COST 526

"Automatic Process Optimization in Materials Technology"

(APOMAT)

Half-Year Report

1. Reporting Period	**1.1.2003 – 30.6.2003**
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, Dr. A. Lejeune, G. Ayad 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	Optimat Project	40 kEuros

3. International Collaboration (Mentioning the group and type of work done in collaboration in the reporting period)
Participation of the Working Group Meeting in Brussels + project progress report YES

4. Industry participation (Mentioning the name of companies and work done in collaboration in the whole project)
Comotec, Hoptec, La Doyle, 39402 Morez, France

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**
Working Group meeting Exchange of scientists	Brussels, May 2003 - Mr. CHENG Zhiqiang performed a 6 months period in Besancon under the cotuterial direction of Prof. Gelin and Prof. Liu - Prof. Liu get a position of invited professor for 2 months in LMARC/ENSMM, France

6. Progress in the reporting period

(Not exceeding 3 pages, including tables and figures)

HYR1: Project F2: From final properties of components to mould and process design in metal injection molding.

Summary: Accordingly to the updated work plan of the project, the last developments concern the definition on overall strategy for optimization of the injection and sintering stages in MIM.

1 Definition of the general strategy for optimization in MIM

The overall optimization strategy defined for MIM is schematized in Fig. 1, including all the links with finite element simulation software [1].

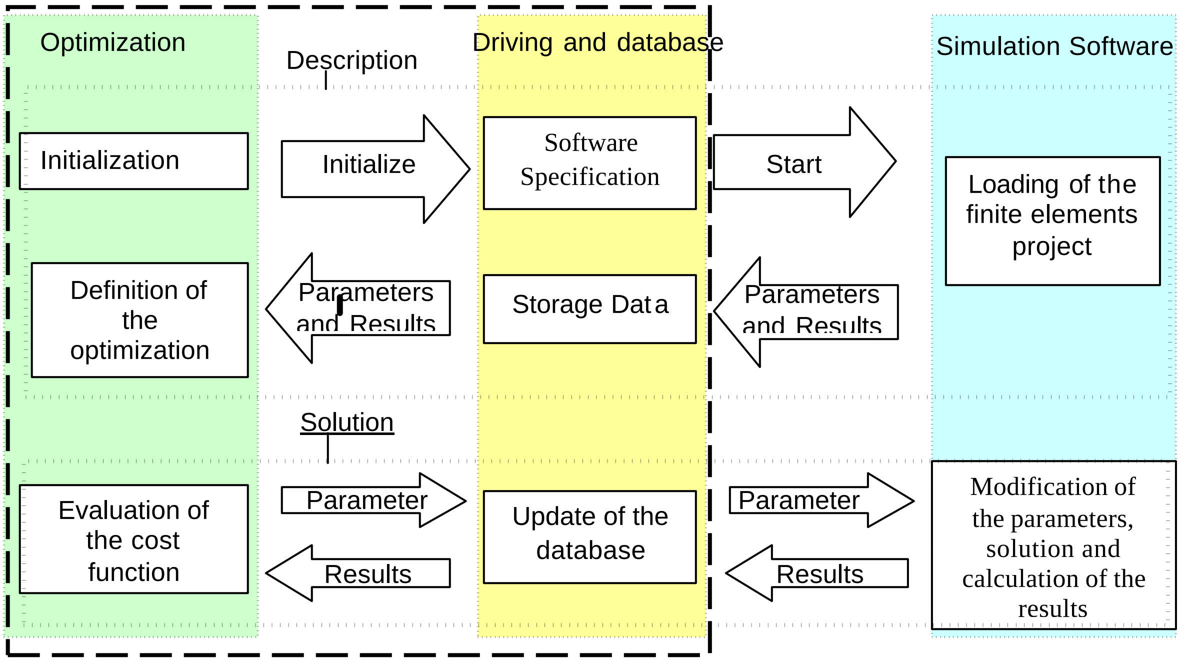


Fig 1: The overall strategy for optimization in MIM

2 Parameters to be optimized and cost function

The main parameters to be optimized are defined as following:

Injection parameters:

- Injection Pressure and Velocity,
- Packing Pressure,
- Injection Temperature,
- Mold Temperature,

- Melt Temperature,
- Filling Time,
- Cooling Time,
- Runners cross section,
- Number of mould gates.

