

# Setting of the Operative Processing Window in Injection Moulding Using a Multi-Optimization Approach: Experimental Assessment

C. Fernandes, J.C. Viana, A.J. Pontes, A. Gaspar-Cunha

*IPC- Institute for Polymers and Composites, Dept. of Polymer Engineering, University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal.*

*URL: [www.dep.uminho.pt](http://www.dep.uminho.pt)*

*e-mail: [cbpf@dep.uminho.pt](mailto:cbpf@dep.uminho.pt); [jcv@dep.uminho.pt](mailto:jcv@dep.uminho.pt)  
[pontes@dep.uminho.pt](mailto:pontes@dep.uminho.pt); [agc@dep.uminho.pt](mailto:agc@dep.uminho.pt)*

**ABSTRACT:** The use of commercially available injection moulding simulation software's allows us to predict the process response to the operating conditions defined. These codes can be used to define better injection conditions to use in specific situations, i.e., to optimize the process. Generally, this is an iterative procedure requiring the analysis of multiple outputs (pressures, temperatures, shear stresses profiles) supported by pre-established decision criteria. Most of the cases the taken options may lead to opposed results. In this sense the development of optimization methodologies are of paramount importance in order to facilitate the definition of processing windows in injection moulding. In this work the results obtained by the use of an automatic optimization methodology based on Multi-Objective Evolutionary Algorithms (EMOA), where an EMOA is linked to an injection moulding simulation code (CMOLD), will be assessed experimentally. For that purpose the processing conditions will be optimized for a desired process performance, where criteria, such as the evolution of the pressure inside the cavity, the maximum pressure level, the pressure work and the shrinkage, are taken into account. Some of the computational results obtained, selected from the set of optimized and non-optimized solutions, will be compared with the corresponding experimental results in order to validate the optimization approach used.

**Key words:** Injection Moulding, Multi-Objective Optimization, Evolutionary Algorithms

## 1 INTRODUCTION

The injection moulding technique is a high throughput process adequate to manufacture thermoplastic components of complex geometry with tight dimensional tolerances. Injection moulding of polymeric materials is an intricate dynamic and transient process, involving convoluted melting-flow-pressure-solidification phases and a complex material behaviour strongly affecting the quality and properties of the final moulded component.

In injection moulding, the thermomechanical environment imposed to the polymer melt is controlled by: i) the adjustment of operative processing variables ii) the selection of process parameters.

This thermomechanical conditions control the microstructure and morphology of the final moulded

component [1,2], which determines their dimensions (shrinkage), dimensional stability (distortion and warpage) and properties (e.g., mechanical behaviour, permeability, appearance) [3, 4]. Furthermore, in order to produce injection moulding components of high quality at the lowest costs, the processing conditions have to be initially adjusted to avoid moulding defects, such as flash, no completely filled component, surface and aesthetic defects, material degradation and process instabilities. The establishment of the adequate processing conditions to mould a high quality plastic component is therefore a complex task because there are significant number of processing variables, a high level of interactions between these variables and numerous moulding features and end-use properties to maximize.

Nowadays, the use of computational simulations of the injection process (e.g., based on finite/volume element methods) is a well established tool in the

industrial environment. Generally, this is an iterative procedure requiring the analysis of multiple computed outputs (e.g., pressures, temperatures, shear stresses profiles) supported by pre-established decision criteria [5, 6]. Most of the cases, the taken options may lead to opposed results. In this sense the development of optimization methodologies are of paramount importance in order to facilitate the definition of processing windows in injection moulding. The definition of a global integrated scheme for a full optimization of the injection moulding process and maximization of the moulding properties is of therefore of paramount importance. Particularly, the application of this methodology to the proper setting of the processing variables to manufacture engineering injection moulded components (process optimization) is the aim of this work. The optimization of the injection moulding process, where different optimization strategies have been used [7-11].

In this work is proposed the use of an automatic optimization methodology based on MOEA [12] to define the processing window (melt and mould temperatures, injection flow rate, switchover point, holding time and pressure) in injection moulding. For that purpose a MOEA is linked to an injection moulding simulator code (in this case CMOLD). Optimization criteria were defined based on the simulation outputs. The results define the Pareto frontier leading to the multi-constrained optimized criteria, allowing the establishment of the operative processing conditions. An identical approach has been used previously to optimize the processing conditions for a desired morphological state or for an enhanced mechanical response [13].

