Simulation of Polymer Injection Molding: A New Practical Approach to Improve Computation Accuracy

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Simulation of injection molding of polymeric materials is still a series scientific and engineering problem. The quality of the input data is crucial for computation accuracy. The original, relatively simple tool has been designed to validate simulations. This allows a fast identification of the critical input data, and next their proper adjustment to computations. FEM simulations have been compared with directly registered pictures of cavity filling process in a special injection mold with a sight-glass.
Keywords: nano-objects, aerosol generator, aerosol neutralizer, high-temperature furnace, validation, number concentration.

Introduction

Injection molding is widely used in production of all types of goods made of plastics. However, injection molding process and mold filling phenomena are still not fully understood.

Simulation software is a very powerful tool for designing and manufacturing the molds. One of the most important issues of using the software is the quality of input data which are very often wrong or even missed. It is well known that the quality of simulation results is strongly dependent on the quality of input data, mainly material and process data.

Rheological properties of the material are the most important material input data. These are described by the rheological models of different type. Parameters of the models are determined through rheological measurements with using advanced measuring instruments, rheometers. However, the temperature, pressure and shear rate conditions of measurements are usually very far from injection molding process conditions. So, various on-line measurement techniques are of great value for the simulation practice.

Although the quality of input data is very important for computer simulation of the injection molding process, only a few methods of verification and further correction of these have been developed so far. One approach to this problem is a 'reverse simulation method' [1]. It is based on a continuous, repeated comparisons of simulation results and experimental data obtained from an injection molding machine. The comparing procedure continues until comparable data, e.g. filling time and sprue pressure curve are achieved. Some recommendations for using this method are given in the literature [1].

Injection molds with sight-glasses have been used for mold filling studies since the late 50s [2, 3]. Direct observations through a sight-glass have been used for multi-cavity mold filling imbalance phenomenon [4]. In-mold flow of highly filled materials have been also investigated by direct mold filling observations [5].

The great majority of injection molding simulation verifications have been done using a simple 'short shot' method. Most recent attempts been performed by Chen [7, 8] and Okonski [9]. However, accuracy of injection molding simulations can also be tested with 'sight-glass' method which has recently been done in [6].

Generally, the most sophisticated software (the highest versions of the software) have been used to compare simulations with experimental data. However, many of leading injection molding programs have got their simplified, more user-friendly versions added to the commercial CAD systems. These simplified add-ons are still more commonly used in the industry than their more sophisticated 'big brothers'.

The main target of this study was to develop a fast and simple method of verification of computer simulations which can next result in possible improving of input data.

Statistical methods, regression analysis and response surface analysis may be used both for optimization by computer simulation and by analyzing data from experiment. Using factorial design of experiments DOE may allow to optimize input data. The optimum input data may be found by locating the extremum on the response surfaces relating to the simulation/experimental results of the process behavior, e.g. filing time, that are the design criteria of the process. The main drawback of this method is the number of required experiments.

Evolution strategies (Genetic Algorithms) are a good way to omit this problem. They start from a set of randomly generated points and confine the region where the optimum is located using genetic operators like crossover and mutation. It prevents the algorithm from being trapped in a local minimum. GAs do not require any derivatives and do not impose any restrictions on the convexity of the search space. It is a very powerful tool for optimization in polymer processing [10].

This paper is an attempt to present the selected results of studies which consist of the registration of plastic flow in the mold cavity during the filling phase and FEM computations performed by a common-use injection molding simulation software.

Experimental

A special injection mold with two sight-glasses has been designed and manufactured to investigate the mold filling phenomena (Figure 1). One of the sight-glasses has been used for enlightening the cavity, and the other one for video-registration. A high-speed camera PHOTRON SA-5RV has been used for cavity filling registration. The molding cavity of the shape of a rectangular plate with a rectangular opening near the injection gate is shown in Figure 2. General purpose Polystyrene Empera 321 produced by BP Chemicals has been injected into a mold using a laboratory plunger-type injection molding machine (Figure 3). Various operating conditions have been used in the study.

