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Sequential Injection Molding: Design Considerations

New injection processes have been developed over the last decades, improving the designer freedom in order to launch attractive functionalities. All these procedures should be carefully analysed before to decide their use, because it is necessary to understand their natural restrictions, cost and operation requirements and rheological implications in the tools construction. This contribution presents a wide study made in the T.I.I.P., research group from the University of Zaragoza, which gives simulation results and experimental values about sequential injection moulding, and some practical considerations for designers and toolmakers, in order to get successfully results.

Injection molding is the most extended technology to create new plastic parts due to its wide possibilities adding additional value to final user (e.g. combining soft and rigid materials, including living hinges, etc.). New processes have been developed during last two decades and most of them became popular in few years, reader can revise a clear classification of these methods in [1].

Sequential injection molding was born in the 80´s when hot runner systems reach maturity. It facilitates to incorporate decorative film or textile into molding components, but it is widely applied for big automotive parts in order to avoid welding lines. In other ways, family molds use the gate opening looking for balance the filling phase and reduce overpacking effects.

Sequential injection basis is relatively simple: different gates open at different time, depending on a desired effect. For big parts and molds, usually weld lines created between adjacent gates are the main problem, and they could be eliminated. The elimination of weld lines allows introducing a greater number of entry points, which leads to a reduction flow path and the injection pressure.

As usual in other engineering fields, new developments are easily considered as the best solution, and technical staffs do not consider always the physical principles and new risks in a proper way. For example, sequential injection is commonly cited as "low pressure procedure" [1-3], or it is accepted that "it reduces clamping force" [4].

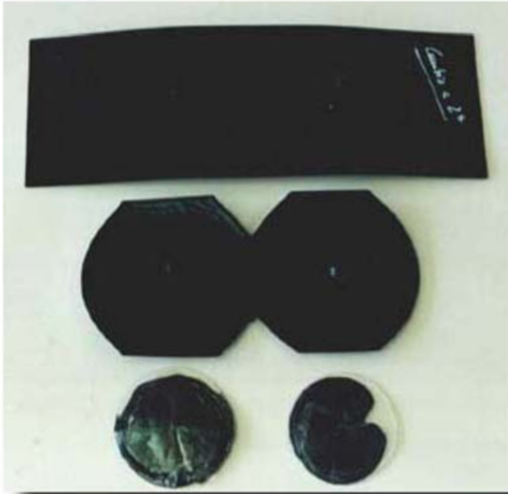

Figure 1: Conventional filling of parts used for this work.

Materials and Method

The experimental work is described below, in order to introduce basic principles of sequential injection. A hot runner mold was manufactured, with two injection valve gates. Mold plate dimensions were 596 x 496 mm. The injected part was a 2 mm thick rectangular plate, 450 x 150 mm, and the distance between gates, centered in the width of plate was 150 mm. The hot runner system was provided by Mold-Masters and valve pin cylinders were operated using an independent and computer-controlled hydraulic unit.

A polypropylene (PP) resin was used for the experimental work, a usual automotive grade for bumpers with EPDM, and it was produced by DSM. This resin had a solid density of 0.90 g/cm_3. The melt index (MI) for the resin was 0.6 dg /min (230°C, 2.16 kg, ISO 1133), and a complete properties set was taken from the C-Mold software. To the observation by photoelastic techniques of residual stress in the process, some samples were made also with PS, produced by ENICHEM.

Figure 2: Sequential filling of part used for this work.

The mold was equipped with three pressure sensors type 6157, provided by KISTLER, in order to register specific pressure inside the mold, and the acquisition software DATAFLOW. At the same time, hydraulic pressure was recorded for each injection shoot using another piezoelectric KISTLER 4095A connected with the same computer device. A MATEU&SOLE 340 ton injection molding machine did the plastic parts.

