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Multi-objective optimization of injection molding

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Automatically defining the values of important process operating conditions results in optimum performance.

Injection molding is an intricate, dynamic, and transient process involving convoluted melting-flow pressure solidification and complex material behavior that strongly affect the resulting plastic quality and properties. The thermomechanical environment imposed on the polymer melt is controlled by the definition of the operational processing variables (such as plasticating temperatures, cycle times, and injection and holding pressures) and/or system geometry (including plasticating screw, injection-gate location, and water-line layout).[1–4]

Our aim is to automatically define the values of important process conditions (such as melt and mold temperatures, injection time, and holding pressure), resulting in the best performance in terms of prescribed criteria (such as temperature difference at the end of filling, maximum cavity pressure, pressure work, volumetric shrinkage, and cycle time).

Our proposed approach integrates computer simulations, an optimization methodology based on evolutionary algorithms, and multiple objectives to establish the set of operational processing variables yielding high-quality molded parts. Our adopted optimization methodology is based on multi-objective evolutionary algorithms (MOEAs).[5–8]

The link between MOEAs and the problem is made in two steps. First, the population of variables is initialized randomly. Each individual parameter (or 'chromosome') is represented by the binary value of the set of all variables. Next, all variables are evaluated by calculating the values of the relevant objectives using the modeling routine (we used C-MOLD). We adopted our previously developed MOEA, 'reduced Pareto set genetic algorithm with elitism' (RPSGAe).[5]

Based on this optimization strategy, we set the processing conditions for polystyrene (Styron 678E) molding (see Figure 1). We obtained the relevant polymer properties for the flow simulations from the C-MOLD software database. Our simulations considered the mold-filling and holding (post-filling) stages. We selected a node near the P1 pressure-sensor position (see Figure 1) as a reference point. The operational

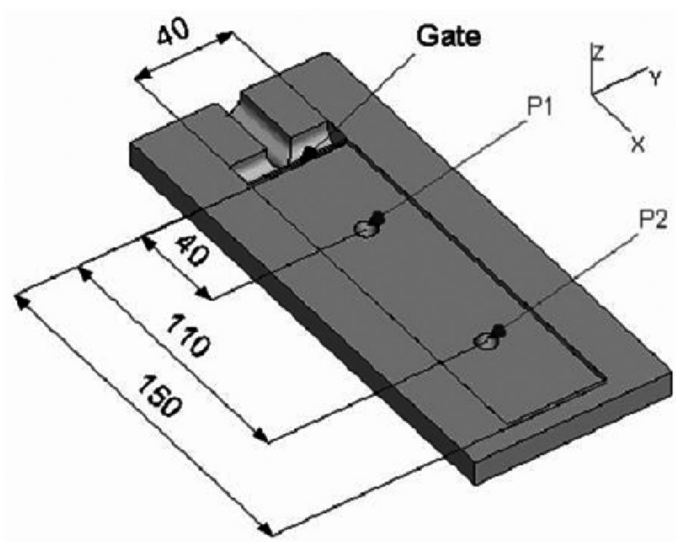

Figure 1. Die insert of injection-molding part (2mm thick, all dimensions in mm). P1, P2: Pressure-sensor positions.

variables for optimization were the injection time ($t_{inj} \in [0.5, 3]$s, corresponding to flow rates from 24 to 4cm^3/s, respectively), melt and mold temperatures ($T_{inj} \in [180; 280]$°C and $T_w \in [30, 70]$°C, respectively), the holding pressure ($P_h \in [7, 38]$% of the maximum injection pressure with fixed switchover point at 99%), a holding-pressure time of 15s, and a cooling time of 15s.

Our optimization objectives ensured that the temperature difference at the end of filling was minimized ($dT = T_{max} - T_{min} \in [0, 20]$°C). We also minimized the volumetric shrinkage ($VS \in [0; 15]$%), as well as the maximum cavity pressure ($P_{max} \in [1, 70]$MPa), the cycle time ($t_c \in [30, 35]$s), and the pressure work (defined as the integral of pressure over time: $PW \in [0, 200]$MPa s).

