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**DEVELOPMENT OF MATERIAL TESTING AND QUALITY CONTROL METHODS
USING SENSOR-EQUIPPED INJECTION MOULDS**

THESIS BOOK OF PHD DISSERTATION

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The review and the defense report of the doctoral dissertation can be viewed at the Dean's Office of the Faculty of Mechanical Engineering of the Budapest University of Technology and Economics

1. Introduction

Injection molding is one of the most efficient processes in modern plastics processing. Its dynamic development is attributed to its ability to produce complex geometry products with high productivity, using a batch process that can even be waste-free. The rapid spread of plastics is largely driven by the novel advancements in plastic material science.

Fitting the demands of the continually increasing quantitative and qualitative plastic part is not an easy task. During the production of injection-molded products, wall thickness is always a critical factor. According to industrial trends, more components are being replaced with plastics, and micro-injection molding is also gaining significant ground. In the production of thin-walled products, typically with a thickness of 1 mm or less, any change in injection molding parameters has a huge impact on the properties of the products. Thin walls require rapid injection speeds, high temperatures, and high pressures. The pressure needed for filling is inversely proportional to the third power of the wall thickness. Even slight changes in the physical state of the material can have a significant effect on the structure and the quality of the product. It is important to note that since the development of the most widely used material testing methods and standards, the characteristics of injection-molded components have changed significantly.

Thanks to the rapid development of IT and mechanical engineering capabilities, numerous options are now available to maintain control over our production processes and collect data. The processes occurring in the cavity of an injection mold are only partially correlated with the values measurable by the injection molding machine's monitoring system, as the measurement location is far from the cavity. Another disadvantage is that the injection molding machine cannot provide feedback about the differences between individual cavities in multi-cavity molds. Temperature and pressure sensors are often integrated into injection molding tools to provide additional and better-quality information. During serial production, ensuring that product quality remains consistent and measurable from cycle to cycle is crucial. For products with complex geometries, even minimal variations in raw material properties can result in defective products. Injection molding tools often feature partially or fully cold-runner systems, where the design can affect the thermal homogeneity of the melt. Temperature variations influence the material's viscosity, significantly impacting the filling process.

The cavity pressure data measured by sensors is related to the product quality, the final part properties (warpage, size, weight etc.), the changes in raw material condition, and

the injection molding process settings. Cavity pressure measurement is a widespread technology in the production of precision products, enabling better process monitoring and easier process optimization. As wall thickness decreases, the ratio of the shell-core structure in the cross-section of the product changes, and the thickness of the free-flowing core layer reduces. Due to the nature of injection molding technology, an inhomogeneous product structure forms within the mold cavity, which becomes more likely in thin-walled products. Even a small change in viscosity or shear properties significantly affects the filling process. Establishing correlations between the measurable pressure in the cavity and the product characteristics enables a higher level of quality control for injection-molded products, which is a field that requires further research.

The aim of my dissertation is to examine the application possibilities of pressure sensors integrated into injection molding tools and to study the mechanical properties that vary with wall thickness. The current specimen standards only partially describe the case of thin-walled products. Using the pressure data from the cavity, we can infer changes in viscosity, process, or even the mass of the injection-molded product. Using special ejector pins for cavity pressure measurement is not thoroughly studied but can influence the measurable pressure in the cavity. The placement, alignment, and shape of the measurement pins can all determine the accuracy of the measured values. Using the pressure measured in the mold cavity to monitor the quality characteristics of the product can significantly enhance the effectiveness of production monitoring and quality assurance processes.

2. Literature review and critical analysis

During the injection molding process, the melt undergoes a complex thermodynamic process where numerous phenomena influence the quality of the final product. The goal is to ensure consistent product quality, which usually requires dimensional measurement.

The transformation of the industrial trends and the rise of electromobility have significantly reshaped the injection molding industry. Polymer components in the automotive and electronics sectors are facing increasing demands, with a growing number of parts being manufactured through injection molding. The segmentation and complexity of the products often do not follow the design principles of injection-molded parts, resulting in significant variations in wall thickness at different parts of the product. The spread of micro-injection molding and the increasing number of thin wall products require a deeper understanding of the wall-thickness-dependent behavior of injection-molded products. Currently, the literature contains contradictions regarding the mechanical properties

dependent on wall thickness, and existing material testing standards do not accurately reflect the actual manufacturing conditions of thin-walled products.

