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Optimization of Micro Injection Molding of Polymeric Medical Devices using Software Tools

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Abstract

Micro injection molding is a domain which implies challenges for both producers of moulds and technologists. Due to special conditions required by the process of micro injection molding, chemical, physical and thermal properties of the injected polymeric material are affected, material behaviour is different compared with that during the classical process of injection moulding and so, optimization of parameters of the injection process is needed. This work has shown the process of optimization of micro injection in template given a medical application. A numerical analysis has been performed using the Autodesk Moldflow Insight software given a "surgical micro-stitch" marker device.

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Keywords: micro injection, optimisation, medical application, numerical analysis;

1. Introduction

A numerical analysis has been performed in this work using the Autodesk Moldflow Insight for process optimization of the injection of a "surgical micro stitch" in a mold with four nests, in order to obtain a high quality device. To optimize the produced device and implicitly, the template, a simulation was conducted of the process of filling four nests of injection mold and phenomena occurring during flow of melted polymeric material in the template's injected network were analyzed. This analysis has led to optimization of the following issues related to the process of injection: filling time; pressure during injection, positions of meeting fronts of material, weld lines,

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air gaps, orientation of material during flow, volume (shrinkage) contraction and its steadiness, demoulding of the device after solidification, unitary effort during shredding, speed of shredding and quality during filling [1], [4], [7]. Simulation of the filling process allows for improving quality of the final device and significant reduction of costs through shortening time for design and production.

2. Methods and materials

The " Polylactic acid resins biopolymer - PLA" material of which the surgical micro stitch is made, is a polymer with a crystalline structure containing polylactic acid and that has a transition temperature of 105 ºC. This material has been used for various medical applications of which medical stitches to stitch up wounds and operations and also to set in place parts of fractures. The material has been utilized in medical applications due to its biodegradable properties, as it dissolves in human tissue so not any subsequent associated medical interventions are needed. Values of process parameters that the producer recommended for this material have been : temperature of template between 4 and 40 ºC, temperature when injecting melted polymeric material between 160 ºC and 230ºC and temperature at which the producer recommended to eject device from template, 95ºC . This material in its liquid state has a density of 1.0501 g/cm3 [3]. Using the Autodesk Moldflow Insight data were obtained with regard to PLA rheological behaviour [2] [8].

3. Results and Discusion

Using the Autodesk Moldflow Insight, several simulations were conducted with various values of parameters of injection of the "medical micro-stitch" into a template with four nests. These simulations led to improved results and optimal parameters of process. As position of the injection point can be one key factor which determines quality of the final device [5], during the first stage an analysis was performed in order to identify optimal position of injection point also suitable to geometry of the injected micro-stitch [1], [5]. Hence, injection of the latter in a template has to be carried out in a balanced, unidirectional way and under good conditions [6].Results of the analysis were shown in figures 1-2 [1].

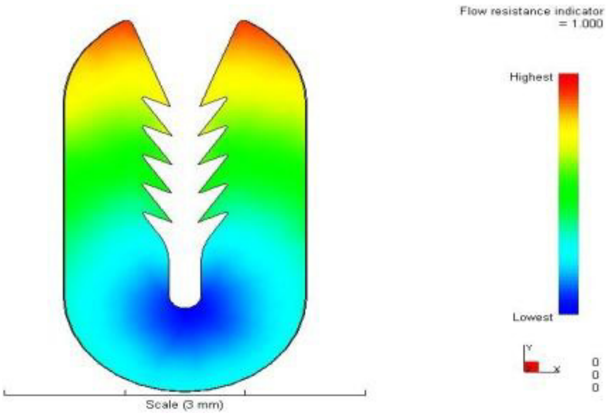

Fig. 1. Resistance to flow of melted material

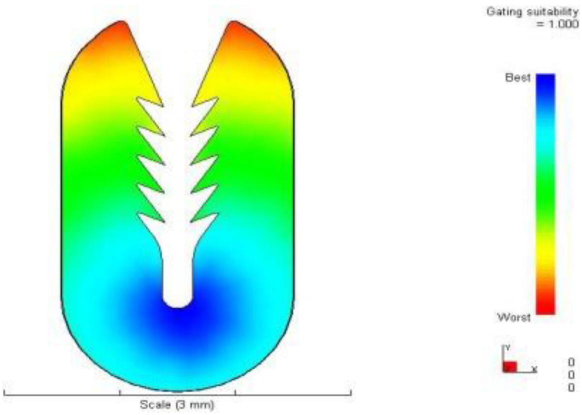

Fig. 2. Feasible position of injection point.

