A COMPARISON BETWEEN VERTICAL AND HORIZONTAL PLASTIC INJECTION MOLDING MACHINES FOR PROTOTYPE TOOLING APPLICATION

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Abstract*. During the product development process, functional prototypes are usually required to perform mechanical and/or functional tests. For plastic injected parts these prototypes can be obtained using a prototype tooling, i.e. a mold for a reduced number of injections. They are usually manufactured of cheaper materials and in a shorter time when compared to production molds. Because the injection of prototypes is usually made using a horizontal injection molding machines, the inserts have to be assembled into a traditional mold base, which increases time and cost to obtain the prototypes. An option that could be used to further reduce costs and time to obtain such prototypes is the use of vertical injection molding machines, which usually requires simpler clamping systems. So far, it was not found in the literature any study in this area. This study aims to conduct a comparison between the injection process in these types of injection molding machines (horizontal and vertical). The idea was to analyze not only the process but also the quality of the moldings. Mold inserts for tensile and bending tests specimens (according to ASTM) were designed and manufactured in SAE 1045 steel using CAD/CAM and CNC machining, for these two machines. The pair of inserts for the horizontal injection machine was mounted in a mold base, while the pair of inserts for the vertical one was mounted directly on the machine (without a mold base). For the latter, C-clamps were used to keep the insert closed during the injection process. Polypropylene was the polymer injected. The time to manufacture the inserts and to inject the parts was compared and tensile and bending tests were performed. The results shown that the moldings have similar mechanical characteristics and that the prototype mold for the vertical machine was ready to produce in a shorter time. The study concluded that vertical injection molding machines can be considered a good alternative to obtain injected functional prototypes using prototype tooling.*

Keywords*: prototype tooling; polymer, injection molding machine*

1. INTRODUCTION

The time required to develop a product is a decisive factor for its success in the market, which is characterized by high competition and rapid changes. If the time to introduce the product in the market is too high, it risks to reach a lower economic return, due to changes in customer needs, or to the arrival of other products (Hartley, 1998). In many cases, product development requires functional prototypes for mechanical or maneuverability tests. According to Amorim (2006), in order to obtain these functional prototypes using the same material and having the same characteristics of the final product, the same manufacturing process must be used. In the case of plastic molded parts, this is achieved by using plastic injection process.

According to Harada (2004), the injection molding machines can be classified as horizontal or vertical, each type having advantages and disadvantages. In general, horizontal machines have higher level of automation and the injection process can be better controlled. On the other hand, vertical injection machines usually are more simplified and have a basic process control. For this reason, the use of vertical machines in production is not widespread and the information about this process is relatively rare in the literature (Serafini and Siegel, 2010). As an example, Fig. 1 presents a typical vertical injection mold, which is a mold for the production of an electronic component case. In this example, attention should be paid to the fact that the injection sprue is oriented in the same plane of the mold parting surface (Fig. 1 and Tab. 1). This indicates that the direction of the opening/closure of this mold is perpendicular to the sprue. In a horizontal injection mold, usually the sprue is perpendicular to the parting surface.

At the industries, the production of injected parts is usually done by horizontal injection molding machines. Due to the complexity of these molds, their manufacture is expensive and time consuming (Menges and Mohren, 1993). This can significantly influence the time and cost to obtain the product. An option to accelerate the process is to use standard mold bases and to manufacture only the mold inserts (core and cavity). A mold base is composed by several steel plates, with various elements for assembly, guiding and fixing, making it complex to manufacture and relatively costly (Manrich, 2005).

In the case of using vertical injection machines, a simplified solution can be adopted, because the inserts can be mounted directly on the machine, avoiding mold base (Fig. 1). Therefore, the process is cheaper and less time consuming, due to the manufacturing simplification of the mold.

For prototyping application, a faster and cheaper mold solution is desired. In such cases, it is expected that the use of a vertical injection molding machine may have advantages over a horizontal machine. However, there is not much information in the literature about if the properties of the molding are affected by the type of equipment used. This brings uncertainty about the feasibility of using this technology as a prototyping solution, especially where the final part will be produced by a horizontal machine.

This work aims to conduct a comparison between injection process carried out on a vertical and horizontal injection machine. The idea is to analyze the difficulties of each process and the mechanical characteristics of the moldings when applied to prototyping of polypropylene. At the end, the paper presents a discussion of the final results and the feasibility of both processes.