One effective method for monitoring product quality in each cavity is the use of pressure sensors, which provide better feedback on product quality compared to the injection molding machine supervision, as they measure much closer to the product. Pressure and temperature sensors are usually applied to injection molds. These make the monitoring of process consistency within the cavity possible, making the injection molding process easier to optimize. In many cases, a strong correlation exists between internal pressure measured during the cycle and product characteristics such as fill quality, shrinkage, and final dimensions. Additionally, analyzing pressure curves provides valuable insights into changes in the injection molding process. Several studies focus on establishing connections between pressure sensor data and the final properties of the product. However, the solutions for pressure measurement and the influence of external factors on these measurements remain under-researched areas. The placement and integration of pressure sensors, as well as the impact of intermediary elements used for measurement, require further investigation. Factors such as the installation method of the sensors, the diameter of the measurement pins, and their position can all influence the measurable pressure in the mold cavity.

The applicability of sensors in injection molding is a continuously evolving field, with numerous studies examining the relationship between the quality of injection molded products and the measurable parameters of the process. One of the most critical material properties during injection molding is viscosity. The viscosity of the raw material determines the process stability and repeatability. However, measuring the viscosity is not a simple task and generally requires specialized equipment. In many cases, the properties of the raw material can vary between production batches. In industrial practice, the melt flow index (MFI) measurement has become a widespread method for evaluating the flowability of raw materials. However, a method that can be used during production would be far more advantageous for detecting changes. Solutions have been developed that enable viscosity measurement using an injection molding machine. Still, these methods commonly rely on external heating and are complicated to operate.

In numerous studies, the pressure values measured by cavity pressure sensors have been correlated with the pressure integral derived from internal pressure. The pressure integral shows a strong relationship with the mass of the product, which effectively characterizes the basic part quality under certain conditions. In many cases, the connection between the pressure integral and product mass has been established as a clear correlation,

allowing for better monitoring and optimization of the injection molding process.

After reviewing the literature, I have set a goal to investigate the mechanical properties of products with different wall thicknesses as well as the impact of the measurement setup on the measurable pressure. As the wall thickness changes, the tensile mechanical properties can vary significantly, so it is important to know the behavior of the final product geometry. Pressure sensors are commonly used for quality monitoring. However, the information that can be obtained at different points in the cavity is not well understood. Therefore, in my thesis, I investigate the internal pressure that can be measured at different points and sides of the product. In addition, I will also investigate the effect of different configurations of measuring pins on the pressure that can be measured in the mold cavity. The applicability of pressure sensors to measure viscosity in the mold and to better determine the product mass is an important direction of my research. Measuring viscosity in a cold runner mold can provide a simple solution for testing raw materials and identifying deviations. Mass measurement is a commonly used practice to detect basic quality and process defects in injection molded products, which I aim to investigate during production by measuring internal pressure and determining a better correlation between internal pressure and product mass.

3. Materials, equipment, and methods used

For the experiments, I used two types of material. The first is an acrylonitrile butadiene styrene (ABS, Terluran GP 35, Styrolution Group GmbH) with a melt flow rate (MVR) of 34 cm³/10 min at 220 °C/10 kg. The material was dried at 80 °C for 3 hours before processing.

I used a polypropylene (PP, Mol Tipplen H145F) with a flow index of 29 g/10 min (MFI, 230 °C / 2.16 kg). The material was processed after removal of surface moisture and a short drying at 60 °C for 30 min.

3.1. Injection molding machine and peripherals

For the injection molding tests, I used an Engel TL-170 injection molding machine, an all-electric machine with a 25 mm diameter screw with a clamping force of 50 t. In terms of control, the injection molding machine is capable of using an external signal for switchover (switching from injection to holding based on a signal from a cavity pressure measuring system). Two Wittmann C90 temperature controllers were used for temperature

control, allowing the water temperature to be set between 30 and 90 °C. I used a Moretto X-Dry90, a small hot air dryer for drying. The temperature used for drying was controlled by a J-type handheld thermometer. The moisture content of the raw material was checked after drying with a Mettler Toledo HX204 moisture meter.