It can be noticed from figure 1 that the melted polymeric material is easiest to be injected towards the bottom of the device as less resistance to flow is encountered at the bottom and the farther from this location, the more resistance to flow is to be found out. In figure 2 the most as well as the least indicated areas were shown in regard to position of the injection point. Hence the blue areas were the most indicated while the red areas, the least indicated. Since the surgical micro stitch is to be injected in a mold with four cavities, in order to design appropriately an injection system in the template and also the material to penetrate more easily in the four cavities, the optimal injection point was chosen in the position shown in figure 3.

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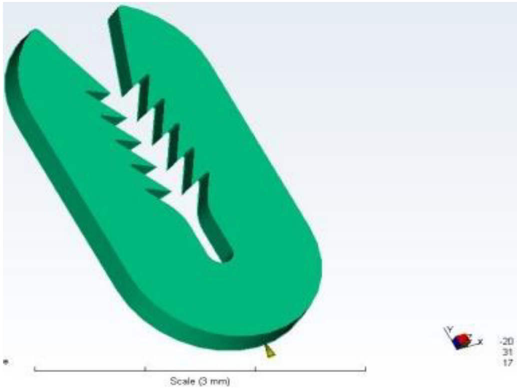

Fig. 3. Optimal position of injection point

It can be noticed from figure 1 that the melted polymeric material is easiest to be injected towards the bottom of the device as less resistance to flow is encountered at the bottom and the farther from this location, the more resistance to flow is to be found out. In figure 2 the most as well as the least indicated areas were shown in regard to position of the injection point. Hence the blue areas were the most indicated while the red areas, the least indicated. During the second stage, the system of injection of the four cavities, feeding channels and dams were designed and their dimensions established, to further inject the surgical micro stitch marker device. We chose the separation plan at the level of the injection point as shown in figure 4. The volume of injected polymeric material was 0.017cm3 weighing 0.018 g. In view of attaining optimal parameters so to have an efficient well designed project of injection, several numerical simulations were conducted using Moldflow Plastic Insight software. For simulation of the injection process, temperature of the environment was set at T = 25 ºC and we chose a machine of injection with the following characteristics: maximum force of closing Fi 25,485 tones; maximum pressure at injection Pimax 275.5 MPa; diameter of the injection screw d =14 mm; maximum flow that can be injected Qimax= 53 cm3/s; hydraulic (system) response time trh=1*10-2 s. Also, the cooling agent utilized was distilled water with the following properties: density 0.988g/cm3; specific heat 4180 J/kg * ºC; thermal conductivity 0.643 W/m* ºC; viscosity 2.86e-005 Pa*s, the Reynolds' number 10000, cooling agent temperature 70 ºC and flow 0.57 l/min.

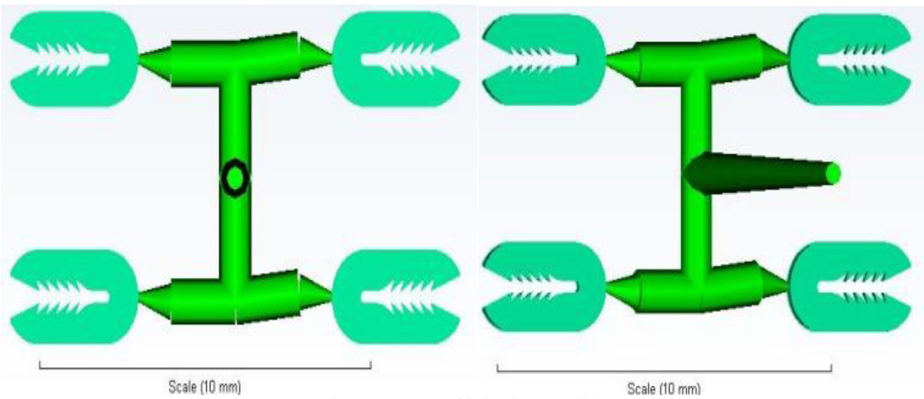

Fig. 4. System of injection mould.