Injected parts were weighted and classified, and different halterio samples were prepared from two different locations in the part, one just between injection gates and affected by welding lines in conventional process, and the rest of the samples were taken near to the second gate in conventional process to investigate the effect of polymer flow when this gate is opened. Both positions were chosen in order to compare mechanical properties of manufactured parts in both cases, conventional and sequential injection molding. The strainstress curves were made using an Instron machine with high resolution extensometer.

In the other hand, several typical parts made with sequential injection were simulated using commercial code as C-Mold (nowadays integrated inside Autodesk package). These tests allow investigating how sequential filling can affect the mold design or the practical setting up in the manufacturing plant. A front bumper will be presented in this work. However, other shapes were observed, as a linear protection or a dashboard. In all the cases similar conclusions were reported.

Experimental Results

Figure 1 shows the conventional filling, while **Figure 2** shows the filling sequence. Conventional filling of this rectangular part creates a central weld line, meanwhile in sequential injection the first gate fills the cavity until it reaches the second gate. Figure 2 shows that the second gate continues the melt front after opened.

An initial consideration should be done on the properties of the piece: the one made by sequential injection shall be an asymmetric behavior, since the form of filling pressure and conditioning the subsequent behavior. This phenomenon could be observed using photoelastic stress analysis, as it is shown in **Figure 3**. Two styrene samples with asymmetrical stress arrangement were captured. The most packed part suffers the most residual stress and plenty of isocromatic lines. Furthermore, residual stress or mechanical properties of polymer to its use, in the author´s opinion, shrinkage differences could be anticipated [5].

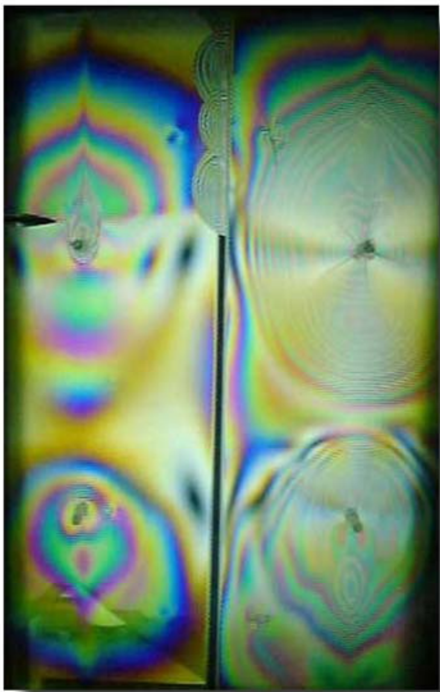

Figure 3: asymmetrical stress distribution for two sequentially injected parts. Upper gate was opened first. Left: packing pressure 20 bar; right, packing pressure 35 bar.

The samples produced by conventional injection showed a brittle fracture for the different conditions tested, with elongation values below 10%, while all other samples, regardless of the location process and showed ductile fracture elongation values above 200 % and corresponds to a PP blended with EPDM [6]. **Figure 4** shows how samples cut from conventional parts show brittle fracture for weld line location and ductile failure for other area.

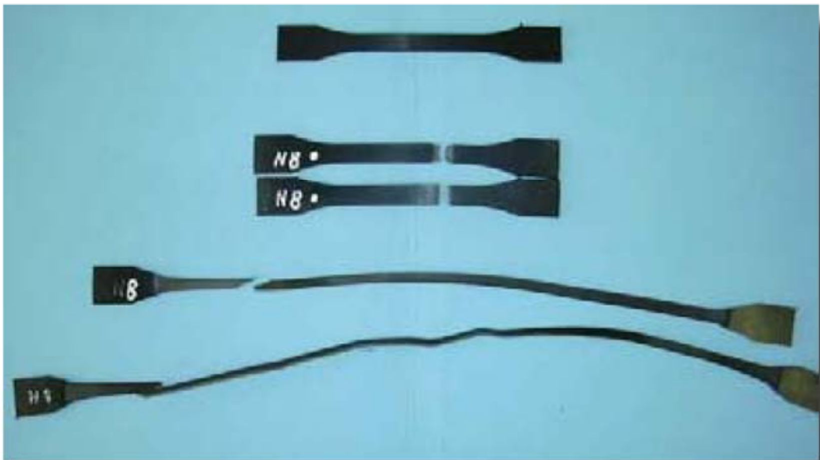

Figure 4: Tensile stress samples after test: brittle fracture for weld line area, ductile failure for other location. This second behavior was encountered for sequential injection specimens.