## 2 PROBLEM STATEMENT

Computer simulations of the injection moulding process are widely used in the design stages of engineering plastic components [e.g. 5, 6]. Commonly, a (finite element) mesh representative of the part geometry is constructed, the materials (e.g., polymer, mould, cooling fluid) are selected, the gate location is defined and the initial processing variables are introduced. The simulation is launched and the selected outputs are analysed. An iterative process progresses, where the initial conditions (geometry, material, processing conditions) are modified until the desired results are obtained. This is a trial-and-error approach and most of the cases

multiple criteria are to be optimized that makes the decisional process rather complex. Furthermore, the finding of a global optimum solution is not guaranteed.

The approach proposed in this work integrates the computer simulations of the injection process, an optimization methodology based on evolutionary algorithm and multi-objective criteria in order to establish the set of operative processing variables leading to a good moulding process. Initially, a set of process and moulding component criteria is defined based on the outputs of the simulation code that were selected accordingly to the common practice followed in the results analysis of the computer simulations [5, 6]. The optimization methodology adopted is based on a Multi-Objective Evolutionary Algorithm (MOEA) described in more detail in section 3 [12].

## 3 OPTIMIZATION ALGORITHMS

Evolutionary Algorithms (EAs) are search and optimization methods that mimic the process of natural evolution. They are based on a population of potential solutions (or chromosomes) that evolves during the successive generations (or iterations). To each individual is associated a value (fitness or objective function) that represents a measure of its performance on the system. Individuals with greater performance have a bigger opportunity for reproduction, i.e., to pass their characteristics to future generations [14].

EAs starts by the initialization of population, i.e., the random definition of all individuals of the population. Each individual (or chromosome) is represented by the binary value of the set of all variables. Then, the individuals are evaluated by the calculation of the values of the criteria using the modelling routine (in this case C-MOLD). To each individual is assigned a single value identifying its performance on the process (fitness). This fitness is calculated using a Multi-Objective approach as described below. If the convergence criterion is not satisfied (e.g., a pre-defined number of generations), the population is subjected to the operators of reproduction (i.e., the selection of the best individuals for crossover and/or mutation) and of crossover and mutation (i.e., the methods to obtain new individuals for the next generation).

Simultaneously, real optimization problems are generally multi-objective, i.e., they require the

simultaneous optimization of various, often conflicting, criteria [15-17]. The solution must then result from a compromise between the different criteria. To take into account this characteristic, an approach based on the concept of Pareto frontiers (i.e., the set of points representing the trade-off between the criteria) together with an EA was been used. The objective is to obtain simultaneously several solutions along the Pareto frontier. A Pareto frontier is constituted by the set of non-dominated solutions. Figure 1, where two criteria to maximize are represented, illustrates this concept. For example, point 2 is better for the two criteria than point 5, thus point 5 is dominated by point 2. The same conclusion can be draw when point 6 is compared with point 3. Therefore, points 1, 2, 4 and 4 are non-dominated and constitute the Pareto frontier. A MOEA using this concept, was been developed, the details are given elsewhere [12].

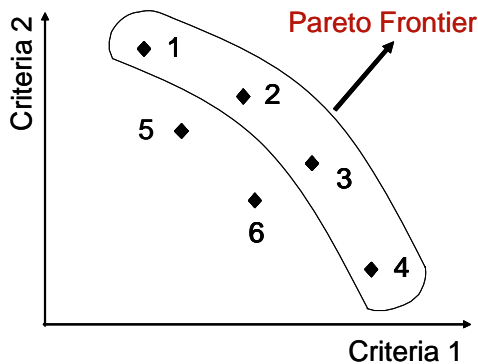


Fig. 1. Pareto frontier

#### 4 EXAMPLE OF APPLICATION

The proposed optimization methodology was used to set the processing conditions of the moulding (Figure 2) in polystyrene (STYRON 678E). The moulding was injected in a fan gate. The relevant polymer properties used for the flow simulations were obtained from the software (CMOLD) database.