We performed simulations at different temperatures of the polymeric material, in accord with producer's recommendations (160 ºC, 170 ºC,180 ºC, 190 ºC, 200 ºC, 210 ºC, 220 ºC, 230 ºC) and with a template temperature of 40 ºC. From these simulations, in order to determine optimal process parameters, we kept records of time of filling cavities, maximum pressure at injection, maximum speed of injection, volume contraction, deviations of marker device in x, y, z directions and total deviation at various values of melting temperature [1] [9]. Restrictions software takes into account when establishing deviations of the marker (device) were: not uniform contractions in a parallel and perpendicular direction with the direction of material flow, not uniform cooling, orientation of material molecules during solidification. These data were shown in figures 5-11 [1].

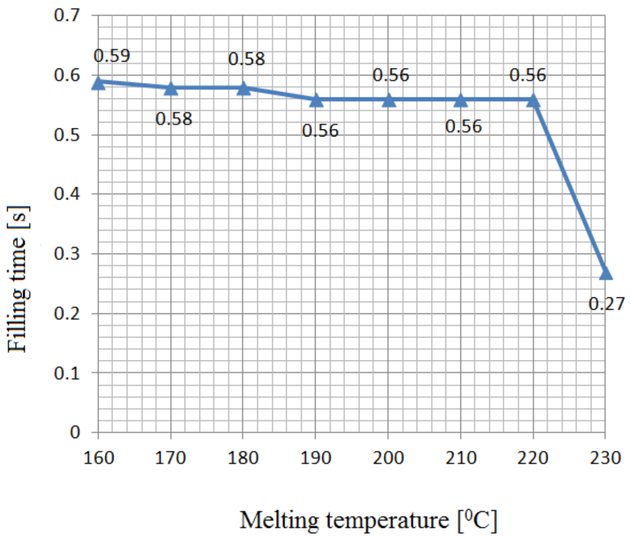

Fig. 5. Filling time depending on temperature of melted material (Melting temperature [^{0}C]; Filling time [s]).

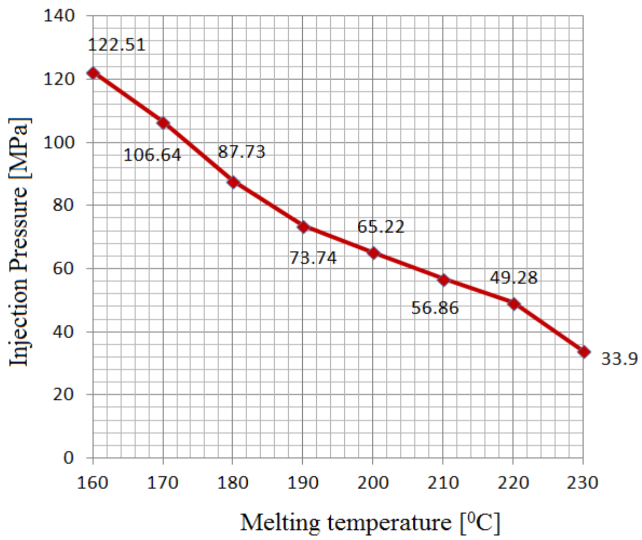

Fig. 6. Maximum pressure during injection depending on temperature of melted material (Melting temperature [^{0}C]; Injection Pressure [MPa]).