Mold parameters:

- Runners cross section,
- Number of mould gates.

Viscosity law:

-Viscosity = $f(\Phi_S, T, \dot{e}, ...)$.

3 Objective function

The proposed objective function accounts for the effects in mould cavity geometry and concerns the minimization of powder segregation in injection molding. It is expressed as:

$$f(x) = w_1 \left(\frac{1}{M} \sum_{i=1}^{M} \frac{\left| X_i^{CAO} - X_i^{NUM} \right|^p}{X_i^{CAO}} \right)^{1/p} + w_2 \left(\frac{1}{N} \sum_{i=1}^{N} \frac{\left| \Phi_{S,i} - \Phi_{S_0} \right|^q}{\Phi_{S_0}} \right)^{1/q}$$

The physical and technological constraints are listed as:

$$\begin{cases} T_{mold}^{\min} < T_{mold} < T_{mold}^{\max} \\ T_{melt}^{\min} < T_{melt} < T_{melt}^{\max} \\ t_{cooling}^{\min} < t_{cooling} < t_{cooling}^{\max} \\ P_{inj} < P_{\lim} \\ \Phi_S < \Phi_C \\ \left| V_{fill} - V_{cavity} \right| < Tol \end{cases}$$

4 Optimization Method

The proposed method for optimization consists firstly to the generation of a response surface associated to the cost function [2]. Then the optimization method is applied to the response function that permits to reduce the total number simulations during the optimization stage.

In order to determine the most sensitive parameters [3], the proposed process consists in the first stage to the design of experiments to define the driving parameters, see figure 2.

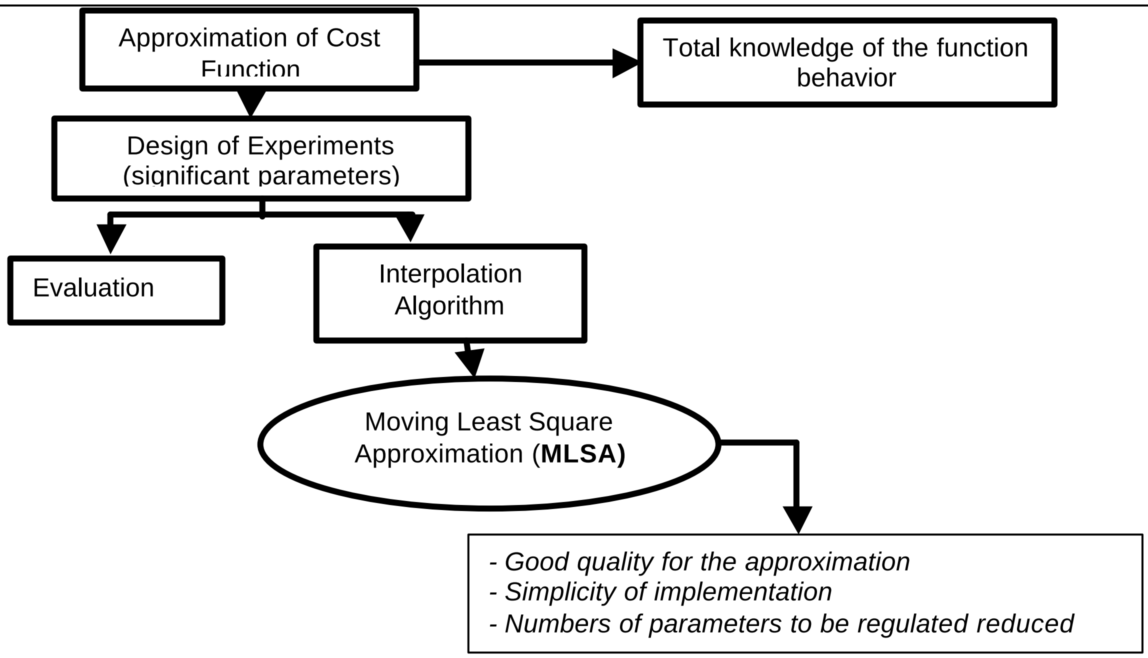


Fig 2: The optimizations strategy

In order to provide an analytical form as close as possible to the response of the process, an innovative interpolation algorithm (Moving Least Square Approximation MLSA) is adopted for the interpolation the response surface. The construction of an approximated analytical function by MLSA method is illustrate In figure 3, corresponding to the following equation:

