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Criteria on feeding system design: Conventional and sequential injection moulding

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Abstract

Sequential injection moulding technology appeared several years ago in the thermoplastic manufacturing field. Its importance has been increasing since then, and so does the knowledge about the technology. At this moment, it is possible to establish relevant parameters of the process, some of its limitations and design guidelines. This paper pretends to show the advantages of sequential injection moulding, and the importance of the feeding system design, to be able to get all the best of this technology. By means of FEM simulation results on pressure and filling pattern will be compared for both conventional and sequential feeding systems showing the influence on the results, of the appropriate feeding system.

Keywords: Sequential; Injection moulding; Hot runner system; Valve gate

1. Introduction

TIIP–AITIIP group is a research and development team from University of Zaragoza (TIIP), and from AITIIP Foundation. For more than 15 years, this group has been working in the field of thermoplastic injection moulding, focusing its efforts on the application of new processing technologies. AITIIP foundation joints leader companies related to injection moulding, and its scope reaches all around the world.

One of the most important basic elements of thermoplastic injection moulds is the feeding system. It carries melt material from the mould entrance to the part gates. Feeding systems can be divided into two types, cold runner systems, and hot runner systems.

In cold runner systems, Fig. 1, melt material goes through cold runners, and polymer gets frozen into them in the same way as in the part, so they must be extracted during ejection as well as part. In hot runner systems, Fig. 2, material circulates along manifolds and hot nozzles, that are heated runners (inner or outer heated), by means of electrical resistances, in such way that material flowing in it keeps at required temperature during all the flow length (see Fig. 3). Hot runner systems are more expensive and complicated than cold runner systems, but they exhibit many advantages: temperature variations due to flowing into cold runners are eliminated because melt temperature is controlled; drop pressures in feeding runners are lower; there is more freedom when locating part gates; runners scrap is eliminated, etc. One reference about the usage and importance of hot runner systems can be seen in [1].

When working with conventional injection, melt material circulates freely from the machine nozzle, through the hot runners, and goes out through the different hot nozzles at the same time, maybe with slightly time delays, beginning to fill the mould. As an alternative, we find sequential injection in which, nozzles are modified by adapting their valves and obturators (see Fig. 4). By means of a suitable control system, time when these valves are opened and closed can be controlled during injection process cycle. This allows the pass of material to the cavity through the nozzles at the desired time, improving considerably the process. This technique was used as a low-pressure technique, considered among others in [2].

The equipment necessary for sequential injection moulding consists of a hot runner feeding system with valves and obturators, as well as a control system for the opening and closing of the valves. This control can be included in the injection machine or can be independent, and it can be hydraulically or pneumatically actuated [3]. Therefore, it is a more expensive and complex process than conventional injection. This cost and complexity

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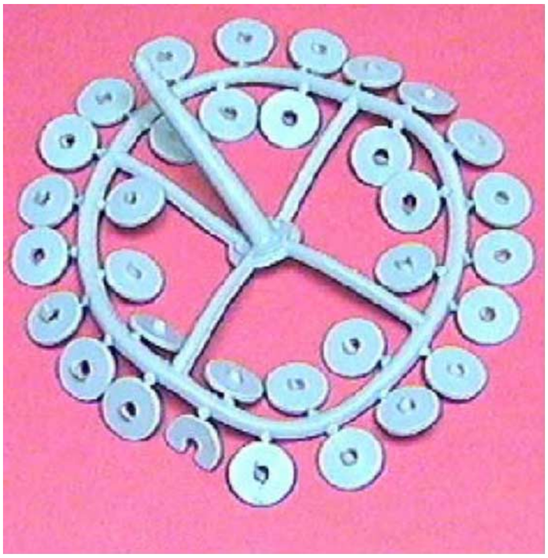

Fig. 1. Cold runner system.

Fig. 2. Hot runner system.

Fig. 4. Hot nozzles with valves for sequential injection.

increasing is justified many times by the advantages obtained with sequential injection, if the feeding system and valves control are well defined [4].

Generally, sequential injection is used to eliminate weld lines in parts with several injection gates, or to obtain unidirectional filling of the part [5].

Next example shows a feeding system design for the part shown in Fig. 5, with three gate points.

With conventional injection, simulated filling pattern in the part would be as shown in Fig. 6.

When introducing melt polymer into the mould through several gates, weld lines will be formed, where flows coming from different gates, find each other. These weld lines are not desirable because they implies both, a deficient visual aspect and poor mechanical properties (see Fig. 7).

Sequential injection can control valves state, by choosing the time when each valve is opened and closed. Besides, gates can

Fig. 3. Hot nozzles and manifolds systems.

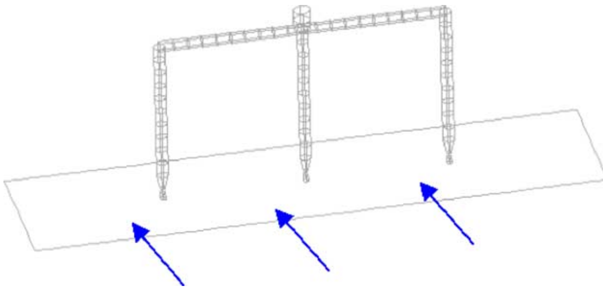

Fig. 5. Part and hot feeding system with three points.

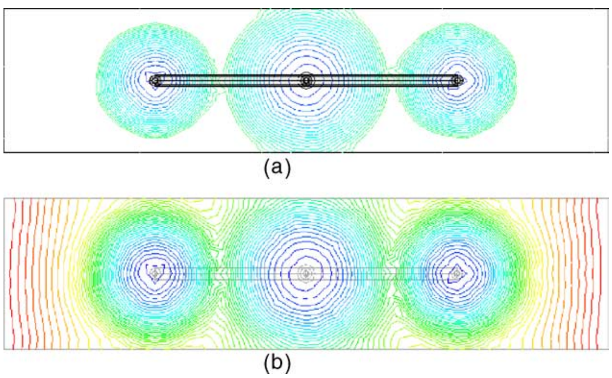

Fig. 6. (a) Conventional filling with three gates, at 40% of filling time, when flows find each other; and (b) conventional filling with three gates, at the end of filling time.

