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ScienceDirect
Procedia Engineering 132 (2015) 1021 – 1028
Procedia Engineering
www.elsevier.com/locate/procedia

The Manufacturing Engineering Society International Conference, MESIC 2015

Analysis of the feeding system in the injection process of peek in fixed partial dentures

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Abstract

In dental sector, PEEK is a new material used in the injection process of fixed partial dentures (FPD). The design of the feeding system is one of the most important stages in the injection process. This study simulates different locations of the feeding system in fixed partial dentures of PEEK, varying number of the injection points, using the software Moldflow. Variables used to compare simulations are the complete filling of the FPD mould cavity, the filling time, the minimum amount of rejected material of the feeding system, defects due to air traps, welding lines, etc. As results, depending on the geometric complexity, and the number and position of the injection points, it is possible to reduce the rejected material and to improve the filling time of the FPD.

Peer-review under responsibility of the Scientific Committee of MESIC 2015

Keywords: Peek injection; Injection process simulation; Fixed partial dentures of peek

1. Introduction

PEEK (poly-ether-ether-ketone) is considered an advanced biomaterial polymer of great interest in dental area [1]. PEEK is used for the implants manufacturing as fixed partial dentures (FPD) or complete arcs (Fig. 1(a)), replacing metallic materials, as titanium, Cr-Co, and zirconia. It is due to its biocompatibility, color and mechanical properties. PEEK is more elastic than metals and zirconia, avoiding cracking in the implants, and its elastic Young's modulus is more similar to the bone than those materials [2]. In the literature, there are few articles that study PEEK

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Peer-review under responsibility of the Scientific Committee of MESIC 2015
doi:10.1016/j.proeng.2015.12.591

in dental area. These studies are focalized in the surface conditions to bond the PEEK [3] and the behavior of PEEK in fatigue tests [4], but not in the FPD manufacturing process.

Nowadays, PEEK is starting to be used in fixed partial dentures or complete arcs manufactured by injection process. Usually, companies that supply raw material, as Bredent GmbH & Co.KG, also provide the injection equipment for PEEK (Fig. 1(b)) and instructions to inject the part to the dental technicians [5].

Manufacturing process of FPD or complete arcs carries on the following steps. In the first step, the dental technician takes a dental impression from a real patient and then makes a plaster model. This model is processed in the laboratory, in order to get the negative of the plaster model. In the second step, the dental technician makes a wax model of the FPD, defining a feeding system to assure the filling of the part in the next lost wax process. In the third step, the dental technician prepares a mould of the part, removing the wax to obtain the cavity of the part to be injected.

However, one of the most important stages in the injection process is the design of the feeding system. The feeding system is composed by the injection points, runners and gates. Gates should be easily removed from the part, and marks produced on the part after its elimination should be minimal because of aesthetic considerations. Gates should be located in the non-visible surfaces of the FPD, when it is mounted in the mouth of the patient. Nowadays, dental technicians want to assure the complete filling of the part. Because of that, they use some gates joining among them in a lineal entry to the mould (as a flash gate). Gates are made joining the system entry to the wax model of the part. In this way, the filling of the part is guaranteed, but a high amount of material is rejected (Fig. 1(c)).

The objective of this work is to simulate the behaviour of PEEK during the injection process with Moldflow software, and to establish the number, shape and position of injection points, to avoid air traps, cracks, welding lines, etc., improving the filling time and minimizing the rejected material. This is a preliminary work and its final objective is to build some useful tables in order to help the prosthetic technician to improve the PEEK injection process.

