Optimization of injection parameters from the aspect of dimension accuracy

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Abstract. During the injection molding process, the polymers are subject to shrinkage and bending, which causes an unwanted change in geometry. These deficiencies can be caused by many factors: injection pressure, overpressure, overpressure time, cooling, etc. Within this work, the influence of overpressure and overpressure time on the accuracy of product dimensions is presented. Dimension control was performed by measuring on a 3D coordinate machine. The products are injected in 2 different combinations of parameters. For each combination of parameters, measurements were performed in five injection cycles.

1. Introduction
Injection molding is a manufacturing process that creates plastic products. The injection molding process itself is when the plastic mass in the form of granules melts to the extent that it is injected by pressure into the injection molding tool, where it is cooled to a given shape. When the product is sufficiently cooled, the tool is opening, and the product is ejected from the tool. The whole sequence of events when injecting one piece is called the cycle [1].

The main goal of the process is to get a part in one place and in one operation with exact dimensions and properties for use.

The injection parameters of such systems are based on iterative procedure, ie on the "Try and fail" method. The most important parameters for injection molding are: injection pressure, overpressure, overpressure time, cooling time that affect the accuracy of the dimensions of the finished product [2].

In the control of the accuracy of construction, three-coordinate measuring devices that serve for the spatial measurement of the measuring piece have a great role. The measurement is based on the identification of points from the surface of the piece, and they are identified with respect to the position in X, Y and Z coordinates.

Within this work, the influence of overpressure and overpressure time on the accuracy of product dimensions is presented. Dimension control was performed by measuring on a 3D laser machine. The products were injected in 2 different combinations of parameters. Measurements were performed in five injection cycles for each parameter combination.

2. Injection molding
Injection molding is the most important process in the processing of plastic products, because today more than a third of thermoplastics have been reshaped by this process. The process is very suitable for making a large number of pieces of complex shapes and achieving narrow dimensional tolerances.
Plastic injection molding machines are used for the manufacture of objects in the automotive industry, for plastic parts of household appliances and the manufacture of simple plastic elements, etc. [1].

The sequence of events when injecting a single product is called the injection cycle. The cycle begins when the tool closes with a certain closing force. This is followed by injecting the polymer melt into the tool engraving with the injection pressure caused by the screw force (F). When the engraving is filled, the application of overpressures is followed, which achieves the geometric and weight accuracy of the piece. After cooling, the tool is opening, and the piece is ejected [3]. After the last cycle, the spraying unit moves away from the tool, Fig. 2.

The filling of the mold is done under the influence of pressure, while the resistances that arise due to the high injection speed are reduced. As the melt cools, the mass begins to shrink, and the resulting space is filled with additional melt. For subsequent dosing of the melt, we need a much lower pressure in the tool, which is also called the subsequent pressure. Therefore, the subsequent pressure strives to keep the size of the product the same as the engraving. The subsequent pressure is set at 40 to 70% of the value of the achieved injection pressure.

Subsequent pressure is only effective if the following basic conditions are met:
  - the filling opening must be large enough not to freeze too quickly,
the „cushion“ of the melt in front of the screw must be large enough to provide sufficient mass for the subsequent injecting of the melt into the engraving,

- the size of the subsequent pressure, the operating time of the subsequent pressure, the temperature of the tool and the melt must be correctly selected [4].

Causes of excessive post-pressure: higher internal stress, larger dimensions, higher weight, tool damage. Causes of too low post-pressure: possession, non-flooding, bubbles, high shrinkage, lower mass [4].

2.1. Injection molding materials

Plastics are polymers to which various additives have been added. With regard to the behavior during processing and application, they are divided into two groups: plastomers and duromers [5].

Plastomers are polymeric materials with linear and branch structures. They dissolve in solvents and are meltable. By heating to the softening or melting temperature, they do not change their structure and therefore their processing involves only reversible changes. At these temperatures they can be formed into the desired shapes. The structure of the plastomer can be amorphous or crystalline.

