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Comparison of methodologies for identification of process parameters affecting geometric deviations in plastic injection molding of housing using Taguchi method

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1. Introduction

In modern global market environment, it is essential for production companies to maintain or improve their competitiveness. That requires transition from sequential to concurrent product development [1]. Due to changes in product and process development and adjustments in existing production systems, it is essential to choose proper methods that will be used for optimal product development from very beginning.

This paper compares two methodologies for identification of process parameters that affect geometric deviations in plastic injection molding (PIM) for production of housing. Compared methodologies use Taguchi's approach to design of experiment (DOE) factorial experiments. First methodology uses simulation, while second one uses experimentation in real production conditions.

Most common problems in PIM is to achieve satisfactory dimensions of products. Technical literature on this subject is limited and modest.

Busick et.al. [2] proposed process simulation as a methodology for evaluating the feasibility of a tolerance scheme in PIM. Simulation is used in order to quantify dimensional errors due to process variations and for estimation of sensitivities. Comparison of simulation results with tolerances specified by designers helps them to evaluate whether the desired tolerances are feasible. The paper describes the steps required for estimating the dimensional errors and defines criticality as a measure of tolerance feasibility. Decision is entirely based on simulation results.

Chao et.al. in [3] consider the application of computer-aided engineering integrated with statistical techniques in order to reduce warpage variation depended on injection molding process parameters during production of thin-shell plastic components. Their paper presents specially developed regression model techniques that link the controlled parameters and the targeted outputs. As a result, the identified models can be used for prediction of warpage at various injection molding conditions.

Ozcelik and Erzumulu in [4] investigated gate location, filling and flow for minimum warpage of plastic part. Process parameters, such as mold temperature, melt temperature, packing pressure, packing time, cooling time, runner type and gate location are considered as model variables. The most important process parameters influencing warpage are determined using finite element analysis results based on analysis of variance (ANOVA) method.

Choi and Im [5] employed the numerical analysis of shrinkage and warpage of injection-molded parts made of amorphous polymers. Main goal was to examine an impact of the residual stresses produced during the packing and cooling stages of injection molding. In order to verify the numerical predictions obtained from the developed program, the simulation results were compared with the available experimental data from the literature.

The approach in paper by Yin et.al. [6] uses a back propagation (BP) neural network trained by the input and output data obtained from the Finite Element (FE) simulations performed on Moldflow software platform. They proved that the prediction system has the ability to predict the warpage of the plastic within an error range of 2%. Process parameters have been optimized using the prediction system.

Ozcelik and Sonat [7] tested the thin shell cell phone cover produced with polycarbonate/acrylonitrile butadiene styrene (PC/ABS) thermoplastic to make decision for adequate model. In first step, the effects of the injection parameters on warpage for different thickness values were examined using Taguchi method. The warpage values were found by analyses, performed using Moldflow Plastic Insight (MPI) 4 software. In the second step, for determination of the forces that cause the plastic part to fail at the points determined over the top surface of the cell phone cover, CATIA V5R12 was used.

Paper by Rrzurumlu and Ozcelik [8] considered minimization of the warpage and sink index in terms of process parameters of the plastic parts that have different rib cross-section types, and rib layout angle using Taguchi optimization method. Tested process parameters are mold temperature, melt temperature, packing pressure, in addition to rib cross-section types, and rib layout angle. Series of mold analyses are performed to exploit the warpage and sink index data. The following polymeric materials were selected: PC/ABS, POM, and PA66.

Tang et.al. [9] explored fabrication of mold that produces a thin plate, with dimensions 120 mm × 50 mm × 1 mm. The thin plate was used for warpage testing. In mold fabrication, the mold base was machined and assembled. After that, the mold was fixed on the injection-molding machine. Then, the machined product was used for testing on the effective factors in warpage problem by applying the experimental design of Taguchi method. Four tested factors were: filling time, melt temperature, packaging pressure and packaging time, resulting with melt temperature as an influential factor.

Technical report by Farshi et.al. [10] presented warpage and shrinkage as defects in injection molding of plastic parts. Moldflow software package was used to simulate the molding experiments numerically. In order to minimize the above defects, the process optimization was carried out by sequential simplex method. Process design parameters are: mold temperature, melt temperature, pressure switch-over, pack/holding pressure, packing time and coolant inlet temperature. The output parameters, aside from warpage and shrinkage, consist of: part weight, residual stresses, cycle time, and maximum bulk temperature. Results are correlated and interpreted with recommendations that should be considered in such processes.