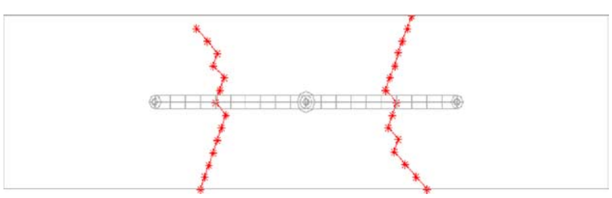

Fig. 7. Weld lines resulting from conventional injection.

be opened or closed several times along a moulding cycle, by means of different systems as stated in [4].

In order to eliminate weld lines resulting from filling the part with several gates, cavity is filled by a single gate, and the rest of the gates are opened at the moment when melt front over passes their positions. In this way, if gates are not opened until the moment that plastic arrives at them, the collision between flows is avoided, as well as the resulting weld lines.

A sequential analysis has been carried out with our example geometry, opening at first time the central gate, and sequentially the side gates. Filling patterns are shown in Fig. 8.

Filling results are similar to the ones obtained by filling with a single point at the centre. But, pressure is lower and property uniformity through the part is better.

2. Comparison between a sequential and conventional feeding system for a simple model

Let us define the feeding system for a simple geometry part, like the one shown in Fig. 9.

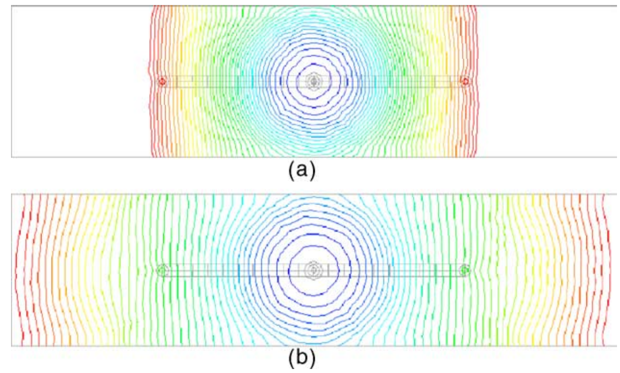

Fig. 8. (a) Valves 2 and 3 open when melt front reaches them and (b) sequential filling with three points, beginning at central point.

The number of part gates is directly related to the material flow length. The longer the flow length is, the higher the pressure for a proper filling is needed. Therefore, optimal number of part gates should be defined taking into account its geometry and dimensions, for cavity pressure to be into an acceptable range for injection moulding. Besides, other material properties into the mould, like shrinkage, depend on the cavity pressure distribution [6]. So, during filling stage, high-pressure differences must be avoided, and during packing stage, pressure must be transmitted properly from the gates to any point of the part. In this way shrinkage will be uniform in different dimensions to control [7].

By means of simulations software, it is possible to analyze different feeding system design options, for the location of one or several entrance points. Parameters used for comparative simulations are exposed in next section. Some basic considerations about software usage and application appear in [7,8].

2.1. Material used

The material used for simulation tests is a polypropylene named HOSTACOM X4323/3 S63 101173. It is a semi crystalline filled enough material to be used in exigent applications like automotive interior trim.

2.2. Process conditions

To compare the different design options proposed, a standard injection conditions for this kind of parts and material are set

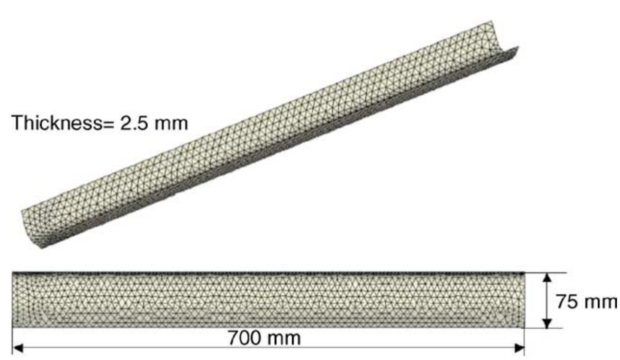

Fig. 9. Theoretical part geometry.