Injection pressure required to complete the sequential parts were higher than value registered for conventional in all experiences (**Table 1**). This value is explained due to the longer flow length that appears in sequential injection.

This result motivates, in author´s opinion, to re-evaluate sequential injection as "low pressure method", at least without additional remarks. This statement could be considered only if introduced some new points of injection into the piece, which means more investment and more delicate maintenance process.

MELT TEMPERATURE	FILLING TIME	MAXIMUM HYDRAULIC PRESSURE CONVENTIONAL PROCESS	MAXIMUM HYDRAULIC PRESSURE SEQUENTIAL PROCESS
215ºC	1 s	55 bar	69 bar
230ºC	3 s	44 bar	49 bar
230ºC	3 s	43 bar	53 bar
230ºC	1 s	53 bar	66 bar

Table 1: Maximum hydraulic pressure results for the rectangular part used, under selected conditions, conventional and sequential process with PP+EPDM.

RESULTS	3 GATES, BALANCED CONVENTIONAL CRITERIA	3 GATES, MORE SEPARATED	3 POINTS, EQUAL LENGHT FLOW
CAVITY PRESSURE REQUIERED (MPa)	131	113	101
CLAMPING FORCE CALCULATED DURING FILLING PHASE (Ton)	430	630	700

Table 2: Maximum pressure and clamping force results simulated for typical injection conditions, sequential injection of a bumper part with PP+EPDM..

Mold Design: Learned Lessons

Plastic part design requires an effective knowledge on manufacturing process and tooling restrictions. In injection molding, due to it special capabilities (undercuts for example), this integration of different subject items is especially critical. Simulation software can help the designers and its accuracy in pressure and clamp force calculation, and it is commonly accepted if a proper model and a good material data is available.

In this point, from several analyses of different geometries, authors can offer two basic considerations in order to prevent great mold design defects:

a) New balance concept to arrange injection gates:

It is well known that gate position determines pressure distribution inside the mold, and in the same way, it affects strongly clamping force required. The basic criteria for big parts which needs several injection gates is to place them equally separated in order to divide the plastic flow in as many volumes as gates provided. However, in sequential injection molding this criterion is not adequate, because the consecutive gate opening changes the melt front advancement. In this way, a new arrangement considering equal flow length for each gate is proposal as the best choice, following [7], as it is shown in **Table 2** for a bumper part.

b) Consideration about hesitation effect for rear flow areas:

The consecutive gates opening introduce a variable flow rate during injection time, because when a new valve is opened, plastic flow suddenly suffers a decompression, because it has no plastic in front of it. This effect is recorded in the hydraulic pressure, where several peaks could be observed [8]. But, in addition, a hesitation effect is introduced in the mold filling because areas at the rear of the new flow front will not receive