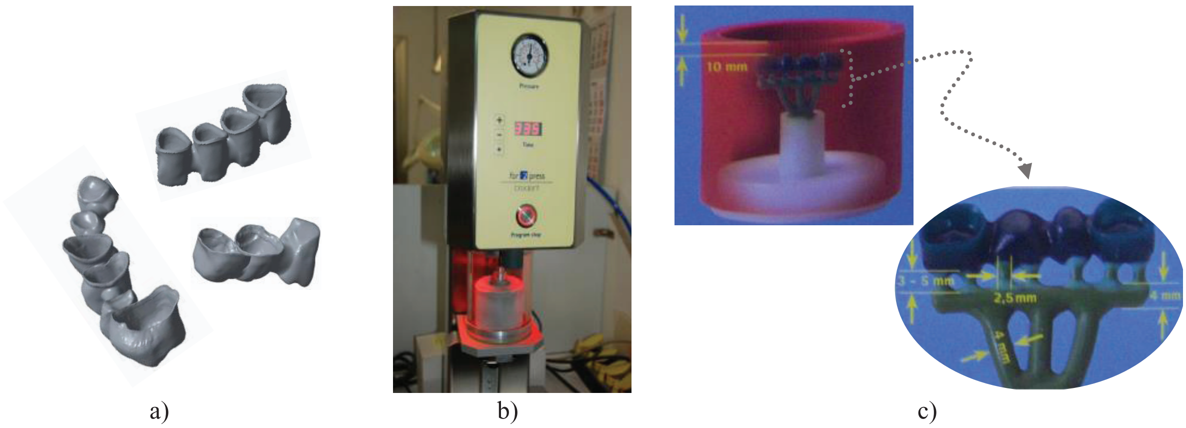

Fig. 1. (a) fixed partial dentures; (b) injection machine; (c) feeding system to the wax model.

2. Experimental procedure

FPD are composed of different number of elements. Some elements in FPD are solid and others have an interior cavity to insert the FPD on the stumps. In a first stage, simulations were performed on a FPD with three elements. The extreme elements (molar and pre-molar) have an interior cavity to insert the FPD on the stumps of the patient, and the intermediate element is solid.

The flow chart in Fig. 2 shows the steps to the simulation study of FPD.

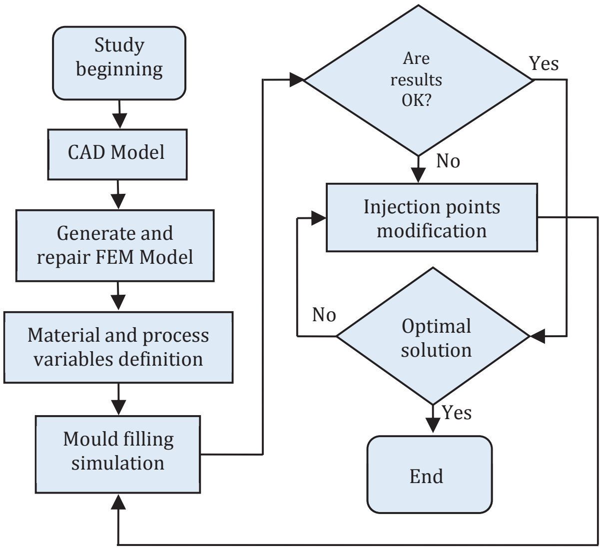

Fig. 2. Flow chart.

The FPD wax models were scanned using the SCAN-FIT® collimated scanner, obtaining files with STL format. These files are treated to correct defects during the scan, such as elements without union, geometry intersections, lack of points in a region, etc., and they are introduced in Autodesk Moldflow Insight Software to initiate the pre-processing. FPD are meshed with tetrahedron finite element (Fig. 3(a)). The software only allows a prismatic mould and it is added to the part and meshed too (Fig. 3(b)). The real mould has cylindrical shape as it is shown in Fig. 1(b)).

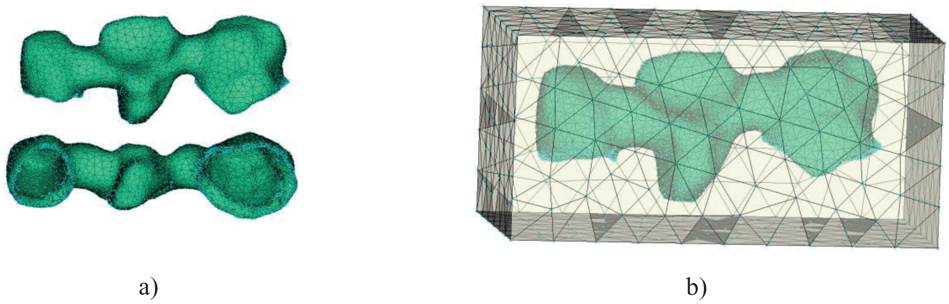

Fig. 3. (a) meshed FPD; (b) meshed model.