Figure 2 shows the results for simultaneous optimization of all objectives, which leads to a five-dimensional Pareto frontier. Points P1 to P5 represent conditions assuming any one of our objectives is the most important. For example, if pressure work is considered the most important objective, we obtain point P1 (the point exhibiting the

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Table 1. *Optimization results for solution identified in Figure 2.*

	Operating conditions				Objectives				
Point	T_{inj} (°C)	T_w (°C)	t_{inj} (s)	P_h (%)	*PW* (MPa s)	*VS* (%)	t_c (s)	P_{max} (MPa)	dT (°C)
P1	210	36.4	1.71	7.1	23.1	3.0	31.9	14.5	3.2
P2	224	32.3	2.36	28.3	197.8	1.2	32.6	40.1	7.7
P3	274	58.6	0.50	17.0	173.7	2.0	30.7	25.9	1.2
P4	260	46.0	2.92	7.0	38.4	2.8	33.2	10.4	13.9
P5	270	50.8	0.50	16.7	155.2	2.0	30.7	25.3	1.3

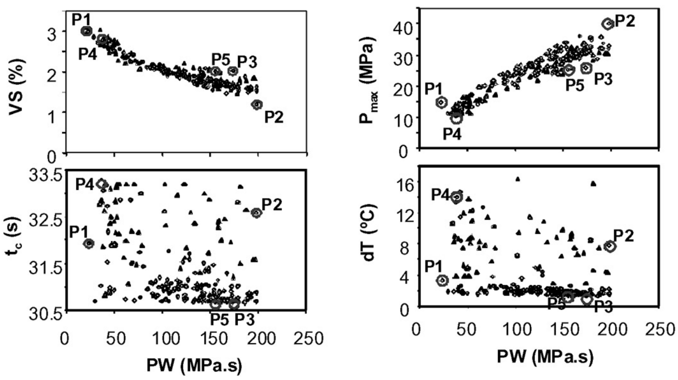

Figure 2. *Optimization results in the objectives domain. Open symbols: nondominant solutions. PW: Pressure work. VS: Volumetric shrinkage. t_c: Cycle time. dT: Temperature difference at the end of filling. P_{max}: Maximum cavity pressure. P1–5: Conditions assuming any one of our objectives is the most important.*

lowest pressure work). In this case, the injection-molding machine must operate with an injection time of 1.7s (corresponding to a flow rate of 7.06cm^3/s), melt and mold temperatures of 210 and 36°C, respectively, and a holding pressure at 7% of the maximum machine-injection pressure (see Table 1). This set of processing variables leads to a relatively high volumetric shrinkage (VS) of 3% and a cycle time (t_c) of 31.9s. The maximum mold pressure and temperature difference at the end of filling achieve minimum values of 14.5MPa and 3.2°C, respectively. Finally, pressure work is minimized for 23MPa s. Therefore, it is clear that this solution is unsatisfactory, considering objectives such as cycle-time and volumetric-shrinkage minimization.

Thus, the selected objectives cannot all be optimized simultaneously so that a compromise must be reached. Graphical and tabular Pareto frontiers can be used to enable the decision maker to select a range of solutions representing different compromises affecting the objectives considered.

In summary, our proposed multi-objective optimization methodology[9] is an excellent tool to deal with problems where no a priori knowledge is available about the process that needs to be optimized. This approach can, in a single run, establish a tradeoff between the different process parameters, the decision variables, and objective space. Therefore, MOEAs can be applied without large changes in the optimization of complex processes such as those where the operating conditions and, for example, the runner system are considered simultaneously. Our next steps will focus on the links between the plasticating and injection phases and between the process variables and the properties of the final parts. We will also need to develop a user-friendly interface for use with our proposed methodology.

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Antonio Gaspar-Cunha received his PhD from the University of Minho in 2000. He is currently an assistant professor. His main areas of scientific interest are modeling polymer extrusion processes and multi-objective, multidisciplinary design and optimization systems.

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