3.2. Injection molds

VT-specimen mold (Variable Thickness test specimen mold)

The tool has two cavities and a cold-runner system. The mold cavity is filled through a film gate, with a thickness of 2 mm and a width equal to the size of the product (80 mm). The wall thickness value can be adjusted steplessly using a wedge mechanism between 0.8 and 4.2 mm (Figure 1). The adjustment of the wall thickness does not affect the thickness of the film gate.

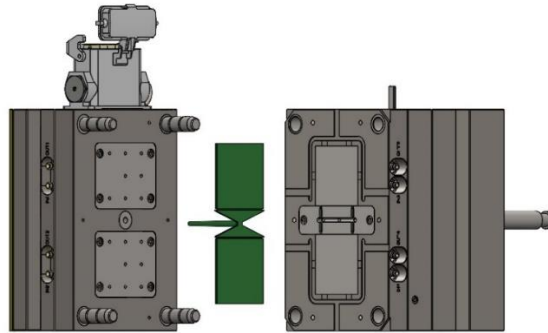


Figure 1 VT-specimen mold fix side (left), moving side (right)

I used indirect pressure sensors manufactured by Cavity Eye to measure the internal pressure. A total of 16 sensors were integrated into the tool. The diameter of the measurement pin is 3 mm.

Tensile specimen mold – 1A

The tool has two cavities, and its geometric configuration complies with the 1A-type injection-molded test specimen standard (ISO 527-1:2019). Four pressure sensors are integrated into the stationary side of the mold plate. The measurement points are located at the center of the clamped section. An interesting feature of the tool is that its wall thickness can be adjusted between 2 and 4 mm by changing the movable side of the cavity plate.

Tensile specimen mold – 1BA

The test specimen tool complies with the standard 1BA (ISO 527-1:2019). I created 4 different cavity inserts with varying thicknesses for the tool, each with a different height, allowing the wall thickness of the injection-molded test specimen to be adjusted within the range of 0.8, 1, 1.5, and 2 mm (Figure 2).

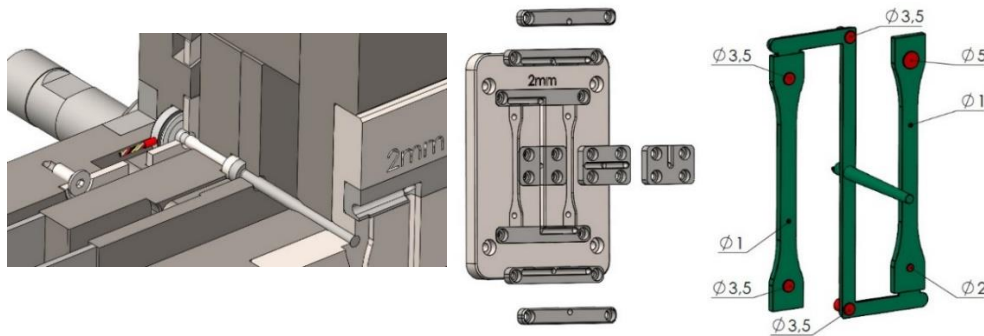


Figure 2 The sensor installation layout on the moving side of the 1BA test specimen tool (left), the interchangeable insert with available gates (center), and the measuring pin dimensions on the stationary side marked on the test specimen (right)

A total of 10 sensors were placed in the tool, with a small-diameter (1 mm) measurement pin positioned at the $\frac{3}{4}$ point of the flow path on the stationary side.

Key chain mold

The tool has a four-cavities, cold-runner system with a 1 mm diameter pin gate (Figure 3). The tool has 6 ejectors for each product, and the sensors were integrated under 4 of them in every cavity. The wall thickness of the product is 2.6 mm, with negligible variation between the cavities in both filling and mass. The flow path length from the gate to the end of the mold cavity is approximately 61.5 mm. I used the results from the top-right (2nd) cavity for the measurements.

