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# APPLICATION OF ADVANCED MEASUREMENT TECHNIQUES FOR DETERMINATION OF INJECTION MOLDING SHRINKAGE

*Research paper*

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**Abstract:** Plastic injection molding (IM) is a complex and technologically demanding process; therefore, it is characterised by IM parameters and material properties that influence the product quality. Setting satisfactory IM parameters requires knowledge of the processing properties of the material, the mold shape, and the technological capacity of the injection molding machine (IMM). Injection shrinkage causes changes in the shape and dimensions of the molded parts; therefore, it is one of the most significant problems that must be solved, both during the mold design phase and the numerical simulation phase. The paper presents determined IM parameters as well as material parameters influencing the value of the shrinkage. The conducted experimental tests were related to selected topics connected with the injection process and considered the change of the processed material characteristics, and change of certain, relatively the simplest to regulate IM parameters. Geometrical Product Specification (GPS) of the molded part was measured using two methods: Contact and Non-contact (3D scanning). The analysis of injection shrinkage illustrates that an effective influence on its value is possible by selecting appropriate IM parameters and material condition. The connection between the shrinkage and different filler concentration was established.

**Key words:** injection molding, shrinkage, measurement, 3D scanning, contact CMM

## INTRODUCTION

Injection molding is the most widely used manufacturing process of plastic parts. There are different forms of injection and periodicity is its characteristics. Injection is used for processing almost all polymer materials, as well as rubber compounds, liquid silicon and composites. The result of injection molding is a plastic part, which depending on the type of injection and the material used, have a wide range of application possibilities, variety of shape, manufacturing accuracy and endurance properties [1-3]. Shrinkage is an extremely important parameter that must be considered during injection molding, because it affects the structural features and GPS of the molded part. It also determines the applicability and aesthetic features of the plastic part [4]. The process of IM is determined by the material type, and its IMM capacity. The IM parameters influence directly or indirectly final dimensions, the structure and the shape of the plastic parts, in accordance with the specification range established in the development process and the processing anomalies (material and surface), essential from the point of view of the user. Processing shrinkage depends on many factors, which can be grouped as follows [5]:

- material – density, structure (crystalline, semi-crystalline or amorphous),
- plastic product – shape, dimensions, dimensional accuracy,
- structure of the mold – runner system, number of cavities, shape of the cavity, cooling system, inserts, etc.
- IM parameters – melt temperature, mold temperature, holding pressure, holding time, injection pressure, cooling time, etc.

The effect of IM parameters on shrinkage and certainly sink marks has been discussed for many decades. As a matter of fact, shrinkage is an inherent property of polymer and it should be precisely handled to improve the product quality. Especially in the thick part improper setting of holding pressure, holding time and melt temperature may generate shrinkage. Therefore, satisfactory IM parameters must be carefully monitored and their impact recorded in terms of diametrical shrinkage, mass and depth of the shrinkage [6].

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Global influence of the injection parameters according to the processing of shrinkage is presented in Fig.1.