Durometers are soft at first, but during heating at elevated temperature, irreversible 3D crosslinking into a solid material occurs. Further heating leads to their thermodegradation.

Today, polymer materials are used in all areas, they are indispensable for industry, because due to good physical properties such as good design, easy processing, light weight and satisfactory mechanical properties, they are increasingly displacing classic materials such as metal, wood and fabrics. Polymer products are found mainly in the automotive industry, packaging production, electrical industry, construction, furniture, and sports industry, but also in space technology and aviation due to their light weight.

The main methods of plastic processing are injection molding, gas injection, thermoforming, extrusion, blowing and 3D printing. In particular, injection molding is very widespread, because the polymers thus produced are suitable for mass processing as well as for individual test products [6].

3. Experimental work

In order to perform the experiment, the material PA6 GF 25 was injected. It is characterized by light processing and relatively good mechanical properties, which is maintained even at higher temperatures. It can also be recycled [7]. It is most often used in the automotive industry, and for various plastic products of higher rigidity and strength.

The tool is made with two nests, and an inflow point system. Filling points shall be set reasonably in accordance with the given functional requirements and the selected product geometry, Figure 3.

Figure 3. Injection tool, ejection side, nozzle side
During the injection molding process, the polymers are subject to deformation, which causes an unwanted change in geometry. The accuracy of the geometry can be caused by many factors such as: injection pressure, overpressure, overpressure time, cooling, etc. For the experimental, we selected two parameters: overpressure and overpressure time. Since it was necessary to determine higher and lower parameter values, we took the existing settings on the machine, according to the recommendations from the literature. For the first test, series 1, injection into the mold, a subsequent pressure between thirty and fifty percent of the injection pressure was used, and the time was four seconds, according to the literature. For Series 2, we reduced the overpressure and the overpressure time. Selected parameters and values are shown in Table 1.

| Injection parameters | Series 1 | Series 2 |
|----------------------|----------|----------|
| Profile              | 1 2 3    | 1 2 3    |
| Overpressure         | 700 600 100 | 500 430 100 |
| Overpressure time    | 4 4 0,5 | 2 3 0,5 |
| Cycle time           | 20,4 sec | 20,4 sec |
| Total cycle weight   | 37,09    | 36,92    |
| Gate weight          | 0,88     | 0,82     |
| The weight of the piece | 16,13/20,08 | 16,07/20,01 |

Based on the injection parameters, we can see that due to the variation of overpressure and overpressure time, there was a change in weight in both the workpiece and the gate.

In order to perform an analysis of the influence of parameters on the dimension, shape and errors of the product, it is necessary to measure the dimensions of the product. The measurement was performed on a three-coordinate machine manufactured by TESA MICRO-HITE 3D, Figure 4.

![Three-coordinate machine](image)

**Figure 4.** Three-coordinate machine [8].

The measurement is performed by placing the measuring product on the desk. The machine is positioned at the zero-point depending on the shape of the piece, and the given dimensions are measured. The measurement was performed on both workpieces from the nest, Figure 5, and Figure 6.
The measurement results are given in a Table 2.

**Table 2.** Measurement results Series 1 - Workpiece 1.

| Ref.br. | Specifications | Measured | Yes | No  |
|--------|----------------|----------|-----|-----|
| Fach1  | Ø85,6 ±0,340   | 85,97; 85,99; 85,97; 85,99; 85,98 |     |
| 02     | 2,20 ±0,100    | 2,35; 2,36; 2,36; 2,35; 2,36 |     |
| 03     | 0,3            | 0,3; 0,3; 0,3; 0,3; 0,3 |     |