All presented papers indicate that comparison of simulation and real experimental data is extremely important for determination part deviation in plastic injection molding. Examined parameters vary in different researches. Hence, it was not possible to draw conclusions about influential parameters, since choice of factors is limited to production of specific parts described in papers. Therefore, it can be concluded that this area is still insufficiently investigated and the real result could be expected in the future researches.

2. Research background

This paper represents an attempt to search for proper methodology – simulation and real experimentation to recognize influential parameters and define the equilibrated values of parameters for the smaller dimensions deviation. For both approaches, Taguchi's experimental design is used. Approaches are applied in order to identify potentially influential important parameters affecting post-shrinkage and post-warpage deviations of plastic injected Housing.

In PIM, two most common geometric deviations occur – shrinkage and warpage. If the shrinkage is evenly distributed, that results in geometric reduction of part dimensions without changes in a form. Warpage occurs in cases due to uneven shrinkage in one or more part coordinates. Unequal part shrinkage causes internal tensile strains. Depending on the tenseness of the part, these strains could result in part deformations and change of shape. In extreme cases, part can be broken [11].

Geometric deviation in PIM is complex problem. Therefore, only critical points of the part with chosen geometry are observed. That includes two most important part areas - the area around injection point (three measurement points) and farthest area from injection (two measurement points). Areas around the injection point are simpler to be exposed to higher or, if necessary, lower pressure than in other areas, especially at farthest points.

Close to the injection point, it is much easier to control the ratio between pressure, time and shrinkage. High holding pressure results in smaller shrinkage as long as pressure in injection point exists until end of spree freezing. In this case, shrinkage in the area around the injection point in general will be smaller than in further points. If the holding pressure is not preserved until the end of injection process, pressure in the mold cavity will produce the return of plastic material back into the distribution system. This could result in larger shrinkage around the injection point than in the rest of the mold cavity.

High holding pressure results with high initial flow, since pressure is rapidly distributed in mold cavity. Once the mold cavity is under the pressure, the flow will occur due to material contraction. That could result in much slower flow in relation to initial flow from injection molding in molding point. In the other words, high initial flow will exist, followed by very slow flow of plastic material.

Low holding pressure can result with opposite effect. Initially, the flow will be considerably slower than in case of high holding pressure. That leads to rapid level of plastic material cooling. However, during material hardening, volumetric change, from high to low temperature, is much higher when holding pressure is low. That further yields the higher flow caused by compensation. Therefore, high holding pressure does not automatically imply smaller shrinkage at the farthest points.

It is common opinion that shrinkage and consequently warpage is caused primary by production conditions. That means that final shrinkage and warpage are complex functions of process parameters and machine settings, as well as of characteristics and capability of the equipment.

Analysis of parameters that have influence on geometric deviations in molding was conducted on sample Housing presented in Fig 1. Approximate weight of Housing is 26 g. Dimension of part are 143 × 92 × 9 mm; the part is made from Cycoloy, PC/ABS, Grade C2800.

Fig. 1 Housing for electronic device

Simulation is conducted using Moldflow Plastic Insight 2010, while second experiment is conducted in real production environment, on machine Battenfeld BK-T 1300/500.

Measurement of the parts obtained by real experiment to a great extend depends on the stability and reliability of the measuring equipment [12]. Therefore, a dimensional measurement and mold dimension is carried out on the coordinate measuring machine Zeiss Contura G2 Aktiv 700, with measuring range 700 × 1000 × 600 mm, uncertainty (by ISO 10360-2): MPE_E = (1.8+L/300 μm), MPE_P = 1.8 mm.

3. Experimental setup

For both experiments, geometric deviations are measured the same way in 5 characteristic points (Fig. 2). The origin of part coordinate system was placed at the end point of the spree. Vectors of mold dimensions are subtracted from vector part sizes and this difference is taken into account.

For experimentation, five potentially important injection molding parameters, that could have impact on geometric deviations of plastic product, are examined:

temperature of molded plastic (TMP), injection time (IT), cooling time (CT), holding pressure (HP) and holding pressure time (HPT). The parameters are chosen according to possibility of controlled variation at the molding equipment used. Most of these parameters were also varied by other authors [4, 8, 9].