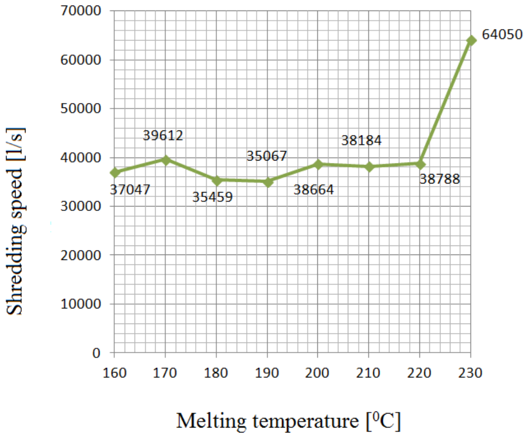

Fig. 7. Maximum value for shred speed depending on temperature of melted material (Melting temperature [^{0}C]; Shredding speed [1/s]).

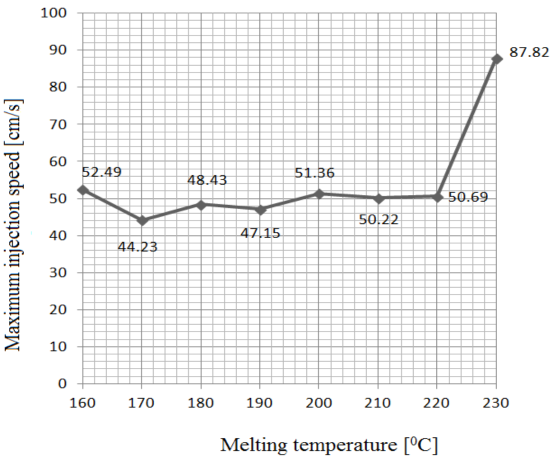

Fig. 8. Maximum speed of injection depending on temperature of melted material (Melting temperature [^{0}C]; Maximum injection speed [cm/s]).

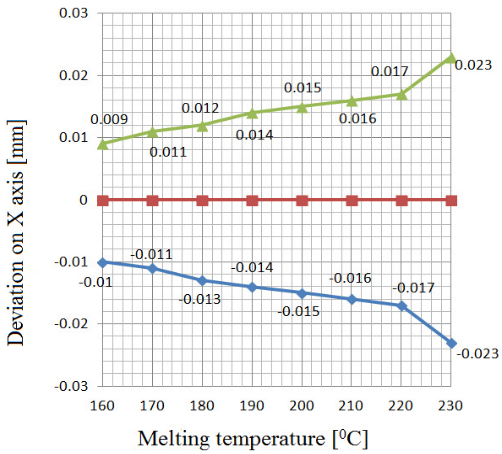

Fig. 9. Minimum average and maximum deviation of the marker device in the x direction depending on temperature of melted material (Melting temperature [^{0}C]; Deviation on X axis [mm]).

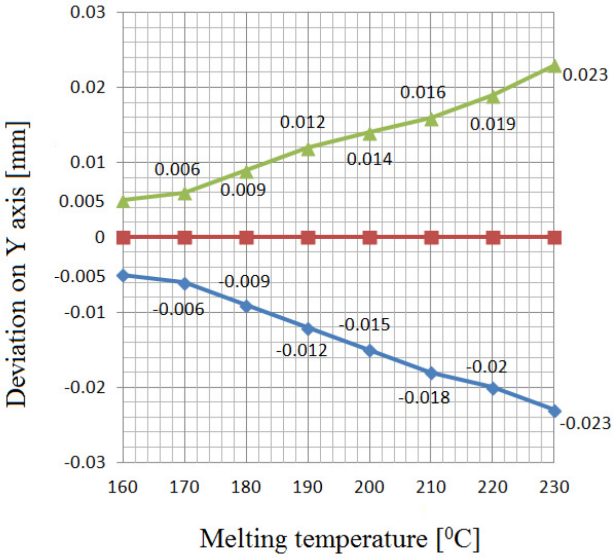

Fig. 10. Minimum average and maximum deviation of the marker device in the y direction depending on temperature of melted material (Melting temperature [^{0}C]; Deviation on Y axis [mm]).