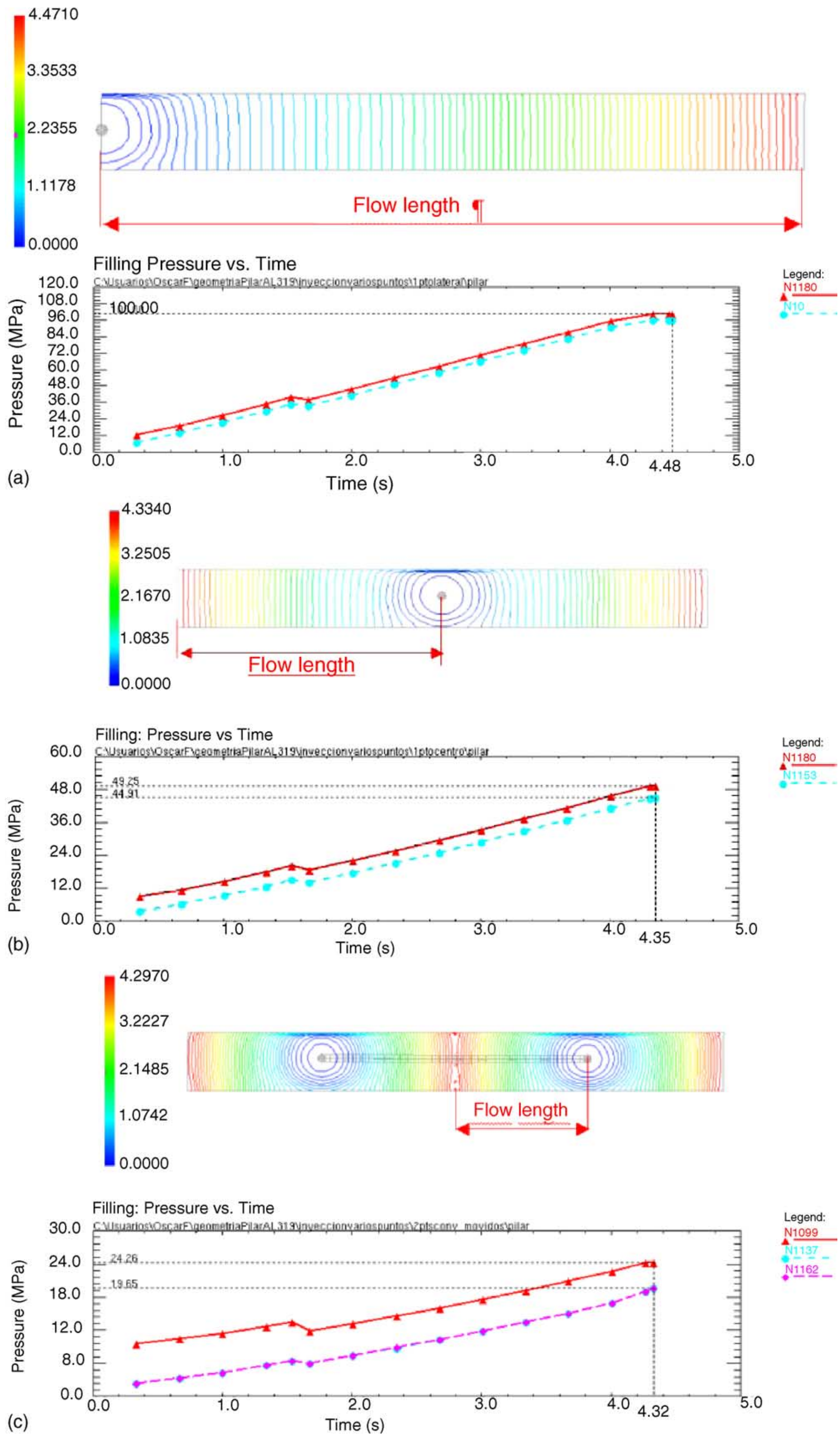

Fig. 10. (a) Cavity pressure evolution by a side point; (b) cavity pressure evolution by a central point; (c) cavity pressure evolution by two points; and (d) cavity pressure evolution by three points.

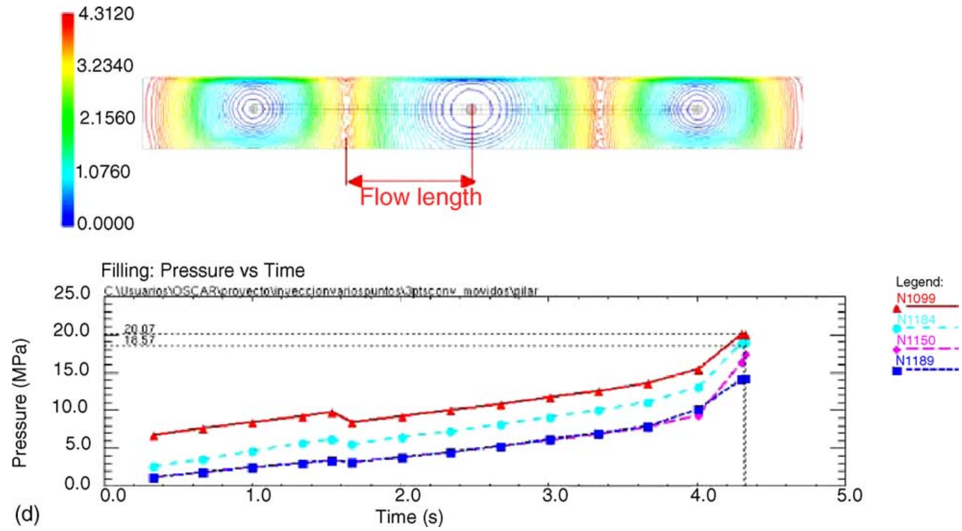

Fig. 10. (*Continued*).

Table 1
Standard process conditions for polypropylene

Filling time	4 s
Injection temperature	240 °C
Mould temperature	40 °C

up. They appear summarized on Table 1. These conditions can be optimized particularly for each injection system tested.

2.3. *Result analysis*

To compare different situations, melt front advancement, welding lines, and cavity pressure level and evolution are analyzed. The result showing top curve stands for the pressure at the entrance of the mould. The rest of the curves stand for pressure at different part entrances.

2.3.1. *Conventional feeding systems*

All the conventional feeding systems tries to fill a similar part volume with each entrance point, as well as to have a filling pattern as uniform as possible, to minimize welding lines driving them to non visible areas, and to get a proper packing at any point of the part. For those cases with very irregular cavity shape, or parts with great thickness variations, runners must be balanced for the time necessary to fill the assigned flow length to each runner, to be as equal as possible. Table 2 shows a comparison of relevant results for the following cases that have been studied:

Table 2
Results for comparative conventional study cases

Number of part gates	Maximum cavity pressure (MPa)	Flow length (mm)	Weld lines
C1: 1 side point	100	700	No
C2: 1 central point	44.91	350	No
C3: 2 points	19.65	175	Yes
C4: 3 points	18.57*	120	Yes

* Study case C4 shows an increasing pressure curve slope, at the end of the filling, due to the effect of slight overpacking. If this effect were eliminated, cavity pressure would be next to 15 MPa.