Feature: IM Design Continued

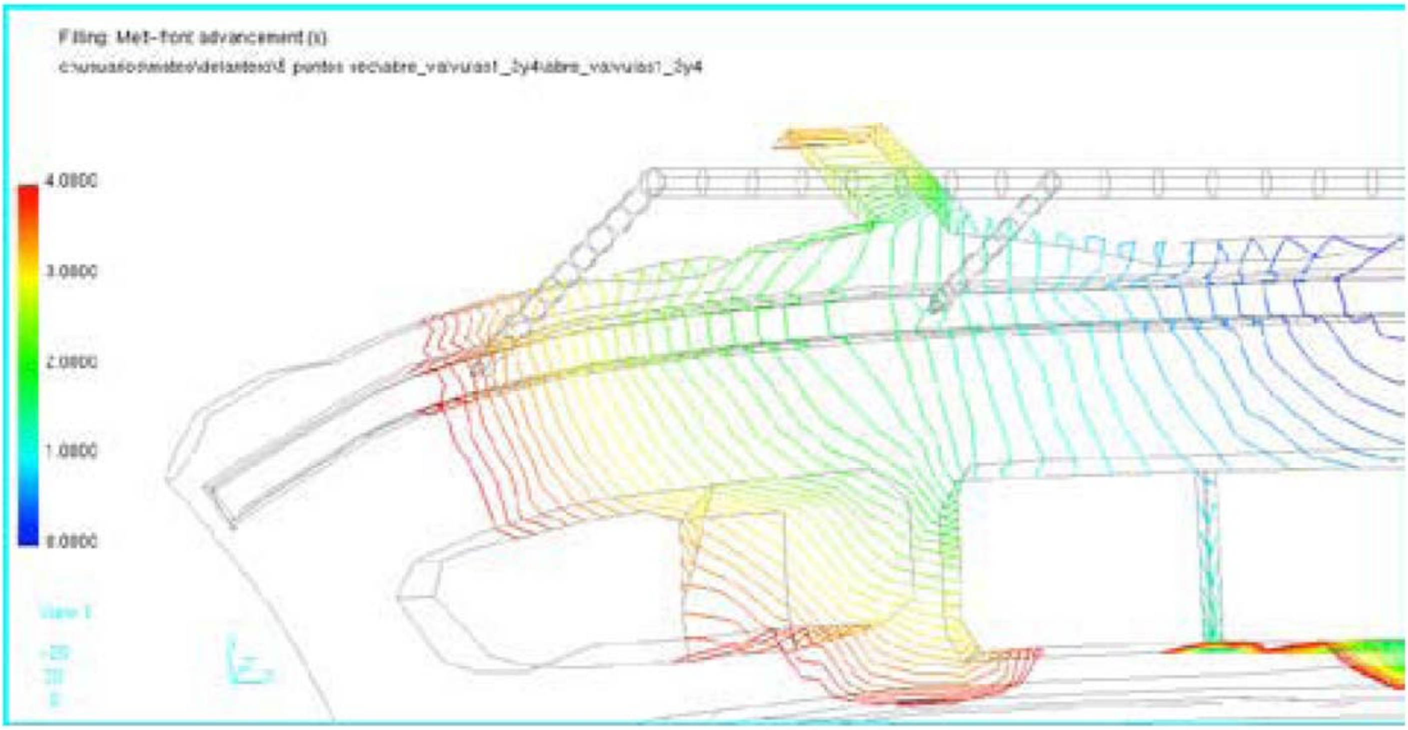

Figure 5: Hesitation of melt front advancement in a bumper injection using sequential injection. The bottom of the part is not filling through central gates, but from the lateral ones

plastic from the barrel when the next gate is opened. In **Figure 5**, readers can observe how the bottom area of a rear bumper will not be filled if designer does not consider this phenomena.

An additional injection point solves this hesitation effect, (**Figure 6**) but, under "a traditional point of view", it would be no necessary this extra investment. Notice that if a conventional criterion is used, mold can produce non-useful parts, and a later re-design not always will solve the flaw, especially for complex parts.

Setting up Cautions

In addition, an important remark should be done in order to understand the setting up of sequential molds. During the mold filling process, the flow rate is introduced by the schedule of the screw speed, and it is common to use a profile with the first stage slow down to prevent streaking or surface defects related to an elevated shear stress.

The same fact is reproduced in sequential injection each time a new gate opens, the flow rate being introduced into the mold and that was distributed over a large bore, it is forced to move through the new entries opened. That is why it is necessary to consider the necessity of a programming filling phase much more complex, including screw speed reductions at intermediate points.