**Table 3.** Measurement results Series 2 - Workpiece 1.

| Ref.br. | Specifications | Measured | Yes | No  |
|--------|----------------|----------|-----|-----|
| Fach1  | Ø56,7 ±0,28    | 56,96; 56,95; 56,97; 56,97; 56,95 |     |
| 02     | Ø52,70 ±0,4    | 52,86; 52,85; 52,87; 52,86; 52,87 |     |
| 03     | Ø49,7 ±0,25    | 49,93; 49,93; 49,94; 49,92; 49,93 |     |
| 04     | 17,20 ±0,30    | 17,36; 17,37; 17,36; 17,36; 17,37 |     |
| 05     | 2,2 ±0,09      | 2,29; 2,29; 2,28; 2,29; 2,28 |     |

**Table 4.** Measurement results Series 1 - Workpiece 2.

| Ref.br. | Specifications | Measured | Yes | No  |
|--------|----------------|----------|-----|-----|
| Fach1  | Ø56,7 ±0,28    | 56,96; 56,95; 56,97; 56,97; 56,95 |     |
| 02     | Ø52,70 ±0,4    | 52,86; 52,85; 52,87; 52,86; 52,87 |     |
| 03     | Ø49,7 ±0,25    | 49,93; 49,93; 49,94; 49,92; 49,93 |     |
| 04     | 17,20 ±0,30    | 17,36; 17,37; 17,36; 17,36; 17,37 |     |
| 05     | 2,2 ±0,09      | 2,29; 2,29; 2,28; 2,29; 2,28 |     |
Table 5. Measurement results Series 2 - Workpiece 2.

| Ref.br. | Specifications | Measured | Yes | No |
|---------|---------------|----------|-----|----|
| Fach1   | Ø56,70±0,28   | 56,71; 56,72; 56,70; 56,71; 56,70 | Yes |    |
| 02      | Ø52,70±0,4    | 52,67; 52,65; 52,69; 52,67; 52,69 | Yes |    |
| 03      | Ø49,7±0,25    | 49,55; 49,54; 49,54; 49,55; 49,54 | Yes |    |
| 04      | 17,20±0,30    | 17,11; 17,14; 17,13; 17,13; 17,14 | Yes |    |
| 05      | 2,2±0,09      | 2,18; 2,19; 2,19; 2,18; 2,19 | Yes |    |
| 06      | 21,00±0,15    | 20,94; 20,91; 20,90; 20,91 | Yes |    |
| 07      | Ø39,30±0,20   | 39,28; 39,26; 39,25; 39,27; 39,25 | Yes |    |
| 08      | Ø84,40±0,34   | 84,19; 84,20; 84,18; 84,19; 84,18 | Yes |    |
| 09      | 0,3           | 0,05; 0,03; 0,04; 0,05; 0,04 | Yes |    |
| 10      | 0,75          | 0,8; 0,8; 0,8; 0,8; 0,8 | Yes |    |
| 10      | 45°           | 45; 45; 45; 45; 45 | Yes |    |
| 11      | 10,00±0,11    | 9,94; 9,95; 9,94; 9,93; 9,94 | Yes |    |
| 12      | 120°          | 120,0; 120,09; 120,0; 120,06; 120,07 | Yes |    |
| 13      | /Ø/ 0,2       | 0,18; 0,19; 0,17; 0,18; 0,19 | Yes |    |

4. Conclusion

Based on the obtained results it can be concluded:

At higher overpressure and overpressure time, series 1, and at the same cycle time of 20.4 sec, there was a deviation of dimensions. All deviations were in positive tolerances. In workpiece 1 there was a deviation in all dimensions, while in workpiece 2 some dimensions were in the given tolerances that can be attributed to the place or point of pouring.

Also, by changing these parameters, there was a change in the weight of the workpiece and the weight of the gate by about 0.4%.

Based on this, we can conclude that the values of overpressure as well as the overpressure time itself affect the optimization of the product. In addition to these parameters, it is necessary to consider other parameters that have an impact on the optimization of the injection molding process, so it would be necessary to investigate these parameters.

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