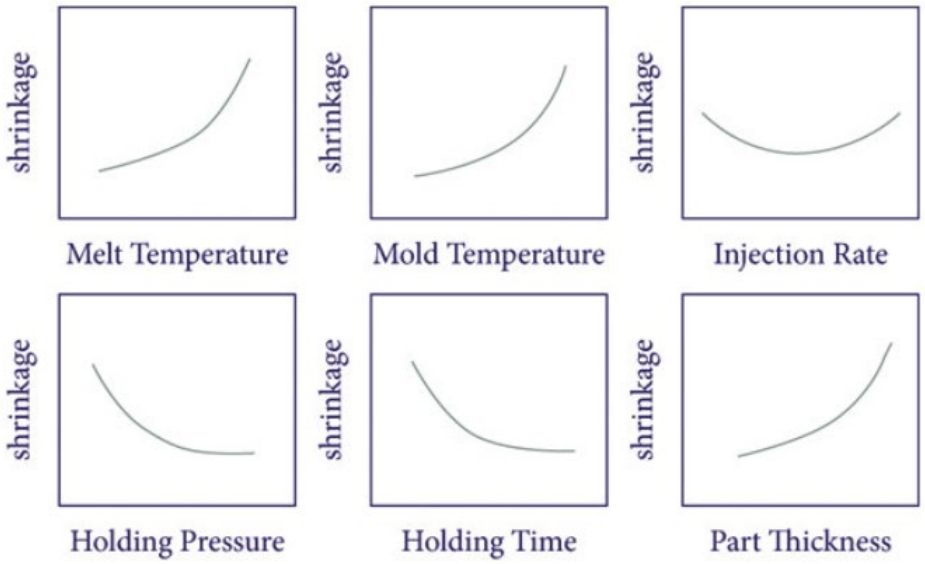



***Fig. 1.*** *Variation of shrinkage caused by IM processing* [7-13]

Materials of greater density show greater processing shrinkage. Materials of lower density crystallise a little less because of their greater chain branching, which leads to smaller shrinkage. Processing shrinkage decreases together with an increase of the mass melt flow index. It is known that crystalline materials have greater processing shrinkage than amorphous materials. The shrinkage process should be identified based on measurements of molded part. The CAx techniques are widely used for the both mold design and IM process design. The main reason of using advanced software tools is reduction time-to-market of new product. The CAE analyses, CAM and CNC manufacturing techniques allow to faster and better fit of the design assumptions. The Reverse Engineering methods can be used to accurately reproduce free-form shapes using contact and non-contact measurement techniques. Mold design and injection molding process require a CAx programme systems and expert systems. The CAx software allows predicting of defects in early stage of the plastic part design and shrinkage elimination [14].

## MATERIAL AND METHODS

The plastic parts were manufactured using a IMM called "All Rounder 270s Compact" manufactured by ARBURG company. The authors selected the previously mentioned IMM using the "SAPA" expert system. In this study, the IMM had been operated in automatic mode, and the parameters were monitored using "SELOGICA" software. The IM parameters were determined using Moldex3D/Solid Pack numerical simulation software. The widely used plastic material "Polystyrol (PS) 456M" by "BASF" was used in case study. This isotropic pure polymer has good tensile strength to weight ratio, good chemical inertness, resistance to moisture, good fatigue life, high flowability and excellent heat resistance, making it ideal for standard injection molding of parts subjected to thermal stress. The input PS granules have spherical shape with medium diameter of 4.1 mm. The composite contains the previously mentioned PS and glass fiber. The concentration of glass fiber in the composite increases in percentage. For injecting the portions of material of respectively 10 %, 20 %, 30 % and 40 % filler amounts were prepared, as well as PS without the filler. The material properties of the PS without glass fibre, and resolved injection molding parameters are both shown in Table 1.

***Table 1.*** *Properties of PS and IM parameters determined using numerical simulation*

| The parameters | Values |
|---|---|
| Drying Temperature ($^0$C) | 75 |
| Drying time (s) | 4500 |
| Solid density (g/cm$^3$) | 1.05 |
| Polymer Poisson's ratio | 0.38 |
| Max Permissible Shear Stress (MPa) | 0.24 |
| Tensile strength (MPa) | 34 |
| Mold temperature range ($^0$C) | 20-60 |
| Normal mold temperature ($^0$C) | 40 |
| Melt temperature range ($^0$C) | 200-250 |
| Normal melt temperature (°C) | 225 |
| Maximum injection pressure (MPa) | 155 |
| Maximal shear rate (1/s) | 100000 |
| Ejection temperature ($^0$C) | 102 |
| Freeze temperature ($^0$C) | 122 |
| Total Element Number of Part | 96328 |
| Total Node Number of Part | 11291 |
| Total Element Number of Part and Runner | 114120 |
| Filling time (s) | 0.4 |
| Holding time (s) | 4.7 |
| Maximal Clamping Force during holding phase (kg) | 13000 |
| Max melt front time (s) | 0.2 |
| Volumetric shrinkage (%) | 1.466-2.816 |
| Maximal shear rate (1/s) | 722 |
| Max Injection pressure | 8.1MPa |
| Max cooling time (s) | 19 |
| Max sink marks | 0.015 |
| Flow rate (mm$^3$/s) | 24811 |
| Maximal bulk temperature ($^0$C) | 225 |
| Temperature of coolant liquid (°C) | 20 |
| Cooling channel diameter (mm) | 8 |
| The percentage of ethyl glycol in the cooling agent mixture ($H_2O$+ethylene-glycol) (%) | 20 |

The authors used variable material options in the experimental tests. The filler was prepared and different mixtures were used. The CAD models are solid prisms with the following overall dimensions (l x b x h): l = 40 mm, b = 40 mm and, h = 3 mm. The P-V-T chart for PS without added filler is shown in Fig. 2.