Finally, the feeding system has to be designed. It is composed of a sprue, runners and final gates. The behaviour of the simulation software is different if the feeding system is added into the Moldflow software or if it comes from an external CAD.

Geometric variability is limited if the feeding system is added in Moldflow, because the gates have to be cylindrical and their diameters are fixed to 3 mm as used by the prosthetic technician. If the feeding system is added from an external CAD, the simulator treats it as if it belongs to FPD part and then the software applies the same equations during the simulation process. In addition, when a feeding system is added to a FPD model, saved as STL format, problems of surface continuity are found, because of new surfaces interact with surfaces of the part.

In this work, the feeding system has been designed into the Moldflow software, but in some models it has not been included in order to study the influence of the feeding system in the final results, e.g. if there is a variation in the number of defects, a lack of material, an injection time increment, etc. This work does not focus on the design of the feeding system. When a feeding system is used in the model, it corresponds with one utilized by the prosthetic technician included in the typical dental kits.

Injection points cannot be positioned on the top of the FPD, because this zone has been designed taking into account the influence of the opposite mandible to avoid interactions. Of the remaining two options, injection points will be placed on the rear surface of the FPD, because this zone is not visible and less relevant.

Process variables, such as material and injection machine parameters, times, speed, etc. have to be defined to perform the simulation. Mould and part temperature is fixed to 380ºC. An important aspect is the commutation between velocity and pressure in the injection machine. The objective of the velocity mode is to fill the cavity of the mould as quick as possible. In this mode, the pressure applied is used in minimizing the resistance of the molten PEEK to fill the cavity. As the mould is filling, the required pressure is higher. In the pressure mode, the fill is completed compacting and compensating the contraction, working at 'high' pressures. The point of changing is important. A fast change can produce shrinkage, non-compact parts, and parts out of tolerances or not complete filled. A later change can produce overpressure that can open the mould and produce cracks in the material of the mould and therefore flushes. The commutation between speed and pressure is established as 'automatic' in the Moldflow because in this way, the software estimates the right percentage.

3. Simulation analysis

Due to the work conditions related with the mould temperature, the vacuum condition, the prefixed diameter for the runners (feed channels) and the limitations in the number and position of the injection points, the simulations were as follows.

All the images show the time to fill the model. The program uses five ordered colours, navy blue, sky blue, green, yellow and red, and of course, all the intermediate mixes. The pure navy blue colour represents the times near zero, red colour is for the maximum time needed to fill the model, and the others are the corresponding fifth of the bar. The maximum values are shown in Fig. 6 (abscissa) for each model tested.

A couple of images, Fig. 4(b) and Fig. 5(a), show the behaviour of the flow in a thin part of the model and in a solid part of the model, respectively. They are pictures taken at intermediate moments since all the simulations filled completely the model, how it is shown in Table 1.

- Central point on solid piece.

One injection point on the solid central piece, without runners (Table 1, row 1, shows the main results).

In Fig. 4(a), the results after the simulation process are shown, with the whole piece filled with PEEK. Red colour marks the area which has been filled last, in this case are the crowns. The time spent in the process is nearly 30 seconds. Due to the features of the machine, when it reaches 30 seconds, the injection process stops and holds the pressure to achieve higher degree of compaction.

If there is any region unfilled, this is usually the zone corresponding to the marginal fit. Moreover, when only one injection point is used, the pressure gets focused in specific regions, around the gates. This situation could create small cracks in the ceramic mould.

- Central point on solid piece with runner of Ø3.

One injection point on the solid central piece, but adding a runner using MoldFlow tools. Runners are cylindrical with 3mm of diameter. Fig. 4(b) shows the runner in blue with one injection point and the simulation process of filling in the 24th second. The result is almost equal to the previous one, the main difference is an increase in the volume injected because of the mass of the runner. The numerical results are shown Table 1, row 2.

- One point on each crown.

One injection point is placed on the backside of each crown belonging to the fixed partial denture, Fig. 4(c). Crowns are the critical regions and a filling belated could cause defects.

This simulation increases the injection time two times, over the previous two simulations, because of the injection points are placed in zones with less wall thickness, in other words, where the flow has more resistance. The initial pressure, Fig. 6 (One point on each crown), rises quickly due to this lack of thickness in the piece.