Table 3
Results for comparative sequential study cases

Number of entrance points	Cavity maximum pressure (MPa)	Flow length (mm)	Weld lines
S1: 2 points sequential	28.25	235	No
S2: 3 points sequential beginning by side point	22.11	175	No
S3: 3 points sequential beginning by centre point	20.68	175	No
S4: 2 points sequential closing first valve gate when opening the second	25.17	235	No
S5 3 points sequential closing first valve gate when opening the second ones	17.78	175	No

- case study C1: filling by a single side point (Fig. 10a);
- case study C2: filling by a single central point (Fig. 10b);

Table 4
Results for comparative sequential and conventional study cases

Number of entrance points	Maximum cavity pressure (MPa)	Flow length (mm)
C5: 2 conventional with runners designed for sequential injection	32.24	235
C6: 3 conventional with runners designed for sequential injection	23.39	175
S6: 2 sequential points with runners designed for conventional injection	40.27	350
S7: 3 sequential points with runners designed for conventional injection	29.5	235
S8: 3 sequential points with runners designed for conventional injection, filling by centre point	25.76	235

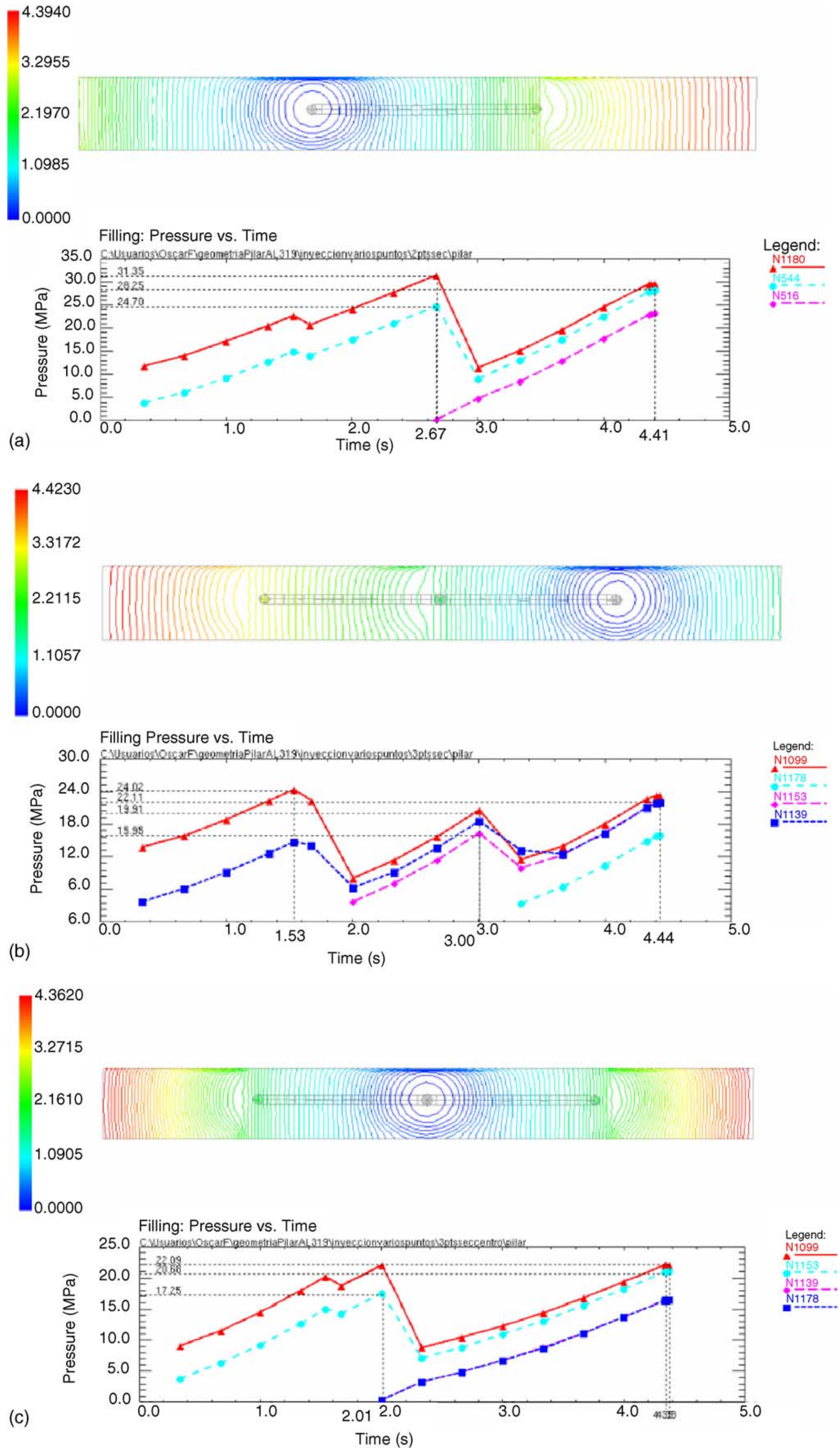

Fig. 11. (a) Cavity pressure evolution by filling through two points sequentially; (b) cavity pressure evolution by filling through three points sequentially beginning by side point; (c) cavity pressure evolution by injection through three points sequentially beginning by centre point; (d) cavity pressure evolution closing the first valve gate when opening the second; and (e) pressure evolution closing first valve gate when opening the second.