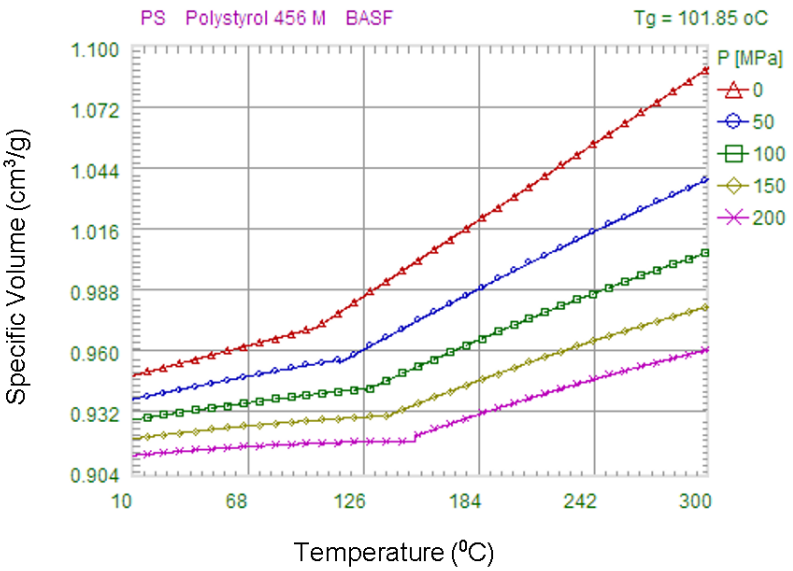



***Fig. 2.*** *P-V-T diagram for PS*

Measurements of the geometrical dimensions of the plastic parts, achieved with identical IM parameters, were conducted using two different coordinate measurement systems:

- Coordinate measuring machine (CMM), Zeiss Contura G2 with VAST XXT tactile scanning sensor paired with a spherical probe tipand,
- Optical measuring system, 3D ATOS Compact Scan for non-contact (3D scanning) applications.

Contact measurement is suitable for applications where high accuracy and precision are required, such as dimensional inspection and quality control in manufacturing. On the other hand, non-contact measurement technologies do not require physical contact with the object and utilize optical techniques to measure surface characteristics, dimensions, or distances. While using the first measuring method, the parts were measured to an accuracy of 0.01 mm with CMM called Contura G2 by ZEISS, and in the second method particular samples were scanned with the use of 3D ATOS Compact Scan. The values of shrinkage were set according to appropriate dimensions of the mold cavity for the first method by using common mathematical dependencies presented in literature [15]. The contact CMM uses a physical stylus to measure discrete points with extreme precision, whereas ATOS utilizes non-contact blue light technology to capture full-surface 3D data instantly. The 3D ATOS scanner is a measurement system which uses the optical triangulation method. According to the measurements of the shape and dimensions of the experimental parts carried out using the 3D scanner, particular values of the shrinkage were based on comparing the results of the 3D scanning associated with the CAD model of the plastic part. It can be generated only when a CAD model is compared to a scanned part. If this condition is met, by the CAD model applied on the "stl" format, the colour visualisation of the deviation maps is obtained. The neutral format "stl" could be avoided by using Associative Topology Bus (ATB). High quality of data, a few measurement points providing information about the surface of the measured element and the direct comparison with CAD data are the main advantages when choosing the 3D scanning method. The dimensional results were inspected using GOM Inspect software. The CAD model of molded part and a CAD model of designed part both created a union, together with the map of deviations between surfaces.
Considering the assumed linear shrinkage of the mold cavity due to temperature estimated by Moldex 3D software, additionally shrinkage of the part has been corrected by PTC Wildfire Mold Design module during the mold design phase. Shrinkage arises from non-uniform cooling and insufficient holding, but it has been prevented through mold design, numerical simulation, and controlled processing.