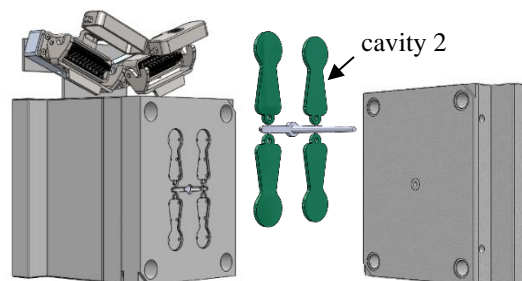


Figure 3 The 4 cavity “Key chain” mold

The tool has 16 pressure sensors, each with a load capacity of 1 kN, meaning there are 4 sensors per cavity. No deviation was observed between the same position sensor values in the cavity (gate, end of the flow path), and the filling of the tool is uniform even within the cavity.

4. Summary of the research

Investigation of wall thickness-dependent mechanical properties

I used tensile test molds to demonstrate the significance of the shell-core layer ratio

formed along the wall thickness of injection-molded products (1BA, 1A). I molded test specimens in this experimental series and then conducted mechanical property (tensile) tests. Based on the measurements with the test molds, it can be concluded that changing the wall thickness of the test specimen affects the tensile strength and the modulus of elasticity. This is due to the change in the shell-core (solid) layer ratio with decreasing wall thickness, which I confirmed by measuring the average orientation (contraction due to heat). When the wall thickness is reduced from the maximum 2 mm specified in the 1BA test standard to 1 mm, the key mechanical properties can change by up to 18%. Similar phenomena have been reported previously, but the effect of injection rate has not been studied within the traditional production speed range. According to my measurements, with a 1 mm wall thickness, the injection rate significantly influences the mechanical properties, with slower injection speeds enhancing the achievable tensile properties. The mechanical properties of the test specimens made according to the standard can differ significantly from actual behavior and may even depend on the injection molding technology used.

Investigation of cavity pressure as a function of wall thickness

I used the 1BA mold with adjustable wall thickness and the PP H145F material for the experiment. During the injection molding trials, I identified three characteristics for the measurements, which I derived from the pressure curves measured by the internal pressure sensors close to the gate. These characteristics were used to compare the results between the stationary and moving sides: filling pressure [bar], peak pressure [bar], and pressure integral [bar*s]. Comparing the results between the stationary and moving sides, it can be stated that with a 2 mm wall thickness, higher filling, and peak pressures can be measured on the hotter mold side. Increasing the temperature on the stationary side resulted in an average 8% measurable difference in the filling and peak pressure differences, with the higher values measured on the stationary side. To confirm the temperature differences between the mold sides, I measured the warpage of the product as a function of the stationary and moving side mold temperatures. The direction of the product warpage corresponds to the measurable pressure and temperature differences on each side, meaning that the test specimen deforms towards the hotter side. By measuring the warping, I confirmed that a temperature difference developed between the mold sides, which causes measurable pressure differences between the stationary and moving sides, in terms of filling and peak pressure, for the 2 mm wall thickness 1BA test specimens.

The effect of the measurement setup on the measurable cavity pressure values

I used the 1BA tensile test mold and PP H145F material for the measurements. The

aim of the study is to examine the effect of different shapes and fit errors of the measuring pins on the measurable pressure, depending on the injection molding speed and wall thickness. Based on the pressures measured on the stationary and moving sides, the smaller the pin diameter and injection molding speed, the greater the difference in pressure. In other words, shorter measuring pins yield lower pressure measurements. Based on the measured results, the relationship is exponential in terms of both the ejector diameter and injection rate concerning the pressure peak ratio measured on the stationary and moving sides. The reason for this behavior is the frozen layer in front of the ejector pin. According to the obtained relationship, the average square error is small ($R^2=0.987$). The effect becomes almost negligible with higher injection molding speeds, even for smaller measuring pins.

Viscosity measurement method in a non-heated cold runner mold

The measurements were performed using the Engel injection molding machine and the VT mold to measure wall thicknesses, materials, material temperatures, and mold temperatures. The pressure sensor values determined the viscosity in the mold cavity, and the necessary rheological corrections were applied. Since the mold was not heated, the shell-core layer was formed during the flow, resulting in additional pressure within the mold cavity, influencing the measured viscosity values. The results were compared to measurements obtained using a capillary rheometer. After applying the appropriate rheological corrections using PP and ABS materials, the viscosity value calculated from the pressure measured in the mold cavity was within 10% error compared to rheometer values. The observed deviations are due to the formation of the shell-core layer (continuous cooling) and shear-induced heat development. The average error in the measured viscosity decreased with increased wall thickness (4 mm) and mold temperature (80°C) for both materials.