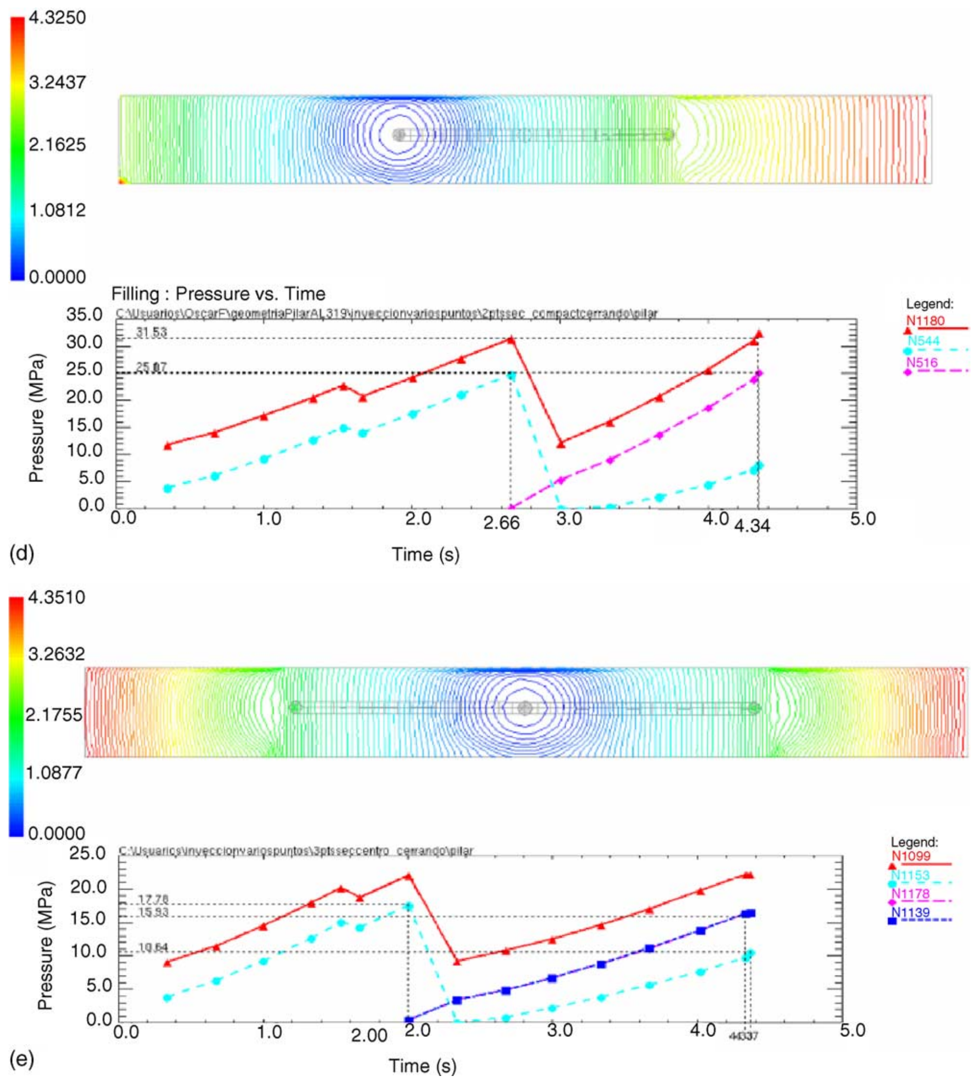

Fig. 11. (*Continued*).

- case study C3: filling by two points. In this case, each point is a must to fill half part in such a way that material reaches the ends of the part and its central area, simultaneously (Fig. 10c);
- case study C4: filling by three points. In this case, each point is a must to fill a third of the part (Fig. 10d).

It can be seen that the shorter the material flow length is, the lower the maximum cavity pressure is.

Case studies, in which part is filled by a single point, show pressure values approximately 50% lower, if the entrance point is in the centre of the part. This result appears because flow length is the half if the entrance point is at this position.

The simplest way of reducing material flow length into the mould is to inject through several points, although a weld line will appear between each of the two injection points.

2.3.2. Sequential injection moulding

For the sequential injection study cases, feeding systems with two or three gates are proposed.

Sequential fillings aim to fill the part unidirectionally, beginning at one gate, and opening the rest of the valve gates, when melt front advancement overpasses these gates. When placing gates, distance between gates, and distance between side gates and part side should be similar. This criteria implies that flow length increases regarding to conventional injection for the same number of gates. Therefore, gates must be placed in a different position from positions in conventional injection.

Results will be analyzed in a similar way to results for conventional injection, but special attention will be paid to material accelerations and decelerations when opening and closing valve gates, and to pressure evolution at entrance points when opening the valves.

Table 3 shows a comparison of relevant results for the following cases that have been studied:

- case study S1: filling by two points sequentially (Fig. 11a);
- case study S2: filling by three points sequentially beginning by side point (Fig. 11b);