$$F(x,y) = 0.01((x+0.5)^4 - 30x^2 - 20x + (y+0.5)^4 - 30y^2 - 20y)$$

$$\begin{cases} -6 \le x \le 6 \\ -6 \le y \le 6 \end{cases}$$

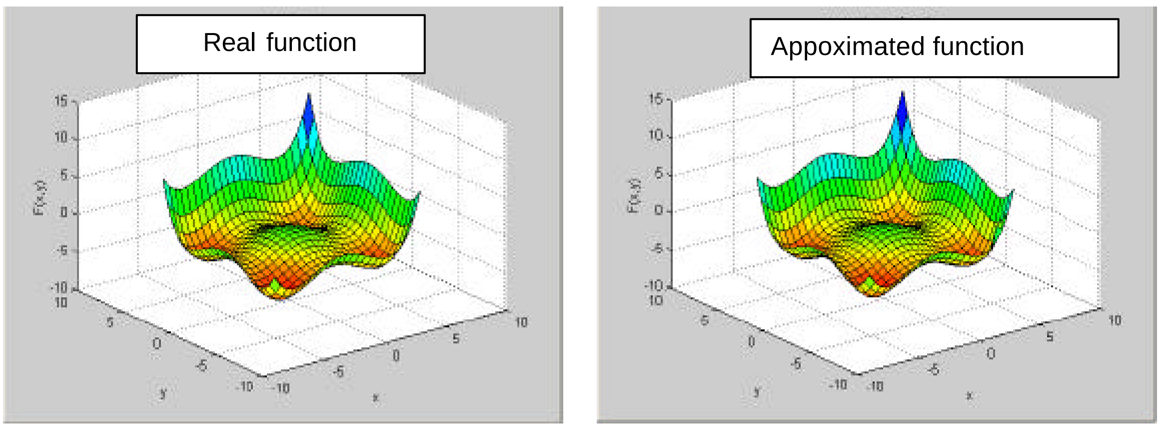
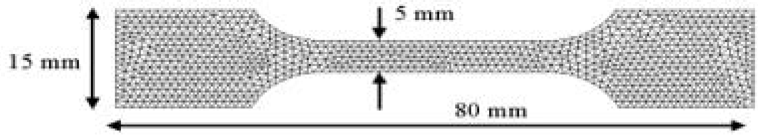


Fig 3: A numerical example which illustrates the MLSA method

5-Application in Metal Injection Molding

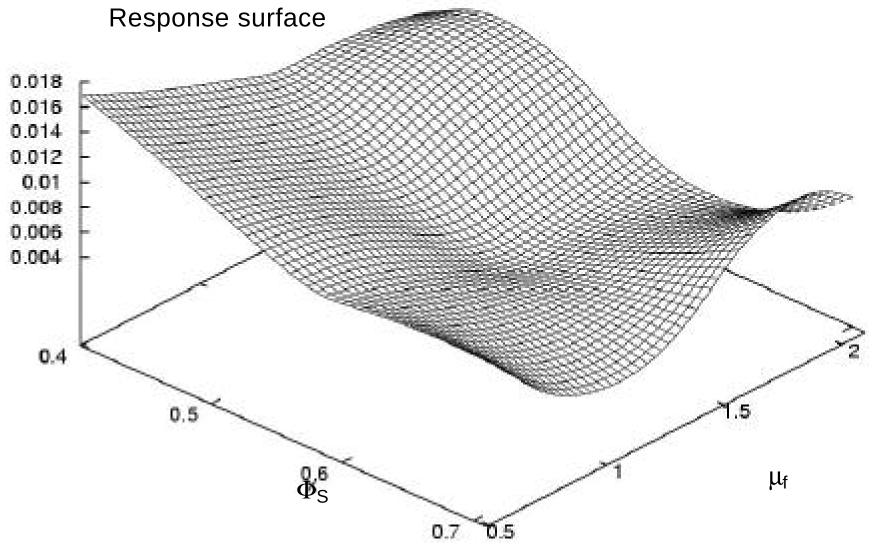
The proposed optimization strategy has been applied in MIM. The studied case is the injection of a tensile test specimen. The admissible range for the selected process parameters are indicated in figure 4.