This fact needs for greater control of the settings, the more skills of the operators and major setup times and tuning of production, which necessarily will involve an extra cost to the investment made. Figure 6 shows the high shear stress values calculated using commercial software. This evidence was checked with several producers and the staff of Fundación aiTIIP (www.aitiip.com), research and technical center born as spin-off from the University of Zaragoza, from the TIIP group. All of them explained that this assessment was really used in their plants and mold test procedures.

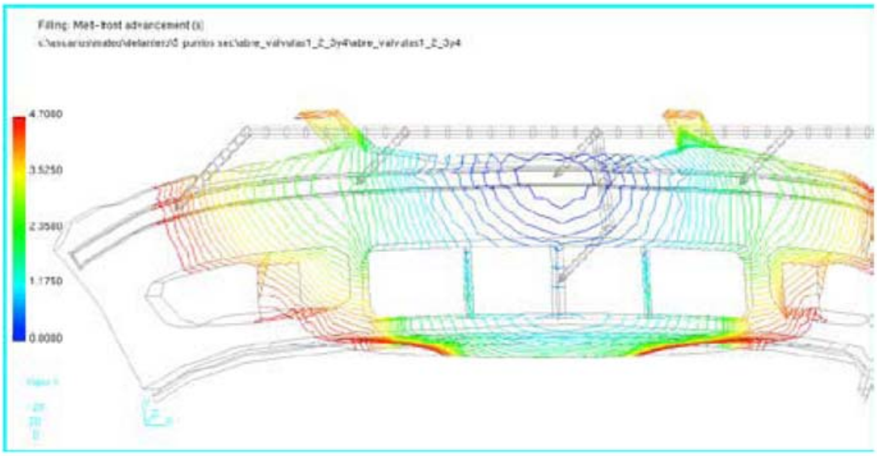

Figure 6: Additional central point eliminates this hesitation effect

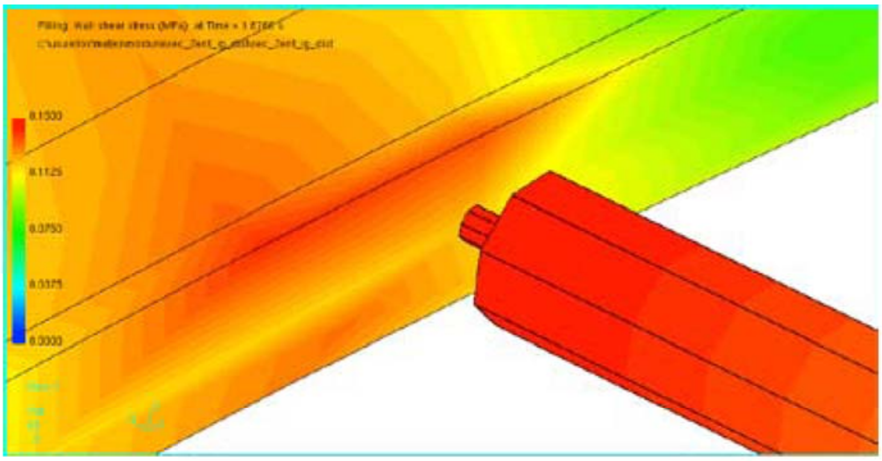

Figure 6: Shear stress evaluated with commercial software just after the gate opening in sequential injection. Value is closer to maximum allowed without polymer degradation.

Conclusions

New injection techniques allow reducing part defects or increasing part functionalities, but designers and mold-makers have to consider the basis of those new process. Sequential injection molding eliminates weld lines, and this fact increases mechanical strength for impact essays and improve aesthetical appearance of final product.

In this paper, authors present some design rules (gate position to optimize injection pressure or how hesitation effect can appear during filling phase) and some considerations on setting adjustment (ram profile will be more complicated than used for conventional process) and, in the same way, some final part properties that engineers should consider during design stage (some asymmetric effects).

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