Computer Simulations

Autodesk Moldflow Adviser 2012 [11] software has been used for computer simulations. A cavity filling analysis at a constant filling pressure (p=1MPa) and flow rate profile has been performed. Three-dimensional mesh has been chosen with resolution defined as 'high'.

Simulation results compared with selected frames from video are presented in Figure 4, Figure 5 and Figure 6. Noticeable differences in flow front position between simulation and experimental results can be seen. Furthermore, the differences seem to progress with increasing filling time.

This brought us to the 'reverse simulation method', and a correction of the material rheological model used in the simulation has been considered.

The Cross-WLF rheological model has been used in the study which describes a dependence of the viscosity of flowing material on the temperature, shear rate, and pressure. The model is given by the following equation:

$$\eta = \frac{\eta_0}{1 + (\frac{\eta_0 \dot{\gamma}}{\tau *})^{1-n}} \quad (1)$$

where:
- η is the melt viscosity, Pa·s,
- η_0 is the zero shear viscosity or the 'Newtonian limit' the viscosity approaches at a very low shear rate,
- $\dot{\gamma}$ is the shear rate, 1/s,
- $\tau *$ is the critical shear stress level, Pa, at the transition to shear thinning behaviour, determined by curve fitting, and,
- n is the power-law index in the high shear rate polymer flow region, determined by curve fitting.

The starting parameters of the model used in the study were as follows:
- the power-law index n=0,1233,
- the zero viscosity:

$$\eta_0 = D_1 exp\left[\frac{-A_1(T - T_g)}{A_2 + T(T - T_g)}\right]$$

- the critical shear stress $\tau *$=46182 Pa,
- the glass transition point T_g=373.15K, and data-fitted coefficients,
- D_1=2.54·10^{14} Pa·s,
- A_1=35.52,
- A_2=51.6K.

All of these rheological parameters have a significant effect on the material flow behaviour. And, a proper adjustment of even one of them can bring simulations results closer to reality, for instance, to appropriate estimation of the mold filling time. According to our experience in injection molding simulations [12-14], we have selected for the study the power-law flow index n and the critical shear stress level $\tau *$.

Figure 7 shows an influence of the power-law index on the flow front position during filling of the mold. It can be observed that lower n values generate lower filling times, and simulations are closer to experimental data.

An effect of the critical shear stress level $\tau *$ on the filling time is depicted in Figure 8. In this case, it can be seen that lower $\tau *$ values generate lower filling times, and simulations are closer to experimental data.

Based on the presented studies we have selected the material parameters n=0,05 and $\tau *$=35000 Pa and made simulations to compare them with the simulations made for the Moldflow data n=0,1233 and $\tau *$=46182 Pa. The results of new simulations are shown in Figure 9. Comparing with simulations based on the Moldflow data (Figure 6) clearly indicates higher accuracy of new simulation and better quality of the parameters of Cross-WLF model.

Conclusions

FEM mold filling simulations can be a great aid to an engineer when used properly, and only computations based on an appropriate data can be useful. A relatively simple tool for fast verification of input data has been proposed. Although, computer simulations results seem to be satisfactory, and no great difference between experiment result and software plot has been noticed, increasing miscalculations of flow front position and its shape can be worrying. They can lead to further inconsistencies in computations of more complicated geometry of injection molded parts, and show a need of input data analysis and corrections. Some of these corrections have been presented in this paper, and suggestions have been made for other ones.

The presented approach allows a fast identification of the critical input data, and next their proper adjustment for computations. This might be especially useful for simulation of injection molding of new polymeric materials, e.g. composites, polyblends. There is a lack of input data for these materials.