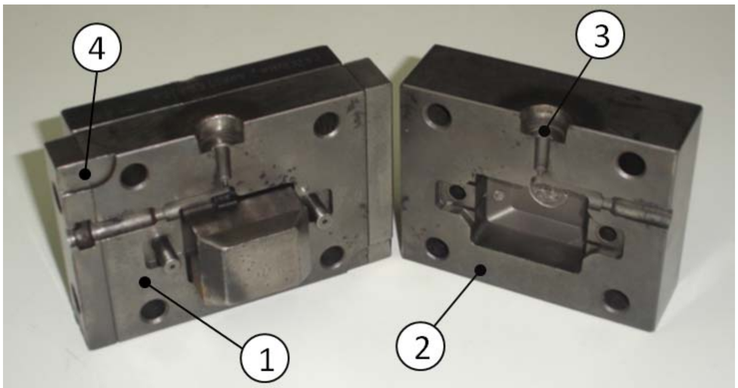


Figure 1. Example of a vertical injection mold from Magnetron Componentes Ltda. (Serafini and Siegel, 2010)

Table 1. Main features of the vertical injection mold from Figure 1

Item	Identification	Observation
1	Core parting surface	-
2	Cavity parting surface	-
3	Injection sprue	Same plane of the parting surface
4	Cut	Facilitate the opening by inserting a wedge tool at this location

2. MATERIALS AND METHODS

The experimental study carried out in this work is detailed below.

2.1. Machines and injection molded material

Two injection molding machines were used in this work. The horizontal was a HTF58X, from Haitian, and the vertical, was a KT 220 DM, from Taiwan Kinki Machinery. Table 2 presents the main machine characteristics. These machines belong to the Polymer Processing Laboratory of Federal University of Technology - Paraná (UTFPR).

Analyzing the machine characteristics, it was possible to observe that the vertical has lower power than the horizontal. Despite of this, the vertical machine has several similar characteristics to the horizontal one, such as closing plates with position control, possibility of run in automatic mode, control the amount of material injected into the cavity, among others. To achieve the purpose of this study, the vertical machine should be used with its basic characteristics. To this end, it was verified that the machine allowed to be manually operated (manual mode), making it possible to simplify the injection process. In addition, a simple way to fix the mold in a vertical machine is using a manual or hydraulic vise (Serafini and Siegel, 2010). Although the machine in question has a hydraulic clamping unit, similar to a horizontal machine, it was decided not to use it, assuming it was a basic machine. Then, it was assumed that the sprue should be maintained aligned to the parting surface. In other words, the direction of the injection sprue could be designed normal to the parting surface of the mold, as used in horizontal machines.

Polypropylene (PP) from Braskem® was selected as the injection material, as it is widely used in industry and is easily molded. This material is easily found on the market and the suppliers offer plenty of information, which is important to the injection process.

2.2 Test specimens

For the mechanical characteristics analysis of the moldings it was performed tensile and bending tests. The standard applied for the tensile and bending tests are respectively: ASTM D638-03 and ASTM D790-03. For injected PP, ASTM D790-03 (2004) recommends a specimen body with 127 mm length, 12.7 mm width and 3.2 mm thick (Fig. 2).

Table 2. Main machine technical characteristics

	Horizontal Haitian HTF58X	**Vertical KT 220 DM**
INJECTION UNIT		
Screw diameters (mm)	26	30
Injection capacity (g)	60	100
Screw velocity (rpm)	255	205
Injection pressure (MPa)	245	140
CLOSURE UNIT		
Clamping force (kN)	580	300
Screw stroke (mm)	270	180
Distance between tie bar (mm)	310x310	520x205
Max. mold height (mm)	320	340
Min. mold height (mm)	120	160
Ejector stroke (mm)	70	45
Ejector force (kN)	22	13
Ejector quantity	1	2

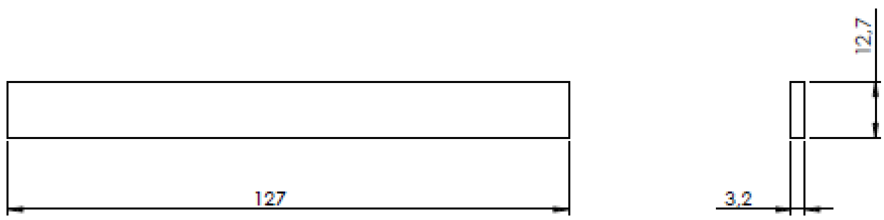


Figure 2. Bending specimen (Adapted from ASTM D790-03, 2004)

For rigid and semi-rigid plastics, the ASTM D638-03 (2004) has a range of specimens´ lengths. Analyzing the limitations of the insert bed in the mold base and considering the bending specimen, it was selected the tensile specimen shown in Fig. 3.

