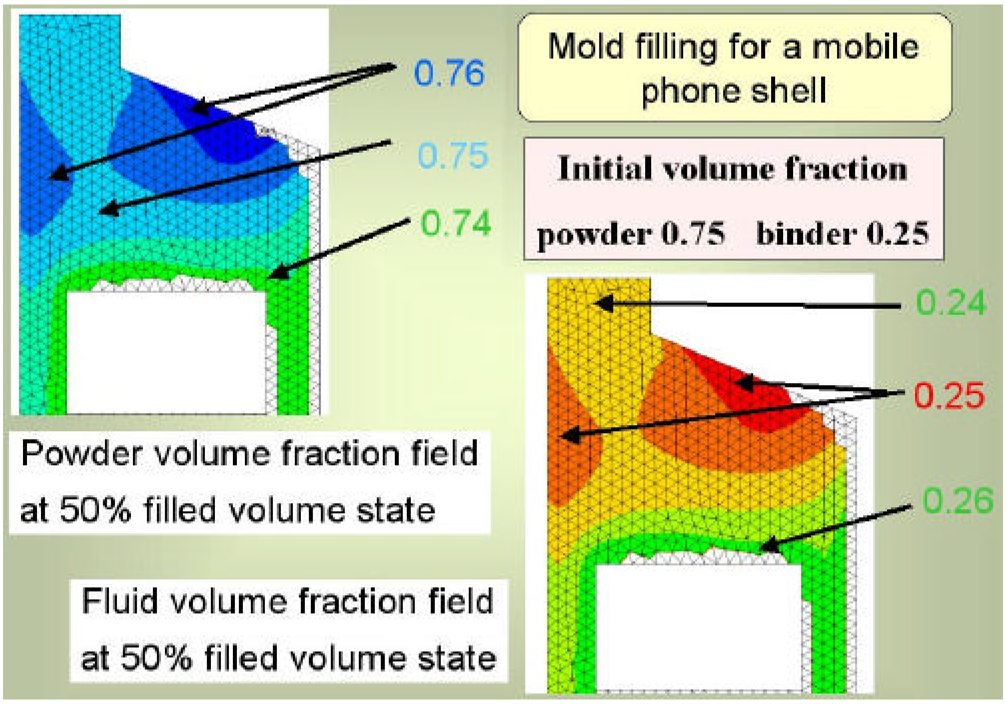

Figure 4. Powder and binder volume fractions corresponding to a filling stage equals to 50%.

6-Further and concluding remarks

The development of an effective simulation tool for prediction of the powder segregation is very important in both analysis of the injection process and associated optimization. This work provides an important way to perform the optimization including a crucial effect in MIM injection. An efficient explicit algorithm is hence a key issue to perform the MIM optimization. The success and further advance in this research subject consist of an important part of the APOMAT project.

References:

[1] Gresho P.M., Chan S.T., Lee R.L. and Upson C.D., A modified finite element method for solving the time dependent, incompressible Navier-Stokes equations. Part 1 and Part2, Int. J. for Num. Methods in Fluids, Vol.4, 1984, pp.557-598.

[2] Lewis R.W.,Usmani A.S. and Cross T.J., Efficient mould filling simulation in

castings by an explicit finite element method, Int. J. for Numerical Methods in Fluids, Vol.20, 1995, pp.493-506.
[3] T. Barriere, B. Liu, J.C. Gelin, Analysis of phase segregation effects arising in fluid-particle flows during metal injection molding, Int. J. of Forming Process, Vol. 3-4, 2001, pp.199-216.

7. List of publications

a) Published

T. Barriere, J.C. Gelin, B. Liu, Experimental and numerical investigations on the properties and quality of parts produced by MIM, Powder Metallurgy, Vol. 44, 3, 2001, pp. 228-234.

T. Barriere, J.C. Gelin, B. Liu, Analysis of phase segregation effects arising in fluid-particle flows during metal injection molding, Int. J. of Forming Process, Vol. 4, N° 3-4, 2001, pp. 199-216.

J.C. Gelin, T. Barriere, B. Liu, Mould design methods by experiment and numerical simulation in metal injection molding, J. of Engineering Manufacture, Part B, Vol. 126, 2002, pp. 1533-1547.

T. Barriere, J.C. Gelin, B. Liu, Experimental exploitation and new simulation method for metal injection moulding, 5th ESAFORM International Conference on Material Forming, Ed. by M. Pietrzyk, Z. Mitura and J. Kaczmar, Akademia Gorniczo-Hutnicza, Krakow, April 14-17 2002, Mini-Symposium 6 – Innovative Powder Forming Processes, pp. 331-334 (keynote paper).

b) Submitted for publications

T. Barriere, B. Liu, J.C. Gelin, Determination of the optimal process parameters in metal injection molding from experiments and numerical modeling, Int. J. of Mechanical Sciences, 2001.

c) In preparation