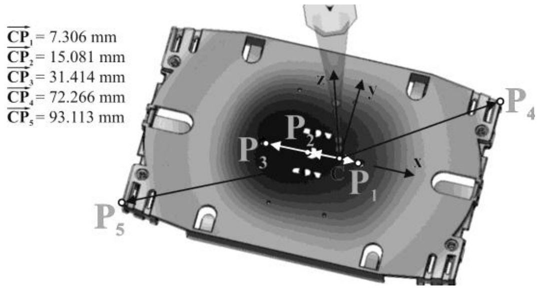

Fig. 2 Measurement points on the Housing

Simulation approach was used as startup for investigation of influence of geometry on molding process and the first experiment was conducted. Some chosen medium levels of factors (parameters) are at asymmetrical disposition from low and high level; hence, it was not possible to conduct experiment with three factor levels. Consequently L_8 Orthogonal Array – OA is used for simulation. Real experiment is conducted by L_{27} OA for three level factors. Factors (parameters) and their levels for both approaches are shown in Table 1.

Disposition of the parameters for simulation is shown in Table 2. The two reaming columns are second order error columns.

Allocation of examined parameters for real experiment is shown in Table 3. Experimental design also contains two error columns. Experiment was conducted with three replications.

Table 1

Parameters and their values for simulation and real experiment

Experimental factors			Simulation		Real experiment		
Annotation	Name	Unit	Low	High	Low	Medium	High
TMP	Temperature of Molded Plastic	°C	220	260	220	240	260
IT	Injection Time	s	0.8	1.2	0.8	1	1.2
CT	Cooling Time	s	15	40	15	25	40
HP	Holding Pressure	bar	40	70	40	55	70
HPT	Holding Pressure Time	s	3	5	3	4	5

Table 2

Allocation of parameters in simulation

Factor	HP	IT	CT	TMP	HPT	e_1	e_2
Column	1	2	3	4	5	6	7

Table 3

Allocation of parameters in L_{27} for real experiment

Effect	HP	IT	HPxIT	HPxIT	TMP	HPxTMP	HPxTMP	HPT	HPxHPT	HPxHPT	CT	e_2	e_3
Column	1	2	3	4	5	6	7	8	9	10	11	12	13

4. Experimental results

In the analysis of experimental results, only the basic analysis by ANOVA for factorial designs is used. Specific Taguchi's approaches in analysis as a S/N ratio or contribution ratio was unable to conduct due to limitations of simulation results [13, 14] For both approaches, simulation and real experiment, the identification of influential parameters is measured in five points, with results shown in Fig. 3. Bold letters indicate significant influence of parameters with $p < 0.01$ while with normal letters are represented significance of parameters with $p < 0.05$.

Results shown in Fig. 3 indicate significant difference in identification of influential parameters for simulation and real experiment. Based on the simulation, the parameter with greatest influence is holding pressure time (HPT), followed by holding pressure (HP). On the other hand, results from real experiment indicate that the most important parameter is holding pressure (HP), followed by injection time (IT) or temperature of molded plastic (TMP), depending on the measurement point.

Viewing representative points (nearest injection point – 1 and farthest injection point 5 indicate completely different parameters that influence geometry of molding. For point 1, relevantly influential parameters are – holding pressure (HP) for real experiment, and temperature of molding plastic (TMP) and holding pressure time (HPT) for simulation. In the point 5 from simulation results, all parameters are influential except cooling time (CT). Results from real experiment identify holding pressure (HP) and temperature of molded plastic (TMP) as parameters that have influence (Fig. 3).

Simulation has only one replication, so experiment is non-replicated. Hence, Taguchi's pooled error method is used for analysis of results [15]. Results from simulation also indicate that, although pooled error method is applied, there are too many influential factors, which conflicts with Pareto principle [16].

Comparisons of results between the two approaches are performed by the method of orthogonal contrasts as a measure of variation (Figs. 4-7) [17]. Also, it was necessary to conduct some adjustments to eliminate difference in size between the simulation and the real experiment.