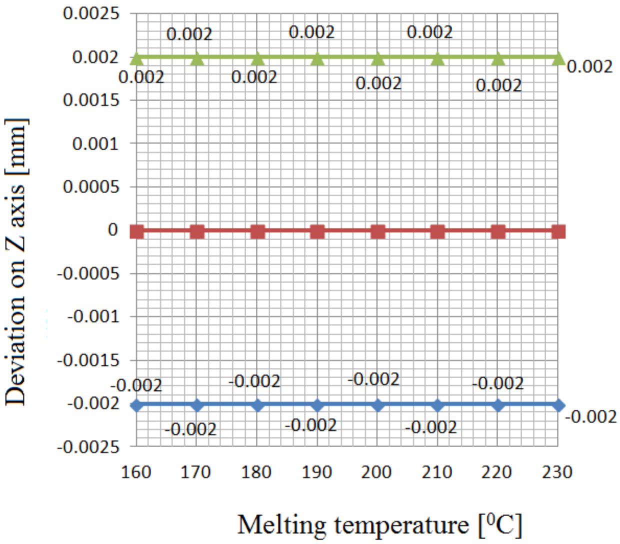

Fig. 11. Minimum average and maximum deviation of the marker device in the z direction depending on temperature of melted material (Melting temperature [^{0}C]; Deviation on Z axis [mm]).

The following resulted from analysis of the above figures:

It can be seen from figure 5 that time of template cavity filling reaches a descending trend once temperature of the melted polymeric material increases. Because of loss of pressure which occurs when polymeric material passes through narrow sections of the injection nozzle and of the injection network, increasing pressure of injection is required at temperatures of the melted material of 160 ºC, 170 ºC, 180 ºC, 190 ºC. As can be seen in figure 6, pressure of injection lowers once the melting temperature increases and reaches a maximum value at the temperature of 160 ºC and a minimum value at 230 ºC. A too large increase in pressure of injection can lead to burns on the device, while a too low pressure of injection can result in agglomeration of material. As can be seen in figure 7, shred speed reaches an ascending trend in relation with increase in temperature of melted polymeric material, while viscosity reaches a descending trend as a consequence of its interrelationship with shred speed. It can be seen from figure 8 that the speed of injection increases once temperature of injection increases. A significant increase can be noticed at the temperature of 230 ºC. Speed of injection had various values for each point of the injected device depending on position of melt front and time. Passage of the melted polymeric material from high values of temperature of operation, temperature at which the material is injected as cases of values of 210 ºC, 220 ºC, 230 ºC to the temperature value of eject of device 95 ºC respectively, and then to the temperature of environment, 25 ºC, respectively has the effect of increase in shrinkage (contraction) of device after solidification, figures 9, 10 and 11. The higher the temperature, the higher the volume shrinkage of the device when ejected from template because of differences in temperatures and small volume of polymeric material injected. Higher values for volume shrinkage (contraction) were obtained at melting temperatures of 220 ºC, 230 ºC, figures 9, 10 and 11.

4. Conclusion

The paper shows the simulation of the filling process allows for improving quality of the final device and significant reduction of costs through shortening time for design and production. A numerical analysis has been performed using the Autodesk Moldflow Insight for process optimization of the injection of a "surgical micro stitch" in a mold with four nests, in order to obtain a high quality device. Time of injection of the piece has a significant influence on solidification of the piece. At high values of speed injection degradation of the polymeric material may occur through presence of burning areas on the device's surface. If the injection is not quick enough then there is risk of premature solidification of the device because of a very small volume of polymeric material injected. Speed of injection had various values for each point of the injected device depending on position of melt front and time.

Optimal parameters of injection in order to have a high quality device standardized as the case of "surgical micro stitch" using " PLA" material injected in a four nest template have been: temperature of material melting 200 ºC, template temperature 40 ºC; filling time 0.56 s; maximum pressure during injection 65,22 MPa; cooling time 1,5s.

Simulation of the process of mould filling allows for improving quality of the final device and significant reduction of costs by way of shortening time for design and production.

Simulation of the process of injection using Moldflow Insight software has allowed for collecting data with regard to rheological behaviour of the " PLA" material.

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