The mesh has 408 triangular elements. The simulations considered the mould filling and holding (post-filling) stages. A node near the P1 position, pressure sensor position (see figure 2) was selected as a reference point for this study. The processing variables to optimise and allowed to varied in the simulations in following intervals were: injection time,  $t_{inj} \in [0.5; 3]$  s, melt temperature,  $T_{inj} \in [180; 280]$  °C, mould temperature,  $T_w \in [30; 70]$  °C, absolute holding pressure,  $Ph \in [7; 38]$  % of

maximum machine injection pressure, with fixed switch-over point, SF/P at 99 %, post fill time,  $t_{2P}$  at 30 s and timer for hold pressure at 15 s.

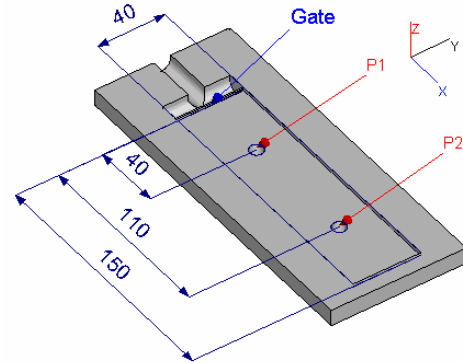


Fig. 2. Injection moulding part with 2 mm of thickness (dimensions in mm)

Two process restrictions were imposed in the simulations: the moulding has to be completely filled, obviously no short-shots were admitted; the computed values of the maximum shear stress and strain-rate were limited to their critical values (defined on the CMOLD database) in order to avoid potential defects (e.g., melt fracture).

The optimization criteria were established based on indirect moulding quality indicators (a-c) and productive parameters (d-f) as follows:

- The temperature difference on the moulding at the end of filling,  $dT = (T_{max} - T_{min})$ , was minimised;
- The pressure difference  $dP = (P_{max} - Ph)$  was minimised;
- The volumetric shrinkage of the mouldings was minimised;
- The maximum pressure was minimised;
- The cycle time was minimised;
- The pressure work was minimized.

#### 5 RESULTS

The purpose of this work is to validate experimentally the optimization methodology proposed. Thus, a single optimization run, using as criteria the minimization of pressure work and of the volumetric shrinkage was been carried out. These criteria were chosen due to the possibility of measuring them experimentally on the available injection machine. Six points were chosen from the Pareto frontiers obtained for the initial and the final populations of the EA (Figure 3). These solutions

were after tested in an injection moulding machine and the corresponding results were compared in Figure 4. As can be seen the general behaviour of the experimental and computational solutions is very similar (i.e., its relative location), the differences been due to the capacity of the modelling program (C-MOLD) in reproducing the reality. Therefore, since the aim here is to validate the optimization methodology, seems that the optimization results obtained are adequate for the process and the optimization procedure can be adopted as a global methodology for this process.