Therefore, the real experiment L_{27} is reduced on 2-3 L_8 designs, each containing combination of three parameters. This reduction neglects other factor in design, and therefore some results could be influenced by other parameters, and to differ between themselves. The Figs. 4-7 represent the comparison of influence of four parameters which were influential in at least one measurement point i.e. HP, IT, TMP and HPT in simulation or in

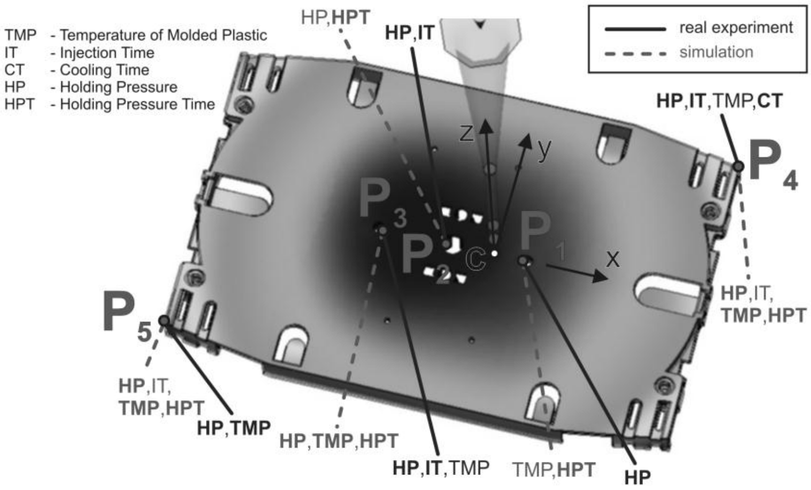

Fig. 3 Influential parameters in measurement points for simulation and real experiment

real experiment. The need for reduced designs in real experiment results with tree L_8 OA containing factors HP-IT-TMP, HP-IT-HPT and HP-TMP-HPT.

The method of orthogonal contrast is used to compare influential parameters in simulation and real experiment. Orthogonal contrast does not represent true deviations in factors, just changes in factors that include all measurements without their physical interpretation.

Fig. 4 compares characteristics of holding pressure in measurement points between simulation and real experiment. Since results for reduced designs HP-IT-TMP and HP-IT-HPT are similar, they are taken as a representative measure and compared with simulation.

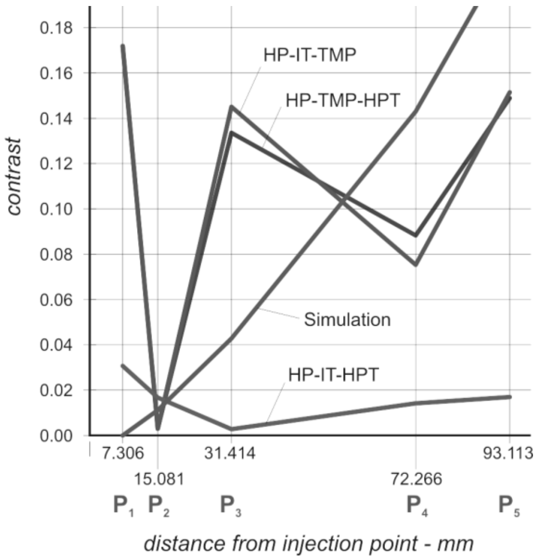

Fig. 4 Comparisons of influential parameters by measurement points for HP

Holding pressure for simulation indicates gradual functional increase of the parameter from injection point to farthest measurement point. The functional correlation is not undertaken due to small number of measurement points. Contrast for real experiment shows the oscillation holding pressure as distance progresses from injection point, with high value in injection point. HP is greater than simulation in points near the injection point, while it is smaller than in simulation in farthest measurement points.

Fig. 5 represents the comparison of injection time influence. In real experiment, injection time has an influence in three measurement points, while in simulation this parameter has no relevance on geometry. Comparing the influence by orthogonal contrast indicates higher influence of the injection time for real experiment than in simulation in all measurement points except in the farthest point. In Fig. 6, orthogonal contrasts for injection time indicate that in all cases overall values are smaller than in other factors, and are similar for both reduced experiments and simulation. Results for simulation are smaller than for real experiment except for measurement point P_4 (11.25 times).