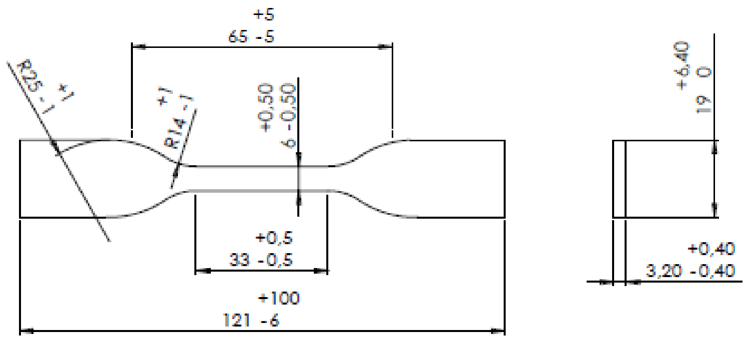


Figure 3. Tensile specimen (Adapted from ASTM D638-03, 2004)

2.3. Design of the molds

To simplify the work, it was decided to group the two specimens into a single pair of mold insert, therefore they will be injected simultaneously. Aiming to obtain the material flow conditions as similar as possible for the two injection machines, a reference point was defined (Fig. 5 and Fig. 7) at the end point of the injection sprue (beginning of runner channels). From this point, the geometry of the two mold inserts was kept the same.

To ensure uniform filling of the two cavities (tensile and bending cavity), the positioning of the specimens, the runner channels and the injection points, were obtained by a balancing technique. This was done by analyzing the projected area, which consists of dividing the mold insert into quadrants and carry out a comparative sum of area of each quadrant.

The main difference between the molds is the sprue design and orientation. In the horizontal inserts, the sprue is perpendicular to the parting surface and for the vertical one, it was designed in the same plane of the parting surface (Fig. 4 and Fig. 6). This required the addition of a cold well (1) at the end of the sprue (Fig. 7). In addition, two holes for guide pins (2) were added in the vertical mold. Another difference was the thickness of the core and cavity, because the horizontal inserts have to be defined according to the bed geometries of the mold base. For the vertical inserts, the thicknesses were kept the same.

The CAD software ProEngineer Wildfire 4.0, from PTC corp., was used for 3D modeling (Fig. 4 and Fig. 6). To check cavity balancing a numerical simulation was performed by the software Moldex 3D, from Core Tech Systems Co. Ltd. (Fig. 8). As shown in this figure, the filling of the cavities occurred at the same time.

For the vertical inserts, with the disposition of the injection sprue close to the bending specimen cavity and the runner, it is expected that the temperature in this region would be higher than that observed in the inserts for the horizontal machine. This can lead to some variation in the injection conditions (filling and cooling of the molding).