This configuration generates welding lines in the central part due to the joining of the flows. This situation could be harmful because this part is cantilevered. This is the part which has the maximum flex during the process of chewing.

- One gate on each connector with runners of Ø3.

There is one gate in each connector, with both runners (Ø3mm), Fig. 4(d). Connectors are not critical zones, thinking on the marginal fit. They are nearer to the crowns, so speed up its filling.

The results in this test are between the results of 'Central point on the solid piece' and 'One point on each crown'. Its flow is between 0.005 and 0.009 cm3/s, as we can see in Table 1, row 4. The stress/time curve is better too, as shown in Fig. 6 (One gate on each connector, runners Ø3).

It is important to remark that the curve in Fig. 6 (One gate on each connector, runners Ø3) grows very quickly at the beginning. It reaches 0.12 Mpa almost immediately and remains here until the phase of compaction, in second 22. Also, the phase of compaction (Commutation V/P in Table 1, row 4) has been lightly advanced, it takes place in the 99.6330%.

Under these conditions welding lines in the central solid piece and in the connectors can appear. Having welding lines in the connectors is a critical situation because they are the link between the artificial part and the supports with the abutments in the patient, and they have to withstand all the efforts.

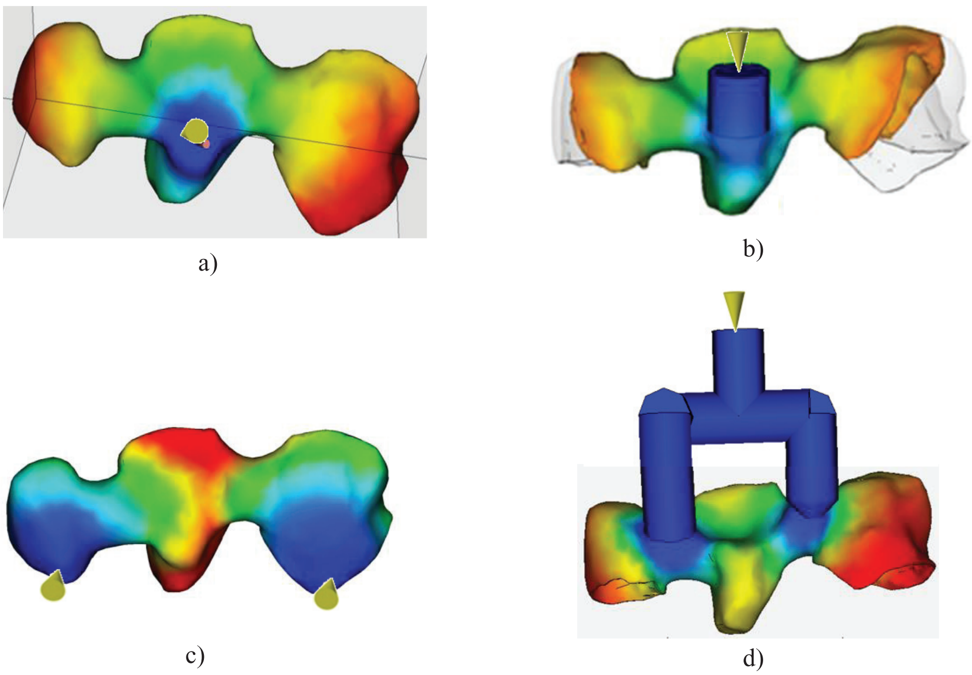

Fig. 4. (a) central point on solid piece; (b) central point on solid piece, runner Ø3; (c) one point on each crown; (d) one gate on each connector, runners Ø3.

In order to reduce pressures, especially the initial ones and avoid the cracks in the mould, many alternatives were simulated. In these ones the number of gates were increased (Fig. 5).

Cluster of gates on solid piece.

This set up is shown in Fig. 5(a). Comparing this case, Fig. 6 (Cluster of gates on solid piece), with Fig. 6 (Central point on solid piece) pressure rises slower. The main reason for this drop of pressure is the use of three gates instead of one, which makes increase the input section.

Concerning to the injection time, it arises because the process needs more material and time to fill the feeding system.