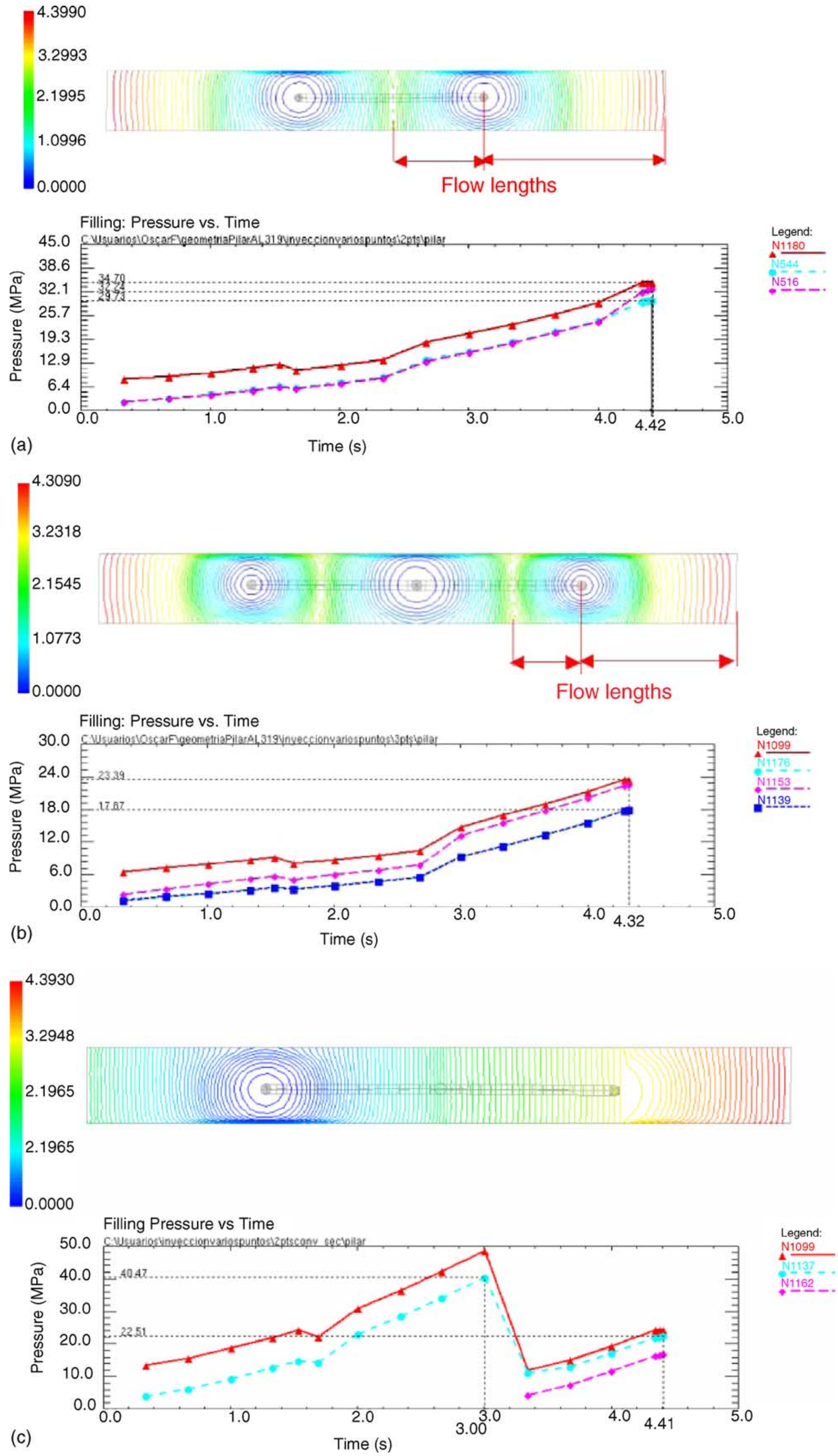

Fig. 12. (a) Cavity pressure evolution for conventional filling by two points; (b) cavity pressure evolution for conventional filling by three points; (c) cavity pressure evolution for sequential filling by two points; (d) cavity pressure evolution for sequential filling by three points; and (e) cavity pressure evolution for sequential filling by three points, beginning by centre point.