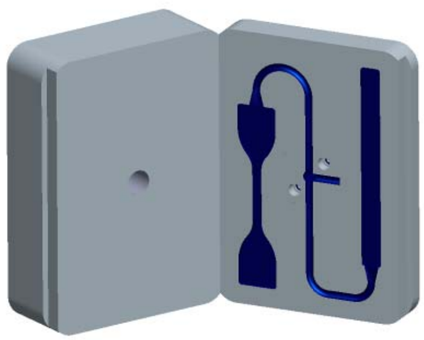


Figure 4. 3D model of the horizontal inserts

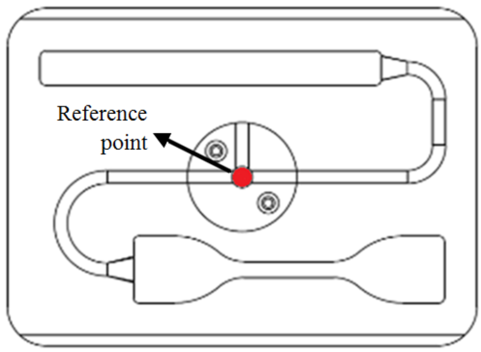


Figure 5. Reference point in the horizontal insert

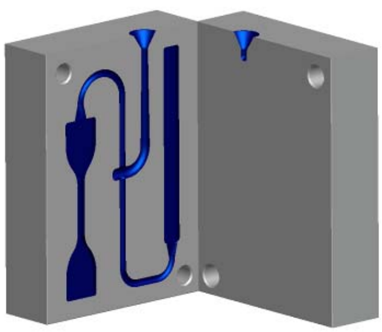


Figure 6. 3D model of the vertical inserts

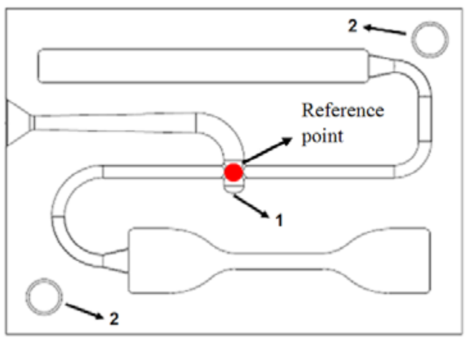


Figure 7. Reference point in the vertical insert

2.4. Material and mold manufacturing

The SAE 1045 was chosen as mold material, due to its low cost, good resistance and relative easiness of machining.

After the mold design, the CAD models were sent to the software CAM PowerMill, from Delcam plc., where the machining strategies were created. The NC programs were generated and sent to be manufactured in the three axes machining center Cincinnati Milacron Arrow 500 (see Fig. 9). The manufacturing times were measured.

2.5. Injection steps

A PP was left in an oven at about 90°C for 4 hours for drying before the injection.

For the horizontal machine, it was measured the time taken to assemble the inserts into the mold base and the mold assembly into the injection machine. In this step, some equipment is needed, such as hoist, clamps and safety devices. The injection cycle time is easily obtained from the sensors present in the horizontal injection machine.

Initially, it was used the injection parameters provided by the injection simulation. However, because of some differences observed (such as: ambient temperature, mold temperature, etc.) in the actual process, the machine parameters have to be adjusted to achieve good injection. Table 3 presents the parameters used. Twenty (20) parts considered of good quality were injected.

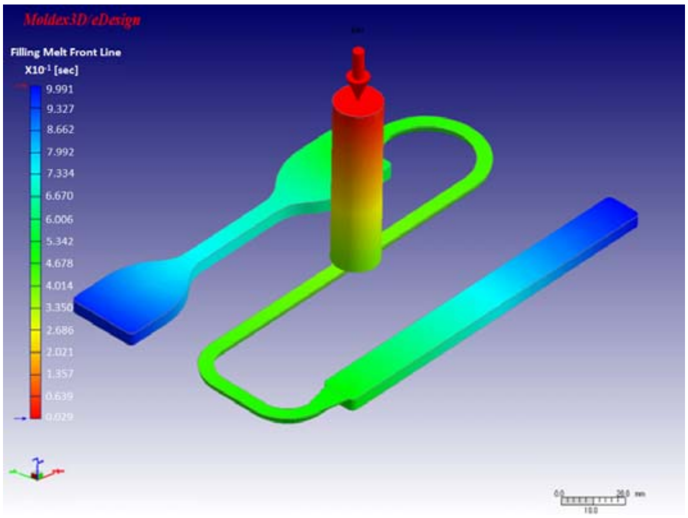


Figure 8. Numerical simulation of injection process (filling) to check balancing

(a) (b)

Figure 9. Horizontal (a) and vertical insert (b)

The clamping system of the vertical inserts was based on C-clamps and screws (Fig. 10). The screws also act as guide pins. The amount of clamps and their position were defined by a finite element simulation in the CAE module of ProEngineer Wildfire 4.0. Figure 11 shows the insert opening trend when injected. By analyzing this opening trend, it was possible to reposition the clamps to avoid flashes in the region where the strain has a greater magnitude. Figure 12 shows the final configuration of the C-clamps.