Method development for monitoring product mass

I performed the measurements with the keychain mold using ABS and PP materials under different holding pressure and holding time conditions. The area under the pressure curve measured by the internal pressure sensors, referred to as the pressure integral, shows a good correlation with the mass of the product, provided that the holding pressure is kept constant. However, if the holding pressure value changes, this relationship also changes. Therefore, for a given pressure integral, multiple product masses can correspond depending on the holding pressure and vice versa. Based on the measurement results, I developed a method for describing the product mass using the pressure integral, the peak pressure within the mold cavity, and the material-specific pVT data, which considers the post-pressure effect. The developed method significantly reduced the error between the actual and measured

product mass compared to the fitting methods described in the literature. The R^2 value of the method we developed was 0.99, while the linear fit described in the literature had an R^2 value of 0.77. Based on the results, with the fitting method we used, the largest error between the measured and calculated product mass was under 0.96% in the 200-600 bar post-pressure range. It can be stated that the product mass can be determined more accurately using the pressure integral and the pressure peak measurable in the mold, compared to linear fitting, provided that the relationship is determined for at least three different pressures and several post-pressure times, where gate freezing is achieved. Using this relationship, the expected product mass can be calculated over a wide range, making on-line monitoring possible.

5. Summary

The market for injection-molded products is constantly facing growing demands for quality and cost savings. In my dissertation, I have demonstrated the importance of the thickness-dependent properties of injection-molded products and examined the applicability of pressure measurement sensors integrated into the molds. In the literature review, I introduced the basics of injection molding as a manufacturing technology, followed by the shear-induced heat generation occurring within the molds during the flow process. Furthermore, I focused on the structure that forms during the polymer melt flow. There are discrepancies in the literature regarding the change in the shell-core layer ratio as a function of wall thickness; however, the variation in mechanical properties of the final products as a function of wall thickness is still an insufficiently researched area. Current material testing standards do not sufficiently characterize the properties of thin-walled products.

In the cavity, viscosity is one of the most important parameters during the flow of polymer melts. To determine it, specialized equipment is typically required, along with corrections to the measured results to obtain the real viscosity. The pressure measured in the cavity provides valuable information about the injection molding process, material properties, and the final product quality. Pressure sensors can be effectively used for viscosity monitoring during the injection molding cycle, but only if the other conditions affecting viscosity remain unchanged or are known. Several publications exist regarding the use of pressure sensors; however, the errors arising from the pressure measurement arrangement, as well as the shape and position of the measurement pins used, have not been researched in relation to measurable values. In industrial injection molds, it is common that the position of a pin used for internal pressure measurement is not properly aligned with the plane of the cavity, or the measurement surface is not perpendicular to the direction of melt

flow. Many research studies have used pressure sensors in heated molds to determine viscosity, but this topic has not been explored in traditional injection molds. On-line viscosity measurement is a very useful and simple method for monitoring the injection molding process and comparing differences between various materials. In addition to viscosity, one of the key characteristics is the mass of the product in terms of quality assurance. Many publications have examined the relationship between the pressure integral derived from the measured pressure in the cavity and the product mass, but the effect of holding pressure has not been considered.

As a result of my dissertation, I have proposed a modification to the standard describing the tensile stress of thin-walled products, as the current standard does not consider that reduced wall thickness can lead to significantly improved tensile strength. Furthermore, the existing standard for describing the injection molding of test specimens does not specify the injection rate independently of the screw diameter, which can lead to significant changes in mechanical properties.

In the variable wall thickness 1BA mold, the measured values of the pressure sensors on the stationary and moving sides reveal the local temperature effect during the cycle. By altering the temperature on one side of the mold, it was possible to identify the changed local viscosity and cooling rate. Furthermore, a higher temperature melt was identified on the stationary side under identical side temperatures, which was attributed to the gate position and shear heating.