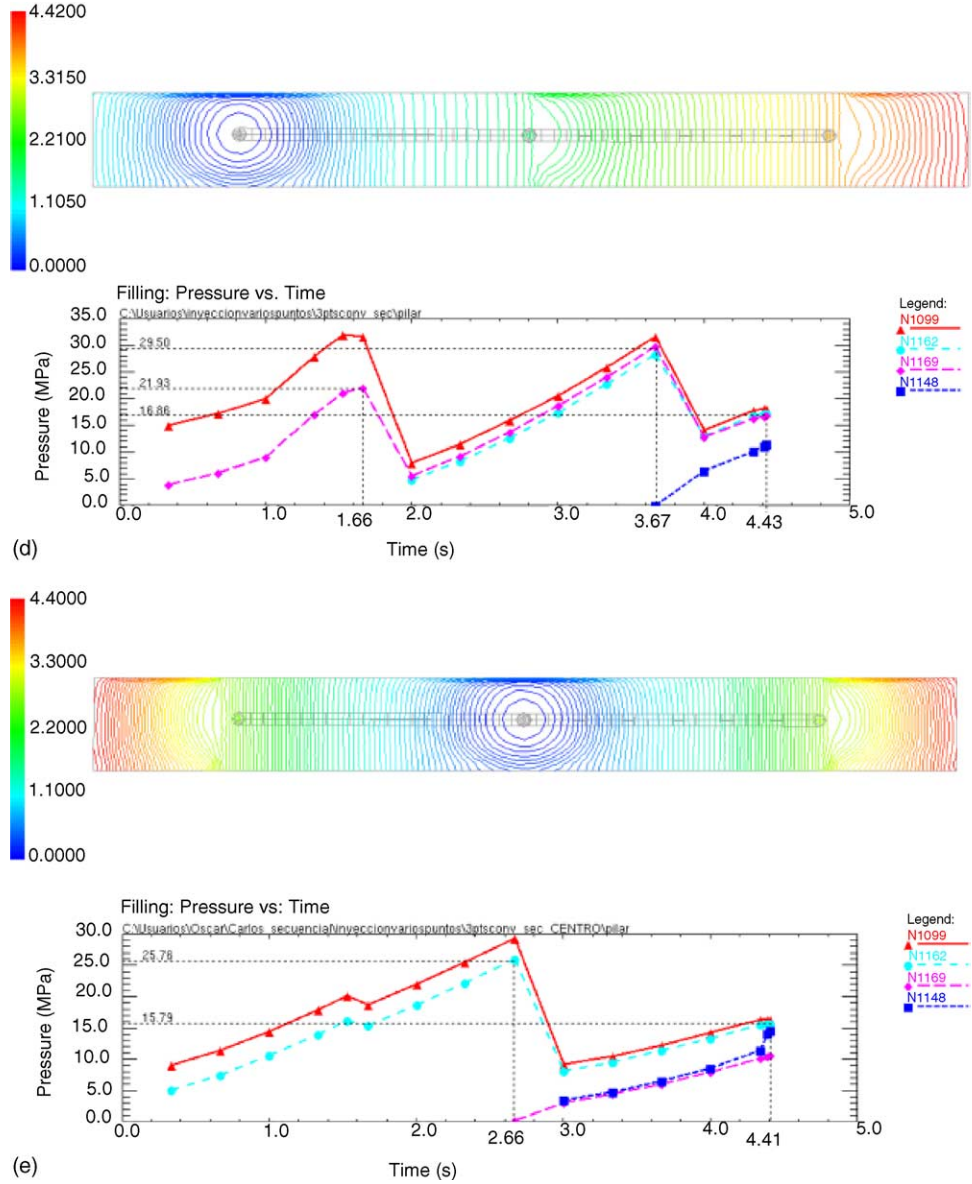

Fig. 12. (*Continued*).

- case study S3: filling by three points sequentially beginning by centre point (Fig. 11c);
- case study S4: filling by two points, closing the first valve when opening the second (Fig. 11d);
- case study S5: filling by three points, closing the first valve when opening the second (Fig. 11e).

In the same way as in conventional injection, cavity maximum pressure decreases if flow length decreases.

A new effect can be observed in the previous results. When opening sequentially the valve gates, maximum flow rate is observed in last opened gate, obtaining a minimum flow rate in the previously opened valve gates. At these gates, where material practically stops flowing, mould entrance point pressure is transmitted almost completely, so pressure values similar to pressure at the mould entrance point are reached. In order to minimize this effect, it is advisable to close valves when opening the following ones, as can be seen at study cases S4 and S5.

By comparing conventional study cases to sequential ones, it can be stated that flow length is longer for sequential injection process if the number of entrance gates is the same in both cases, and so, maximum cavity pressure will be higher too. Sequential injection takes advantage to conventional injection by taking the chance of eliminating weld lines, and by obtaining better and higher flow unidirectionality.

Sometimes, sequential injection tests are carried out with conventional feeding systems and vice versa. Results for this kind of tests are not usually satisfactory. Next study cases show the effect of filling conventionally with a feeding system designed for sequential injection, and the effect of filling sequentially with a conventional feeding system. Results are summarized up on Table 4:

Fig. 13. Light housing used for the study.

- case study C5: conventional filling by two points with a sequential feeding system point (Fig. 12a);
- case study C6: conventional filling by three points with a sequential feeding system (Fig. 12b);
- case study S6: sequential filling by two points in a mould designed for conventional injection (Fig. 12c);
- case study S7: sequential filling by a three points in a mould designed for conventional injection (Fig. 12d);
- case study S8: sequential filling by three points with a mould designed for conventional injection, beginning by centre point (Fig. 12e).

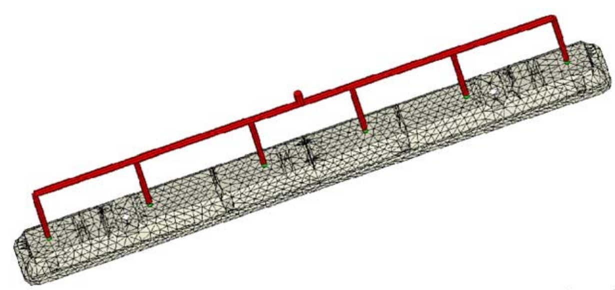

Fig. 14. Part geometry and conventional hot runner feeding system.

By analyzing study cases with two and three entrance points, it can be shown that, among three points study cases, minimum cavity pressure is reached at study case C4 for three points conventional filling (18.5 MPa). By injecting sequentially with three entrances, pressure values are higher, as can be seen at study case S2 (22.11 MPa) +16%. Among sequential study cases closing valve gates (case S5), show lower pressure val-

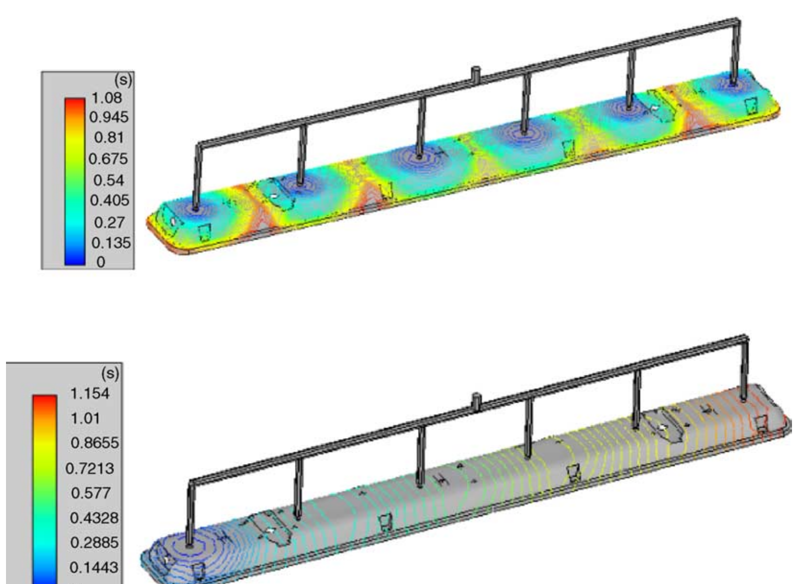

Fig. 15. Melt front advancement for conventional (upper) and sequential (lower) filling.

ues (17.75 MPa). When injecting sequentially with conventional feeding systems or vice versa, pressure values are higher than those injecting conventionally or sequentially with proper feeding systems designs. That is the situation for three entrance points in cases C6 (23.39 MPa) +24% pressure regarding the sequential injection, and S7 (29.5 MPa) +37% pressure regarding to conventional injection.