## RESULTS AND DISCUSSION

The differences in the value of shrinkage set based on the geometrical dimensions of the molded part measurements conducted with the use of the scanner and with the use of the CMM were negligible, as shown in Fig. 3.

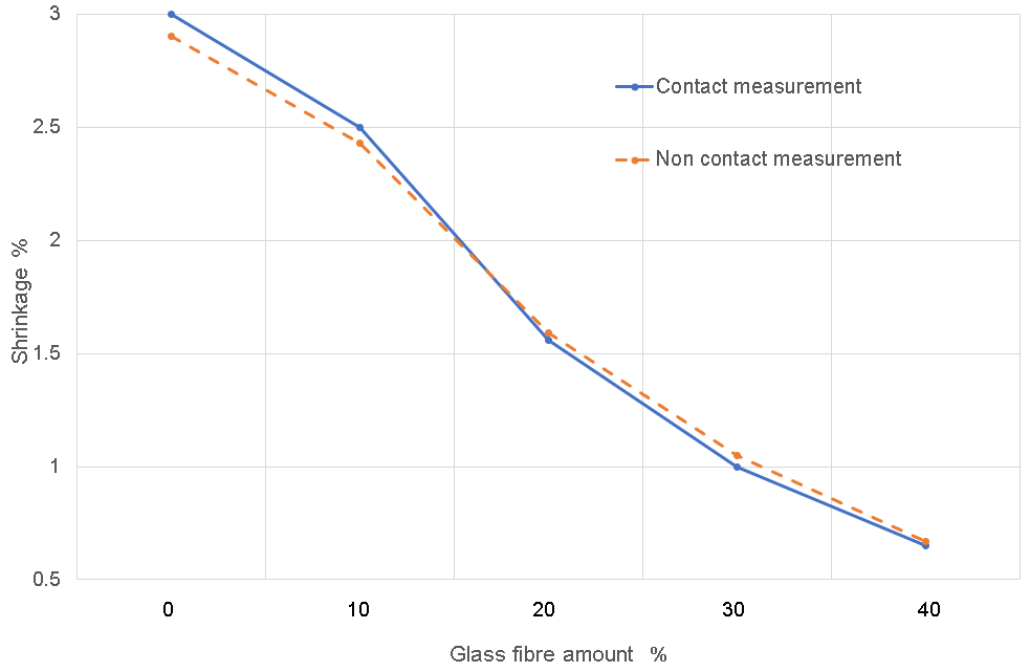



***Fig. 3.*** *Comparison results between amount of filler and shrinkage based on both different measurement methods*

The decrease of shrinkage was visible with increase of filler from 10 % to 40 %.

## CONCLUSION

The plastic injection molding is complex; therefore, it is characterised by several selected parameters. The parameters cause that setting the satisfactory injection conditions requires knowledge of the processing properties of the material, mold geometrical characteristics and the IMM parameters. With regards to the injection process, glass filler shows positive effect causing the decrease of the injection shrinkage and dimensional stabilisation of the parts. The contact (tactile) methods, such as CMM are time-consuming and need qualified operating staff. Non-contact methods, including 3D optic measurement, are an alternative. Non-contact measurement can be effectively used to object dimensioning where other techniques are ineffective or their usage is complex, time-consuming and problematic. When it comes to contact vs non-contact measurement systems, it's worth noting that contact measurements relying on tactile probes will typically be more accurate than non-contact measurement methods. Thus, contact systems are better suited for applications with high-precision requirements, especially where measurement tolerances are in the micrometrer range. Contact measurement systems often provide simpler and more cost-effective measurement solutions for more basic measurement tasks compared to more sophisticated non-contact systems. On top of everything, contact measurement systems are notably less susceptible to environmental interference, which can affect the accuracy of non-contact measurements. In the conducted case study, both previously mentioned measurements meet the requirements of the investigation. Further research should be done with an even greater increase of the percentage amount of glass fiber in composite to see if the shrinkage is still decreasing. Even further research will be based on the application and integration of benchtop tools like the Xplore IM12 Pro to visualize, quantify, and ultimately eliminate these defects early in the

development phase, ensuring that the final product is dimensionally stable and aesthetically flawless especially for micro parts.

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