Another interesting result is the decrease in the clamping force, the less risk to produce cracks and the lower probability of leak material, all of them as a result of the initial drop in pressure.

Cluster of gates on one crown.

Several gates are located on one of the crowns, in a zone with less wall thickness, the same number of runners are added from MoldFlow software, Fig. 5(b). This configuration decreases the initial pressures too, nevertheless, the clamping force needed rises more than 0.009 Tons compared with the other configurations. The main drawback is that the other crown is filled the last.

One point on solid piece and on one crown.

Without Ø3mm runners, one injection point on solid piece is placed and other on one of the crowns, Fig. 5(c). This situation makes decrease the filling time.

On the other hand, no advantage is appreciated compared to the other trials, and one drawback must be taken into account, the second crown is filled the last

One gate on solid piece and one gate on each crown.

MoldFlow Ø3mm runners are placed, as shown in Fig. 5(d). This configuration provides the maximum flow. Besides, the size of the zones filled the last, shown in red, is the lowest of all tests. Red zones represent those ones which are likely to be problematic. Clamping force is lower than the other tests.

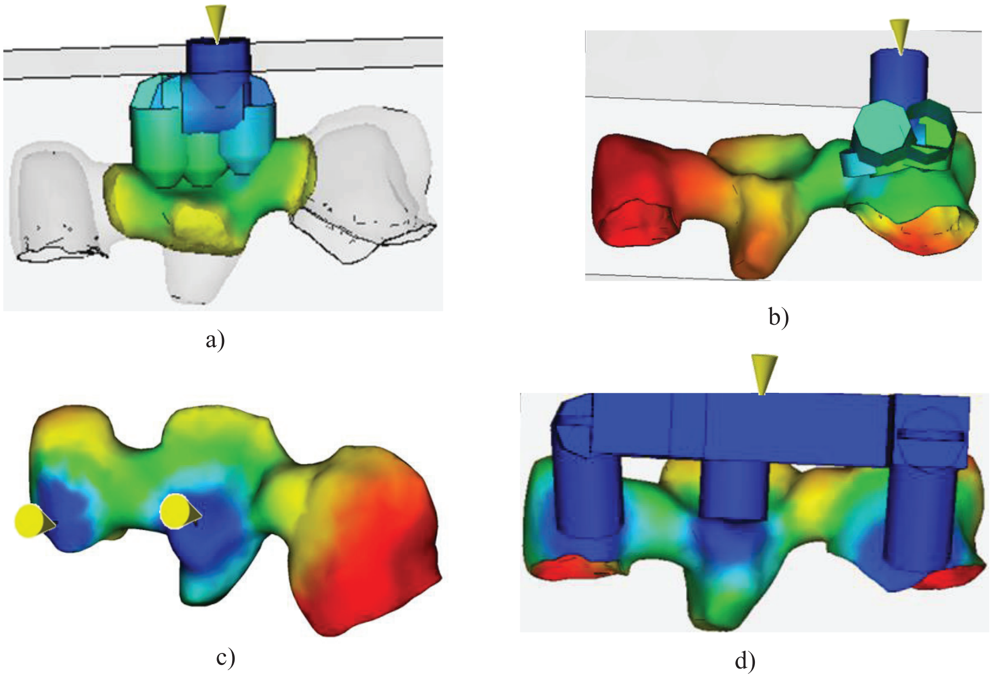

Fig. 5. (a) cluster of gates on solid piece; (b) cluster of gates on one crown; (c) one point on solid piece and on one crown; (d) one gate on solid piece and one gate on each crown.

Table 1 shows the tests results. All of them reach and hold the maximum injection pressure of the machine, 0,55 MPa.