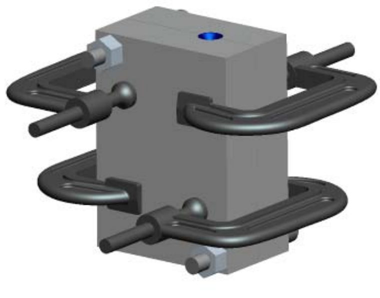


Figure 10. Vertical mold inserts with clamping system

It was measured the assembly and positioning of the inserts in the vertical machine. As the vertical inserts do not have much mass, they can be handled by an ordinary man, eliminating the need for a transport device. The positioning of the inserts in the vertical injection takes place every injection cycle. As the goal is to simplify the procedure, a tape was used to mark the correct XY position of the insert on the machine table (Fig. 13).

Due to the rounded conical profile of the injection nozzle (Fig. 14), it assumes the role of self-adjustment of the mold. Even when the mold is not in the exact position, the injection nozzle moves it to the correct position on the table.

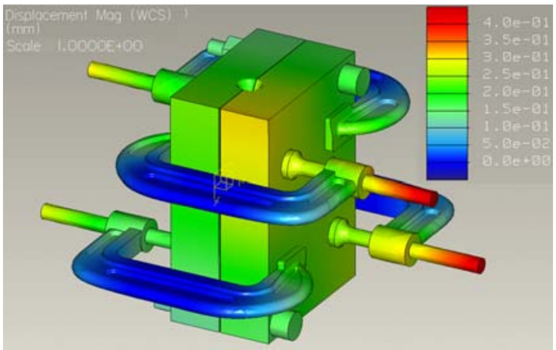


Figure 11. Numerical simulation result (max. deformation 0.4mm)

Figure 12. Final configuration of the clamps

Figure 13. Tape being used to place the insert on the injection table

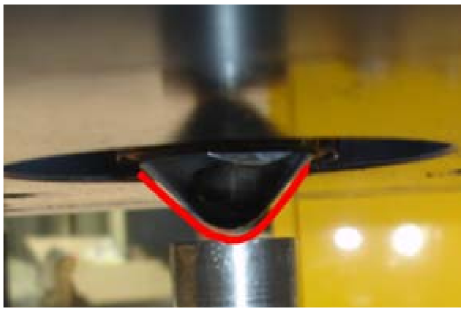


Figure 14. Geometry of the injection nozzle of the vertical machine

For the vertical injection process, first it was applied the same parameters used in the horizontal injection. However, a complete filling of the cavities was not achieved. For that reason, to obtain parts considered good, some parameters had to be adjusted, as can be seen in Tab. 3.

Table 3. Injection parameters applied

Injection Parameters		Numerical Simulation	Horizontal Injection	Vertical Injection
Injection	Pressure (MPa)	23.6	60	70
	Velocity (mm/s)	-	19	25
Holding	Pressure (Mpa)	23.6	30	35
	Velocity (mm/s)	-	15	15
Total injection time (s)		10	60	180
Polymer temperature - setup (ºC)		180	230	200
Mold temperature (ºC)		40	28	26
Ambient temperature (ºC)		25	18	20

Initially, although it was possible to obtain specimens with complete filling and good quality in the vertical injection, an excessive material flash was observed at the entrance of the insert (Fig. 15). As can be schematically seen in Fig. 16(a), it was found that the nozzle was applying a force to open the inserts. To solve this problem, it was designed an adapter device for the nozzle which directed the nozzle force downwards, as shown in Fig. 16b. With the development of this device, it was possible to prevent the flash and 20 parts were injected.

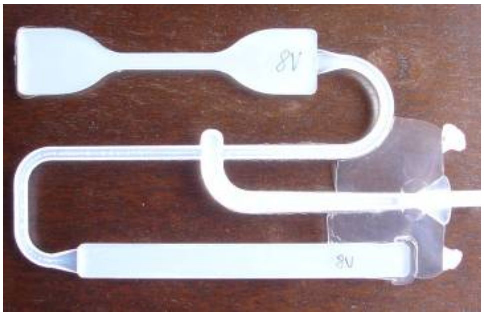
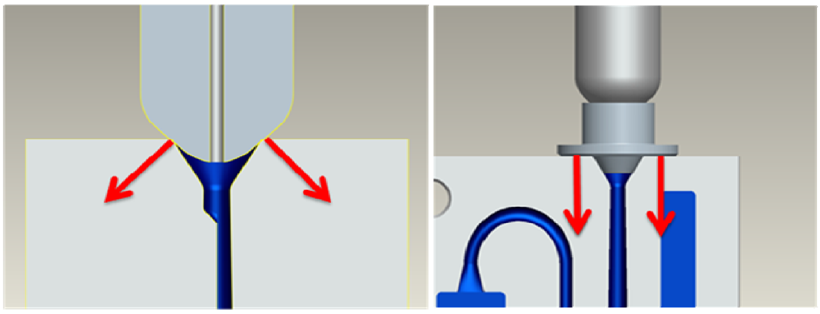