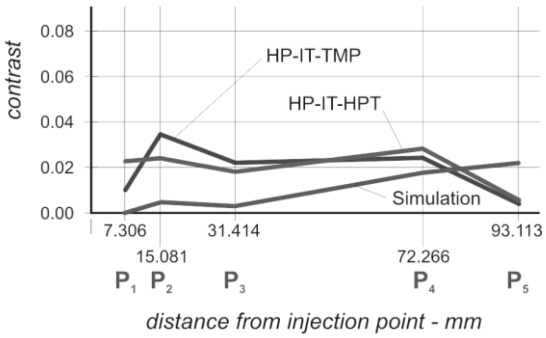

Fig. 5 Comparisons of influential parameters by measurement points for IT

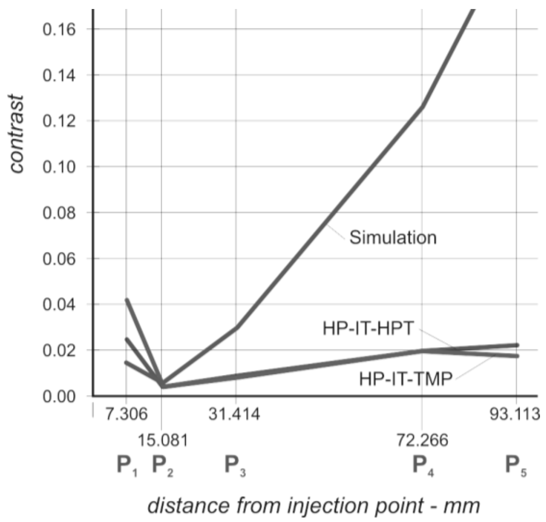

Fig. 6 Comparisons of influential parameters by measurement points for TMP

Comparison by orthogonal contrasts of temperature of molded plastic is shown in Fig. 6. Results of simulation indicate that the parameter has significant influence, while in real experiment this parameter is of no importance for geometry of moiled plastic. This is also obvious from charts in Fig. 6. While there are some influences of the parameter in the injection point for real experiment, as distance progresses from injection point, the influence decreases and remains at the same level. On the contrary, in simulation, TMP increases with distance from injection point up to the same way and level as a holding pressure.

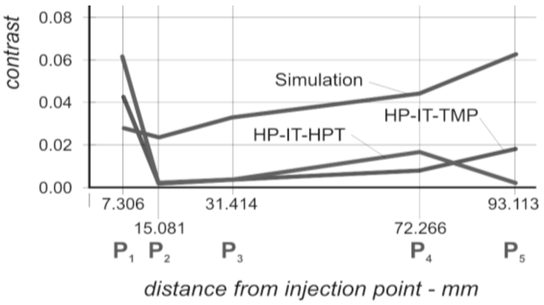

Fig. 7 Comparisons of influential parameters by measurement points for HPT

Fig. 7 compares orthogonal contrast for holding pressure time. Contrast indicates higher values in HPT and increases from injection point to farthest point for the simulation. On the contrary, influence of the parameter decreases from injection point to farthest point for real experiment. Experimental results indicate that HPT is most influential parameter in simulation, while its influence is nonexistent in real experiment.

Comparison of deviation is based on results from real experiment. Reduced designs are used. First, farthest measurement point from injection point is chosen. From these results, a combination of parameter levels that result in minimal deviation is taken as a relevant combination of factor (parameter) levels, since it represents optimal parameter values for molding. For these parameter values, combination deviations in all other measurement points in real experiment, as well as in simulation, are compared and presented in Fig. 8.

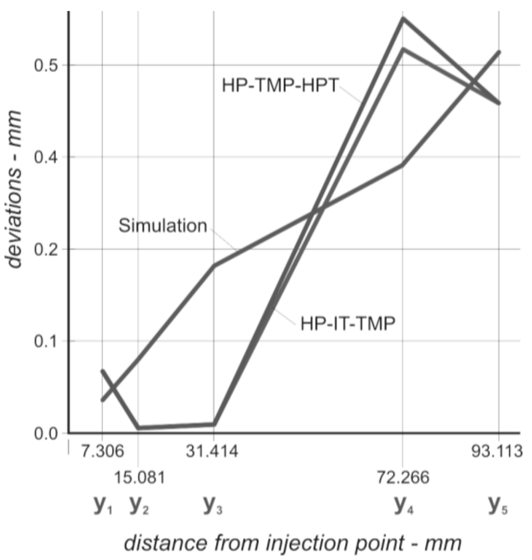

Fig. 8 Comparisons of deviations in representative measurement points

Results of the simulation indicate continual increase in deviations in geometry from injection point as measurements are farther from it. Results from real experiment also increase from measurement point, but with oscillations, i.e. they first decrease in two points from injection point, then they increase in measurement point 4, then again decrease for farthest measurement point 5.