- Factor A: Viscosity Law (Experimental Data or Newtonien Law (10 Pa.s)),
- Factor B: Injection pressure ([1 – 16MPa]),
- Factor C: Melt temperature ([90 – 220°C]),
- Factor D: Mould temperature ([30 – 50°C]),
- Factor E: Powder volume fraction ([0.4 – 0.7]),
- Factor F: Interaction coefficient ([0.001 – 0.007]),
- Factor G: Powder density ([1 – 8g/cm^3]),
- Factor H: Binder density ([0.5 – 2.5g/cm^3]).

Fig 4: A tensile test specimen and the process parameters

A fractional design of experiments (DOE) based on a TAGAUCHI method [4] has been applied. It is found that the most sensitive parameters are: Powder volume fraction, Interaction coefficient, Powder density and Binder density.
The optimization process has been applied in MIM for injection of the tensile test specimen (figure 4), 16 computations are used to evaluate the response surface function. The results are given in Fig 5 a. This obtained response surface represents well the influence of process parameters. But it should be noticed that the sub domain around the minimum point has to be defined more accurately. In figure 5 b, one can find clearly that the segregation effects are considerably reduced.



a)

b) Optimum values :

- Φ_S = 0.56
- μ_f=1.5 g/cm^3

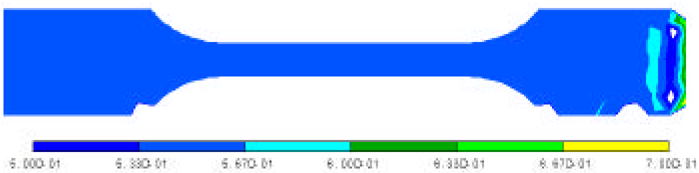


Fig 5:a) Response surface, b) Powder volume fraction contour after optimization

6-Further and concluding remarks

In order to solve large scale optimization problems in MIM, the work is now focusing on the automatic construction of the response surface and the optimization tools (GA, EA or FSQ methods).

References :
[1] T. Barriere, B. Liu, J.C. Gelin, Determination of the optimal parameters in metal injection molding from experiments and numerical modeling, J. of Materials Processing and Technology, Vol. 143-144, 2003, pp. 636-644.
[2] : T.Belytschko et al., Meshless methods : an overview and recent developments, Comput. Methods Appl. Mech Engrg. 139 (1996) 3-47.
[3] : P.Scimmerling et al., Pratique des plans d'expérience, Lavoisier & Doc, 1998
[4] : M. Pillet, "*Les Plans d'Expériences par la Méthode TAGUCHI*", Les Editions d'Organization, ISBN 2-70-812031-X, 1997.

7. List of publications

a) Published

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, B. Liu, J.C. Gelin, Determination of the optimal parameters in metal injection molding from experiments and numerical modeling, J. of Materials Processing and Technology, Vol. 143-144, 2003, pp. 636-644.

J.C. Gelin, G. Ayad, T. Barriere, A. Lejeune, Analysis and finite element modeling of powder segregation occurring in metal injection molding of stainless steels, PM^2TEC conference, USA, Las Vegas, 2003.

b) Submitted for publications

J.C. Gelin, T. Barriere, Ségrégation de phases dans les écoulements de polymères fondus charges en poudres métalliques, Mécanique et Industries, Elsevier, proposed in december 2002.

c) In preparation