I investigated the measurable cavity pressure depending on the length and shape of the ejector pins used for measurement. As a result, it can be concluded that the position and shape inaccuracies of the pins influence the measured pressure in the cycle. This effect becomes more pronounced as the pin diameter and injection rate decrease. Furthermore, the measurable pressure significantly changes if the shape of the pin used for measurement is altered (e.g., angled pins), and it can only be used to a limited extent for process monitoring and optimization. The results are important for selecting the appropriate ejectors and tool machining accuracy.

In industrial practice, MFI devices are used to measure the flowability of materials, considering principles of simplicity, speed, and cost-effectiveness. Many manufacturers offer rheometers specifically designed for this purpose, which require maintaining a separate laboratory to determine the real viscosity of materials. In my research, I used pressure sensors integrated into the mold to determine the viscosity with less than 10% error for two different materials under real injection molding conditions. The viscosity can be measured

accurately under industrial conditions by using a cold-channel mold and increasing the wall thickness to 4 mm, along with the appropriate mold temperature.

Using the measured values from the pressure sensors, we can obtain direct information about the quality of the injection-molded products. The relationship between the cavity pressure integral measured during the cycle and the product weight has been examined in many publications. However, the often established clear correlation between the pressure integral and product weight is inaccurate. To estimate the weight of the product from the pressure integral, it is necessary to also consider the holding pressure. By combining the pressure integral and the holding pressure, the weight of the injection-molded product can be estimated before the product is ejected, opening up new possibilities for process monitoring.

The results presented in my PhD work provide a solid foundation for more efficient investigation of thickness-dependent properties. The impact of the pressure sensor installation arrangement and the shape and size characteristics of the measuring ejectors on the measurable pressure is crucial for proper application. The pressure-based measurements presented here offer a simple method for controlling viscosity and product weight with acceptable error margins.

6. Theses

Thesis 1 [1, 2]

The MSZ EN ISO 527-2:2019 standard does not consider the effect of wall thickness when characterizing the mechanical properties of thin-walled injection-molded products (ranging from 0.8 to 2 mm). By reducing the wall thickness of injection-molded products, the cross-sectional area of the solid layer formed at the end of the volumetric filling becomes larger compared to the wall thickness, which results in the dependence of mechanical properties on wall thickness and injection molding technology. I have shown that the tensile strength of the injection-molded specimen can increase as wall thickness and injection rate decrease, as the proportion of the solid layer formed during the highly oriented filling increases within the given cross-section.

Reducing the specimen (IBA) wall thickness to the design characteristic of the product wall thickness, as well as defining the injection rate independently of the machine (using cm^3/s instead of mm/s), helps in determining the true mechanical properties characteristic of the final product and thus improves the applicability of the standard.

I have proven my claims using ABS GP35 and PP HI45F materials, with injection molding and testing of IA and IBA type tensile specimens, using wall thicknesses of 0.8, 1, 1.5, 2, and 4 mm.

Thesis 2 [3]

In the mold, the effect of different stationary and moving mold wall temperatures and the flow conditions to the molten material properties can be measured through the cavity pressure on the respective mold side. Thus, the direction of warpage in injection-molded products can be determined based on local cavity pressures.

I have proven my claims using PP HI45F material, with injection molding and testing of IBA type tensile specimens, using wall thicknesses of 1 and 2 mm, and in a mold temperature range of 30 and 90 °C. By measuring the warpage of the final product, I confirmed the development of the different temperature differences formed on each side.

Thesis 3 [3-5]

The measurement inaccuracy of the measurable cavity pressure increases exponentially as the injection rate and the diameter of the measuring pin decrease when the surface of the measuring pin in contact with the melt is positioned below the mold cavity

plane.

I have proven my claims by using various diameters (1, 2, 3.5, 5 mm) and different positions relative to the mold cavity plane (+1; 0; -1), as well as various shapes (concave, convex, and at angles of 30° and 45° relative to the mold cavity plane) of ejector pins. The materials used were ABS GP35 and PP H145F, and the tests were performed with 2 mm thick IBA tensile specimen molds.