Deviations obtained by the simulation have larger deviations in measurement points P_2 (19.1 times), P_3 (21.82 times) and P_5 (1.14 times). The real experiment indicates higher deviations in points P_1 (2.2 times) and P_4 (1.4 times).

5. Conclusions

Results of part deviations (shrinkage and warpage) for plastic injection molding of housing are obtained by two methods – the real experimentation and the simulation in Moldflow Plastic Insight 2010. Results are measured in five points, from the injection point towards ends of the mold. According to research results, the following conclusions can be drawn:

1. For the same experimental conditions, the real experiment and simulation express different parameters that influence the geometry of a mold. The primary influential parameters, in all measurement points, are holding pressure time (HPT) and holding pressure (HP) for the simulation and the real experiment, respectively.

2. There is also a difference in other influential parameters between simulation and real experiment.

3. The simulation results with far more influential parameters than real experiment.

4. Part deviation in real experiment oscillates with small values near the injection point and with high values in measurement points near the mold boundary. Contrary to real experiment, results of the simulation give the linear increase in deviation as the measurements are further from injection point.

5. In the simulation conducted using software Moldflow Plastic Insight 2010, it is obvious that it generates the parameter behavior primary from distance from injection point, based on some theoretical function. Characteristics of the function are not examined due to small number of measurement points and they are subject for further research.

Based on the results presented above, one can conclude that a simulation leads to different results i.e., different influential parameters than the real experiment. That means that the simulation could produce false results for identification of the parameters that are influential on part geometric deviations in plastic injection molding, and therefore it is unreliable. For that reason, it could be recommended that either the real experimentation or another simulation software should be used for identification of influential parameters.

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D. Ćurić, Z.A. Veljković, J. Duhovnik

PROCESO PARAMETRŲ, TURINČIŲ ĮTAKOS PLASTIKO KORPUSŲ LIEJIMUI SLEGIANT, NUSTATYMO METODOLOGIJŲ PALYGINIMAS TAIKANT TAGUŠI METODĄ

R e z i u m ė

Šiame straipsnyje tiriami parametrai, kurie gali turėti įtakos geometriniams detalės dalių parametrams (susitraukimui ir iškreipimui) lietame slegiant plastiko korpuse (Cycoloy, PC/ABS, klasė C2800). Tiriami penki parametrai (liejamo plastiko temperatūra, liejimo trukmė, aušinimo trukmė, palaikomas slėgis, slėgimo trukmė). Parametrų įtaka lyginama su modeliavimo ir matavimų penkiuose taškuose rezultatais. Taikomas Taguši ortogonaliųjų vektorių metodas.

Dėl per didelio parametrų, turinčių įtakos geometriniams iškraipymams skaičiaus, modeliavimo rezultatai gali būti nepatikimi. Daugiausia įtakos turintis veiksnys yra slėgimo trukmė. Realus eksperimentas rodo, kad daugiausia įtakos turi palaikomas slėgis. Tolesniems tyrimams rekomenduojama atlikti eksperimentą, jei tai įmanoma.

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COMPARISON OF METHODOLOGIES FOR IDENTIFICATION OF PROCESS PARAMETERS AFFECTING GEOMETRIC DEVIATIONS IN PLASTIC INJECTION MOLDING OF HOUSING USING TAGUCHI METHOD

S u m m a r y

This paper examines parameters that could influence geometric part deviation (shrinkage and warpage) of the Housing (Cycoloy, PC/ABS, Grade C2800) produced by plastic injection molding. Five parameters (temperature of molded plastic, injection time, cooling time, holding pressure, holding pressure time). Influence of the parameters is compared by simulation and real experiment with the results measured at five points. Taguchi's orthogonal array method is used.

The simulation leads to unreliable results, with too many parameters influencing geometric deviation. Factor that has major influence is holding pressure time (HPT). The real experiment identifies holding pressure (HP) as a parameter with major influence. For further examination, the real experimentation is recommended, whenever it is possible.

Keywords: housing, shrinkage, warpage, deviation, Taguchi method, simulation, real experiment

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