Table I. Main results of the simulations

Injection point position	$t_{filling}$ (sec.)	m_{piece} (g)	P (g/cm^3)	$P_{max\ inj}$ (MPa)	Flow (cm^3/s)	Conmutation V/P (%)
Central point on solid piece	25,3118	0,2291	1,049	0,55	0,009	99,8475
Central point on solid piece, runner Ø3	28,2226	0,2291	1,049	0,55	0,009	99,8467
One point on each crown	40,1926	0,2291	1,049	0,55	0,005	99,8571
One gate on each connector, runners Ø3	30,4896	0,2291	1,049	0,55	0,007	99,6330
Cluster of gates on solid piece	41,0504	0,2291	1,049	0,55	0,009	99,8451
Cluster of gates on one crown	40,5509	0,2291	1,049	0,55	0,005	99,8489
One point on solid piece and on one crown	20,3979	0,2291	1,049	0,55	0,011	99,8437
One gate on solid piece and one gate on each crown	20,4863	0,2291	1,049	0,55	0,011	99,5691

Fig. 6 shows the behaviour of the pressure over time for each test. There are two clear groups, tests, with filling time under 30 seconds and the other ones with filling time higher. The main reason for this behaviour is the location of the gates/injection points. When they are in zones with less wall thickness, like the crowns, the flow finds more restrictions to advance.

It is possible to split into two sets of tests according to initial pressures. When the injection point, or a cluster of gates, is located on the solid piece, the pressure increases slowly. It is advantageous because a soft slope in pressures avoid cracks in the mould.

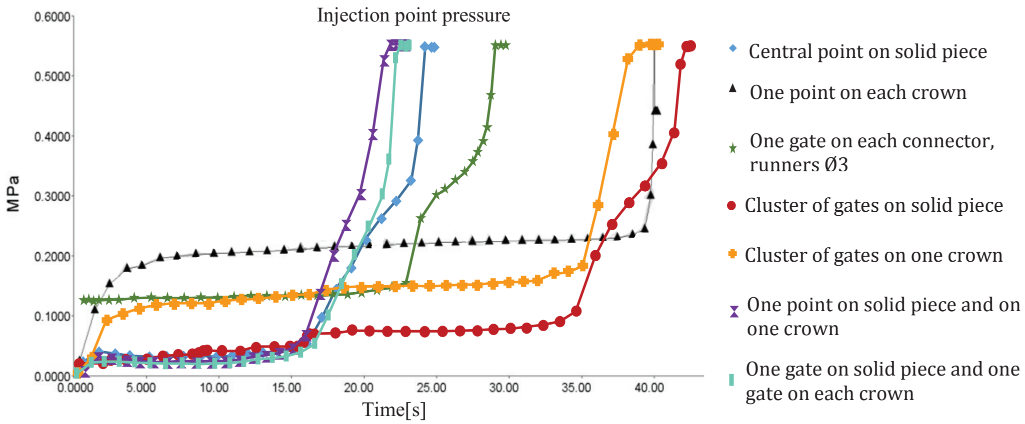

Fig. 6. Stress/time curve.

4. Conclusions

The filling is complete in all tests (Table 1) and also the piece mass remain the same (m piece). This is mainly due to features as, overheating, holding time and the vacuum condition, among others. Nevertheless, in a real situation other variables have important effects, variables like overpressures, accumulated strains in the muffle (due to a wrong application of stabilization times to reach the injection temperature), geometric variations in the model, etc. make no satisfactory all the injections.

Using multiple injection points/gates (cluster type) decreases the initial pressure, but makes complicated its removal in the final piece, also more raw material is necessary.

Because of the great difference between the wall thickness of the crowns and the solid pieces, and so the abrupt changes in sections, situation that increases the resistance of the molten plastic material to forward flow (Back

Pressure), a distribution of the injection points/gates between areas is necessary. Hence, the best option according to the results is 'One gate on solid piece and one gate on each crown'.

With only three distributed gates, as the best option, it is possible to avoid that the process reaches the holding time before a full filling. It is useful to remember that prosthetic technicians use a lot of gates joined together, like a flash gate. Nevertheless, in order to avoid welding lines in the connectors, it is necessary to control the separations between gates/injection points. Changing this separation, the place where the flows meet can be moved, leaving the welding lines to less critical zones.

The preliminary study shown in this article should be completed, extending it to other fixed partial dentures with different setups and quantity of pieces, and of course, contrasting the results with real tests.

The main target of this work is to build a set of tables to help the prosthetic technicians to place the gates according the features and dimensions of the fixed partial dentures.

Acknowledgements

Cooperation with 'Laboratorio de Prótesis y Estética Dental El Carmen S.L.' has been appreciated, because of the practice trials and CAD models provided.

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