Figures

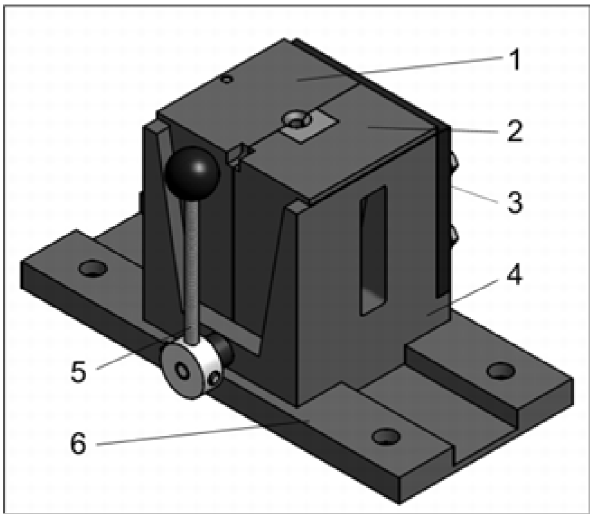

Figure 1. Injection mold with a sight-glass: 1—molding insert, 2—molding insert with a sight-glass, 3—light fitting, 4—clamp, 5—lever, 6—base plate

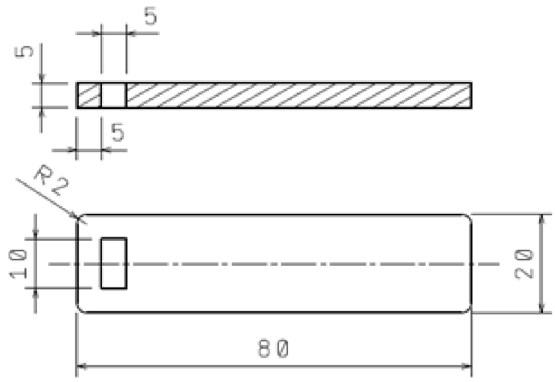

Figure 2. Cavity of the injection mold

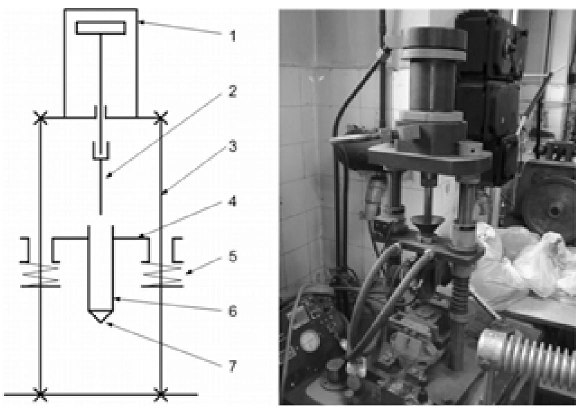

Figure 3. Injection molding machine: 1—plunger, 2—injection ram, 3—columns, 4—movable plate, 5—spring, 6—cylinder, 7—nozzle