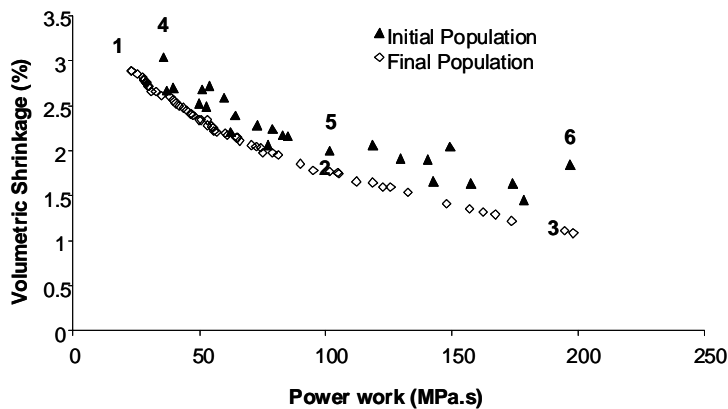


Fig. 3. Pareto frontier

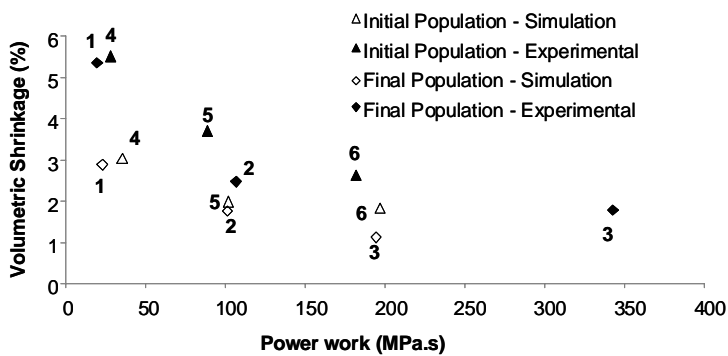


Fig. 4. Pareto frontier

## 6 CONCLUSIONS

An injection moulding finite-element based computational code was linked to a multi-objective evolutionary algorithm allowing the optimization of the process for obtaining high quality parts. This methodology is sensitive to the used optimization criteria, and the obtained results have physical meaning. The experimental results produced validated the proposed optimization methodology.

## ACKNOWLEDGEMENTS

This work was supported by the Portuguese Fundação para a Ciência e Tecnologia under grant SFRH/BD/28479/2006.

## REFERENCES

- Viana J.C., Cunha A.M., and Billon N., 'The thermomechanical environment and the microstructure of an injection moulded polypropylene copolymer', *Polymer*, 43, (2002) 4185-4196
- Viana J.C., 'Development of the skin layer in injection moulding: phenomenological model', *Polymer*, 45, (2004) 993-1005
- Chang T.C., and Faison III E., 'Shrinkage behaviour and optimization of injection molded parts studied by the taguchi method', *Polym. Eng. Sci.*, 41, (2001) 703-710
- Viana J.C., Billon N., and Cunha A.M., 'The thermomechanical environment and the mechanical properties of injection moldings', *Polym. Eng. Sci.*, 44, (2004) 1522-1533
- Cmold User's manual
- Moldflow User's manual
- Kim S.J., Lee K., Kim Y.I., *Proceedings of SPIE – the 4th Int. Conf. on Computer-Aided Design and Computer Graphics*, 2644, (1996) 173-180
- Lotti C., Bretas R.E.S., 'The influence of morphological features on mechanical properties of injection molded PPS and sits prediction using neural networks' *Proceedings of PPS 2003 European Conference*, Athens, (2003) 184-P
- Castro C., Bhagavatula N., Cabrera-Rios M., Lilly B., Castro J.M., 'Identifying The Best Compromises Between Multiple Performance Measures In Injection Molding (IM) Using Data Envelopment Analysis', *Proceedings SPE technical papers ANTEC'03*, Nashville, (2003)
- Tung L.S., Peic M., *Journal of Engineering Manufacture*, *Proceedings of the Institution of Mechanical Engineers Part B*, 216, (2002) 1523
- Alam K., Kamal M.R., *Proceedings SPE technical papers ANTEC'03*, Nashville, (2003)
- A. Gaspar-Cunha and J.A. Covas, *Lecture Notes in Economics and Mathematical Systems*, In: *Metaheuristics for Multiobjective Optimization*, eds, X. Gandibleux, M. Sevaux, K. Sörensen and V. T'kindt, Springer-Verlag, Berlin (2004) 220-249.
- Cunha-Gaspar A., and Viana J.C., 'Using Multi-Objective Evolutionary Algorithms to Optimize Mechanical Properties of Injection Moulded Parts', *Int. Polym. Proc.*, XX, 3, (2005) 274-285
- D.E. Goldberg, *Genetic Algorithms in Search, Optimization and Machine Learning*, Addison-Wesley (1989).
- A. Gaspar-Cunha, *Modelling and Optimisation of Single Screw Extrusion*, Ph. D. Thesis, University of Minho, Braga (2000).
- K. Deb, *Multi-Objective Optimization using Evolutionary Algorithms*, Wiley (2001).
- C.A. Coello Coello, D.A. Van Veldhuizen and G.B. Lamont, *Evolutionary Algorithms for Solving Multi-Objective Problems*, Kluwer (2002).