Figure 15. Injected specimens with flash at the entrance of the insert



(a) (b)

Figure 16. Forces schematically represented in the vertical nozzle: initial situation (a) and after the designed device (b)

2.6. Mechanical tests

The tensile and bending test were performed according to recommendations of ASTM D638-03 and ASTM D790-03, respectively. Seven specimens were randomly selected among the 20 injected of each type to be tested. Both tests were performed in the machine MTS 810 (Fig. 17 and Fig. 18). The speed of the tensile test was 50mm/min and of the bending test was 2mm/min. To calculate the yield stress in the tensile test, it was used the maximum force applied and the section area of the specimen before being pulled. The yield stress of the material can be calculated by Eq (1). The flexural modulus was obtained using Eq (2), where L is the span between two supports, "m" is the gradient of the initial portion of the load versus displacement curve, "b" is the width and "d" is the thickness of the specimen.

$$\sigma_y = \frac{\text{Maximum force applied}}{\text{Section area}} \quad (1)$$

$$Ef = \frac{L^3 m}{4bd^3} \quad (2)$$

Figure 17. Tensile test

Figure 18. Bending test

3. RESULTS AND DISCUSSION

Due to the geometries similarity of the two pairs of inserts and consequently the machining operations, the time spent to manufacture them were very similar. The machining took approximately 4 hours and the total manufacturing time (including preparation of raw materials, fixturing and setup) was about 7 hours. Because of this similarity, this part of the process time was removed from the time analysis to get the prototypes, described below.

To begin the injection in the horizontal machine, it took one hour to assemble the insert into the mold base and two hours to assemble the mold base into the injection machine. After mounting the mold base and defining the machine parameters, the injection cycles are performed automatically, without requiring manual intervention. The average injection cycle time was one minute (Tab. 4).

For the vertical machine, there is no mounting into the mold base step, as the inserts are mounted directly on the machine. As the closure/opening of the insert and the positioning are done manually for each injection cycle, it was espected a longer cycle time. The avarege injection cycle time was three minutes. Table 4 shows the analysis of cycle time to obtain the prototypes.

Table 4. Measured injection cycle time

Cycle	Horizontal Injection (min:sec)	Vertical Injection (min:sec)
1	0:55	2:45
2	1:02	2:57
3	0:58	3:20
4	0:57	3:02
5	1:03	2:56
6	1:02	3:08
7	0:56	2:49
8	1:05	3:03
9	1:03	2:53
10	1:06	3:10
Average	1:00	3:00

From the time analysis, a graph can be drawn contening the amount of injected parts on each machine by elapsed time (Fig. 19). It can be noted that during the first three hours the horizontal machine does not produce parts, because this is the initial setup time. The initial setup time of the vertical machine can be considered negligible, so this task is not present in the time analysis. In this way, up to 90 injected parts can be quicker obtained using the vertical injection machine. For a larger quantity, the horizontal machine is able to faster produce the molding because the injection cycle is accomplished in a shorter time.