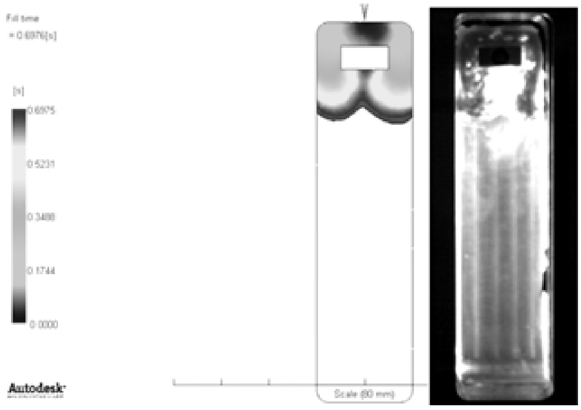

Figure 4. Cavity filling at 0,697 s after injection start

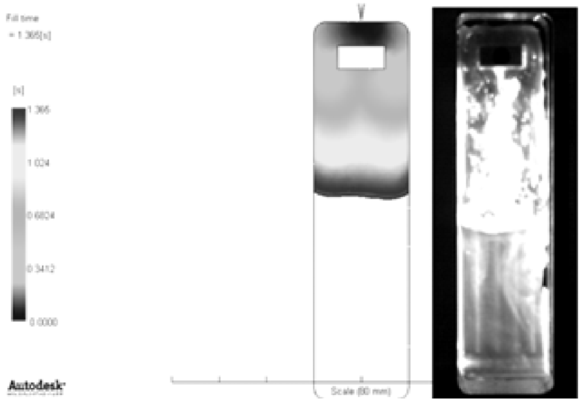

Figure 5. Cavity filling at 1,365 s after injection start

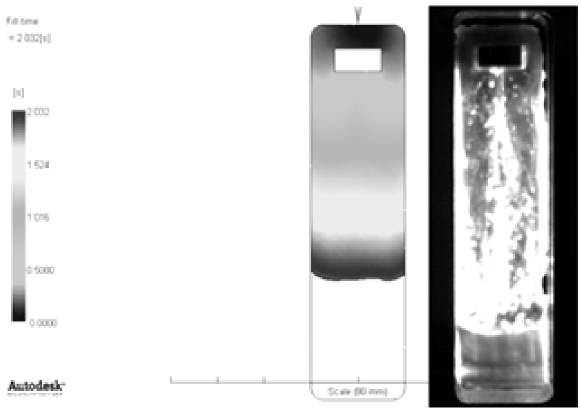

Figure 6. Cavity filling at 2 s after injection start

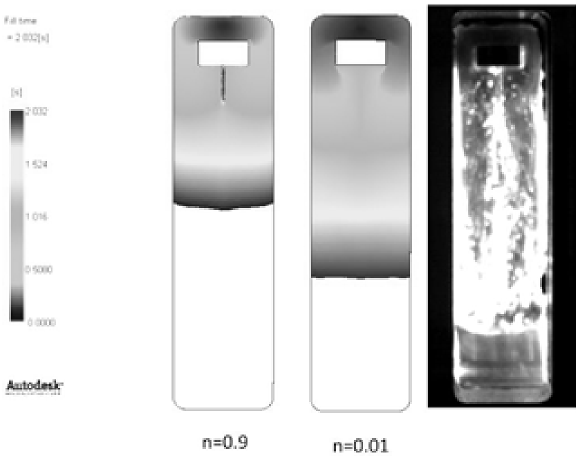

Figure 7. Effect of the power-law index on the fill time (at 2 s after injection start)

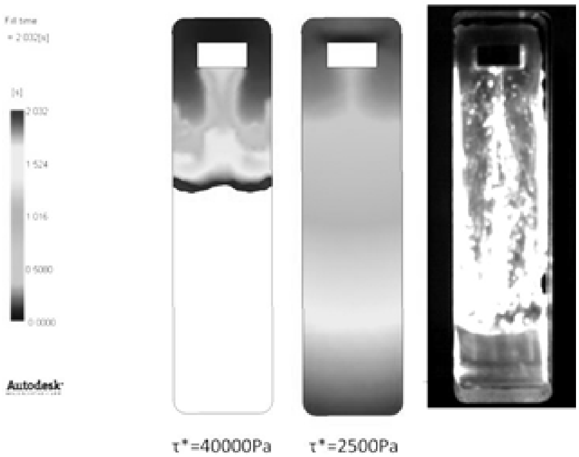

Figure 8. Effect of the critical stress level on the fill time (at 2 s after injection start)

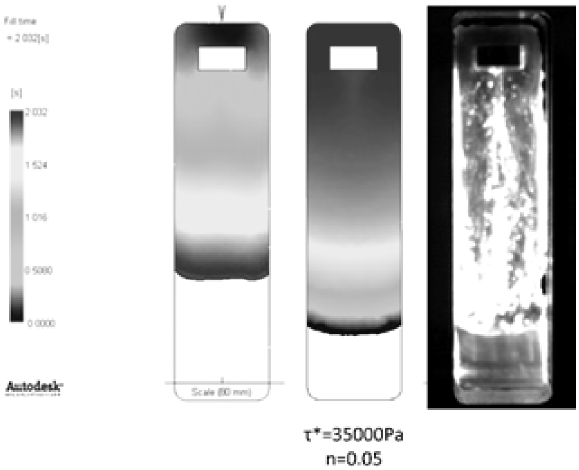

Figure 9. Comparison of simulation results for optimized parameters and primary Moldflow data (at 2 s after injection start)

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