Study cases with two entrance points exhibit a similar behaviour to study cases with three points.

It can be also shown that the advantage obtained with sequential injection is that weld lines can be reduced or even eliminated, and melt flow advancement is more unidirectional.

3. Application to the study of a real case: light housing

A real case study of the light housing shown in Fig. 13 is carried out to compare conventional and sequential injection. Feeding system used is conventional, although both types of injection moulding, sequential and conventional, will be tested.

Material used for this simulation is a Dow Chemical polycarbonate, PC CALIBRE IM 401 18. Standard process conditions are set according to material and part, and they are shown in Table 5. FEM model can be seen in Fig. 14.

3.1. Results

Melt front advancement results are shown in Fig. 15 for both conventional and sequential injection moulding. It can be seen that for conventional injection moulding-filling pattern is radial, which can cause latter warpage in the part. It can be also observed that entrance points are not balance: central points finishes its filling before side points, causing central area of the part to be overpacked. For sequential injection moulding-filling pattern is linear, which improves warpage. Sequential injection moulding eliminates weld lines because there is not any flow crashing into another, like in conventional moulding. Fig. 16 shows cavity pressure evolution along time. It is observed that cavity pressure always increases along time during filling, when injecting conventionally up to the maximum cavity pressure (140 MPa). When working with sequential injection, cavity pressure evolution shows drops due to the opening of the different valve gates. Each valve gate registers a maximum pressure value at the moment just before being closed. At this moment, next valve gate is opened, beginning to register an increasing pressure. At the end of the filling phase, maximum cavity pressure is given by the maximum pressure reached in some of the entrances to the part. Table 6 shows a summary of the results for the light housing simulation. It can be seen that maximum pressure value for sequential injection moulding is about 185 MPa, a quite high value for injection, and difficult to reach for conventional injection machines. Differences in cavity pressures are due to difference in the flow lengths between sequential and conventional injection moulding. For sequential injection moulding melt flow must go from one entrance point to another, for conventional melt flow must reach only half length of one gate to the following. Sequential injection takes very poor profit of the last entrance point, whose flow length is quite short compared to the location of the rest of the points. These facts show the

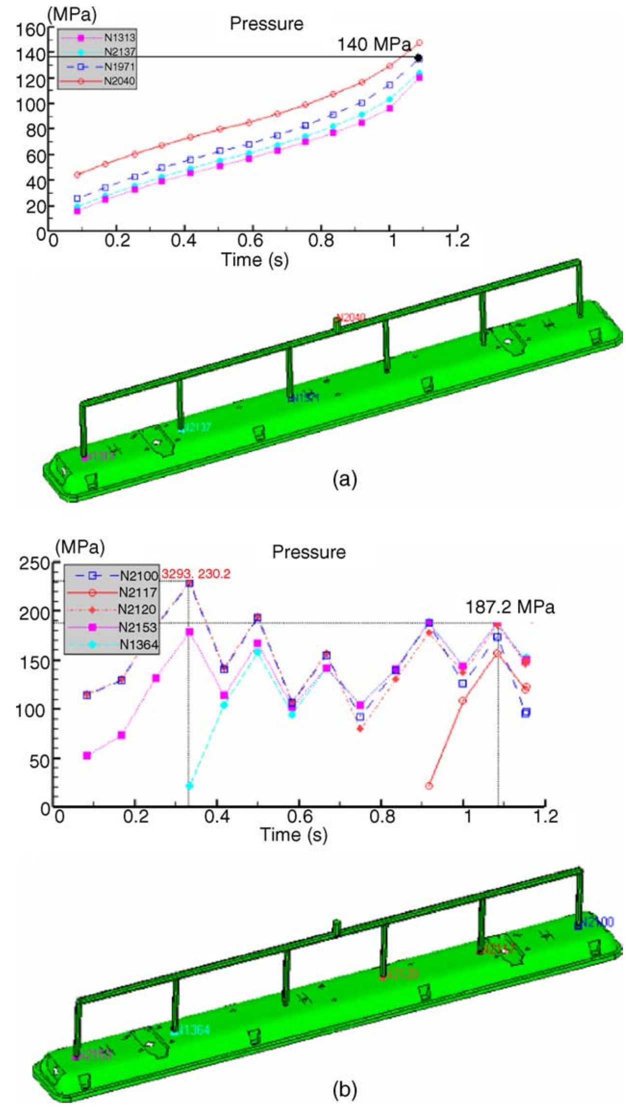

Fig. 16. (a) Cavity pressure evolution along time for conventional injection; and (b) cavity pressure evolution along time for sequential injection.

Table 5
Standard process conditions for a polycarbonate

Filling time	1 s
Injection temperature	290 °C
Mould temperature	80 °C

Table 6
Comparative results for real case

Injection technique	Mould and (cavity) maximum pressure (MPa)	Part flow length (mm)
Conventional injection	150 (140)	220
Sequential injection	230 (187.2)	110

inefficiency or even, like the current example, the unsuitability of using a conventional feeding system for sequential injection.

4. Conclusions

The different simulations establish that, to take the maximum profit of the sequential injection moulding technology, it is necessary that the feeding system is designed according to the technology to be used. By injecting sequentially a mould with a conventional feeding system, cavity pressure is higher than for the proper sequential feeding system. On the other hand, by injection conventionally a mould with a conventional feeding system, cavity pressure is higher than for the proper conventional feeding system. So, it can be stated that optimum results are only reached, when mould-feeding system is designed for the suitable technology. Results are not satisfactory when a mould is designed thinking of using it for both, sequential and conventional moulding.

With the same number of entrance points, lower pressures are reached by conventional moulding, due to shorter flow lengths. To work under a pressure conditions, more injection points are necessary for sequential injection than for conventional injection.

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