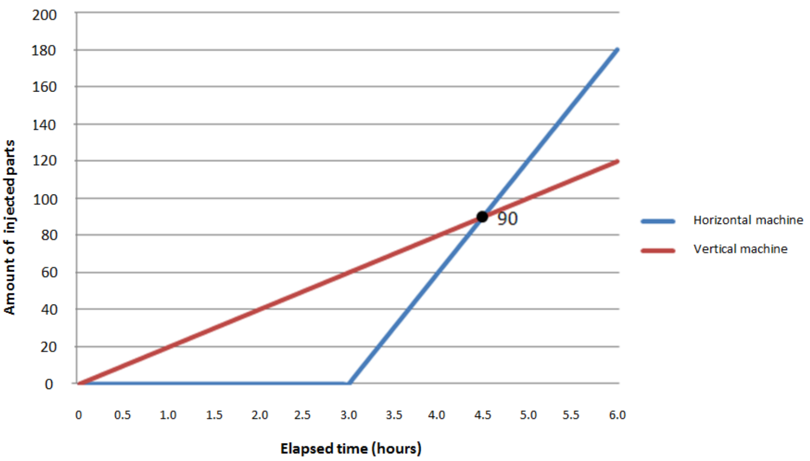


Figure 19. Time to obtain the moldings

It is possible to assume that the quantity of 90 parts may be even greater if the vertical machine operator is well trained to perform the opening and closing of the mold, or through another closing device that expedite this task, for example, a hydraulic vise. This is because the main part of the cycle time is used to perform the manual opening and closing of the mold. In particular, for the vertical injection machine in question, this whole process could be automated using the hydraulic clamping unit mentioned before. This would approximate the injection cycle time between the two machines, which would increase considerably the number of parts (90 parts).

Attention should be paid to the fact that in this time analysis, it was not included the setup of the mold base (beds). It was used a mold base available in the laboratory and the inserts were designed to fit into the beds. In cases where a mold base is not available, its purchase or manufacturing and adjustment would take a considerable time.

The problem related to the material flash in the first shots in the vertical injection was solved by the nozzle adapter device. The main difficulty encountered in the injection step, for both machines, was to adjust the injection parameters to, first completely fill the cavity, and then to produce good quality parts. That was mainly because the injection process was not performed by an experient operator. Despite this, once the parameters have been defined for the two machines, the processes occurred as programmed and with repeatability.

Although the parameters from the numerical simulation did not workout in the machine, it was important to check the balancing of the cavity filling. Some possible reasons that may have contributed to the divergence of the results are the differences in the room temperature at the time of injection and in the mold temperature. Table 5 and 6 show respectively the results obtained in the tensile and bending test for both machines. As can be seen, the avarege values are pretty similar. In Fig. 20(a) and (b), it is possible to observe the shape of the specimens after the tensile test. The stretch behavior was also similar.

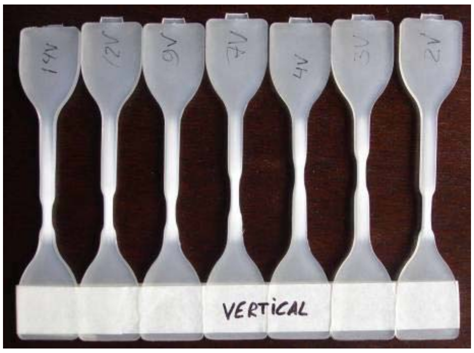
Table 5. Tensile tests results

	Yield Stress (MPa)	
Test	Injected into the horizontal injection	Injected into the vertical injection
1	32.21	31.40
2	31.63	29.90
3	31.02	31.91
4	30.68	30.58
5	31.42	32.07
6	31.70	31.81
7	31.10	29.65
Average	31.39	31.05

Table 6. Bending tests results

	Flexural Modulus (GPa)	
Test	Injected into the horizontal injection	Injected into the vertical injection
1	1.37	1.41
2	1.55	1.19
3	1.39	1.47
4	1.25	1.40
5	1.29	1.40
6	1.42	1.21
7	1.39	1.44
Average	1.38	1.38

(a)



(b)

Figure 20. Horizontal (a) and vertical (b) tensile test specimens after tests

4. CONCLUSIONS

This study has compared the process to obtain injected prototypes in PP in two different injection molding machines, one horizontal and one vertical. Based on the tensile and bending test results, it can be stated that it was possible to produce moldings in both machines with similar mechanical properties.

The time analysis shows the advantage of using the vertical injection machine for small quantities of parts (up to 90 parts in this study). This advantage may be even greater if a improved insert clamping system is employed.

In short, this study shows that a vertical injection machine, even with a simplified insert clamping device, is capable of produce injected prototypes faster (for small amounts) and with mechanical characteristics similar to those injected in a conventional horizontal injection molding machine. It is worth remembering that, in a competitive market, a reduction in prototyping time is an important achievement for any product development process.

It was out of the scope of this work to analyse the prototype cost, but it is likely that also in this aspect the use of vertical injection machine would be advantageous. This is because components such as machine cost and mold base cost (if one is not availabe) would make part of the cost.

Future studies should be performed in order to have a broader understanding of the proposed approach. In particular, a more detailed analysis of the molding properties would be appropriated.

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