Thesis 4 [6, 7]

The average viscosity determined from the pressure measured in the injection mold cavity with a constant cross-sectional flow path gets closer to the values measured by a rheometer as the wall thickness increases. After applying the Rabinowitsch correction, the viscosity measured in the mold can be determined with an error of less than 10% in the deformation rate range of 50-500 1/s using 4 mm wall thickness. Compared to adiabatic and isothermal flow conditions, the measurement error is caused by the formed shell layer, cooling rate, and shear heat development.

I have proven my claims using ABS GP35 and PP H145F materials with an 80x80 mm, film-gated, continuously adjustable wall-thickness mold and by injection molding test specimens with 2, 3, 3.5, and 4 mm wall thicknesses.

Thesis 5 [8]

The mass of the injection-molded product can be determined from the mass injected until full volumetric filling, and the mass increase in holding pressure calculated by using the pvT relationship and pressure integral with the following equation:

$$m = m_0 + \Delta m_{elm} \cdot \left(1 - e^{-C_{hp} \frac{PI}{1000}}\right),$$

where m_0 [g] is the weight of the product without holding pressure, Δm_{elm} [g] the maximum gainable product weight increase determined by the pvT curves, calculated from the specific volume difference value at injecting temperature with 0 bar pressure and from room temperature (23 ± 1 °C) at a specific holding pressure, multiplied by the volume of the part. The C_{hp} [1/(bar·s)] value is the holding pressure dependent pressure sensitivity constant, and PI [bar·s] is the pressure integral of the complete cycle determined by cavity pressure curves integrated over time.

With the relationship I determined, the product mass can be described even with shorter holding times than the gate freezing point when backflow occurs at the gate. In the

above equation, the C_{hp} parameter is the pressure sensitivity constant determined as a function of holding pressure, which is related to the amount of material flowing out from the cavity during the holding phase and depends on the design, temperature, and state of the molten material of the injection mold.

The upper limit of the interpretive range of the above relationship is given by the fact that post-pressure can only be maintained to a certain extent. The compensation process is limited by the gate freezing, thus providing an upper limit for the masses, which can be described by the following equation:

$$m_{\text{upper limit}} = m_0 + K_0 \cdot \left(1 - e^{K_1 \cdot \frac{PI}{100}}\right) + K_2 \cdot \frac{PI}{100},$$

where m_0 is the mass of the product without holding pressure, K_0 [g], K_1 [1/(bar·s)] és K_2 [g/(bar·s)] technology-, tool-, and material-dependent fitting constants, where PI is the measured cavity pressure integral.

The lower limit of the equation is determined by the pressure limit of the injection molding machine, using the C_{hp} pressure sensitivity constant corresponding to the maximum holding pressure achievable on the machine.

I validated my statements using PP HI45F and ABS GP35 materials with a four-cavity mold within a 100-600 bar holding pressure range.

7. Publications

- [1] **Horváth S.**, Kovacs J. G.: Effect of processing parameters and wall thickness on the strength of injection molded products. *Periodica Polytechnica Mechanical Engineering*, **68**, 78-84 (2024).
- [2] **Horváth S.**: Vékonyfalú termék leképzésének elemzése. *Polimerek*, **7**, 239-244 (2021).
- [3] **Horváth S.**, Kovács J. G.: A nyomásmérési elrendezés hatásának vizsgálata a mérhető belső nyomásra. *Polimerek*, **X.**, 258-264 (2024).
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- [5] **Horváth S. V.**, Dániel; Boros, Róbert; Szűcs, András;: Átkapcsolás hatása a fröccsöntési folyamatra és a szerszámnyomásra. *Polimerek*, **3**, 125-128 (2017).
- [6] **Horvath S.**, Szucs A.: Determining apparent melt viscosity by cavity pressure. in '77th Annual Technical Conference of the Society of Plastics Engineers. Detroit, (2019).
- [7] **Horvath S.**, Kovacs J. G.: Determination of wall thickness effect of in-mold viscosity measurement under non-adiabatic, non-isothermal flow conditions. *Express Polymer Letters*, (2025).
- [8] **Horvath S.**, Kovacs J. G.: Real-time product weight estimation based on internal pressure monitoring in injection molding. *Polymer Engineering & Science*, (2025). – *in press*