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ODREĐIVANJE TEHNOLOŠKIH PARAMETARA GRANIČNIH VRIJEDNOSTI NA PLANIRANI POKUS, PRIJEDLOG ZA SLJED PROIZVODA POMOĆU KVALITATIVNIH PARAMETARA TERMOPLASTIKE

DETERMINATION OF TECHNOLOGICAL PARAMETERS LIMIT VALUES ON PLANNED EXPERIMENT, PROPOSAL FOR FOLLOWING PRODUCTS FROM THERMOPLASTICS QUALITATIVE PARAMETERS

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***Sažetak**: Doprinos se tiče određivanja tehnoloških parametara granične vrijednosti potrebne za planirani prijedlog eksperimenta u kojima će se utjecaj pojedinih tehnoloških parametara promatrati. Tehnološki parametri u međusobnoj interakciji utjecaja rezultiralo je kvalitetom plastomera proizvedenih proizvoda kroz tehnologiju brizganja. Tri različita tehnološka parametra koja su korištena uglavnom u međusobnoj interakciji, utječu na i kvalitativne karakteristike proizvoda u proizvodnom procesu te su odabrane od skupine tehnoloških parametara. Za vrijeme eksperimentalnog mjerenja, vrijednost jednog tehnoloških parametra je uvijek bila promijenjena. U svakoj promjeni, eksperimentalni uzorci su proizvedeni, a zatim su izmjereni i vrednovani.*

Ključne riječi:
– eksperiment
– kvalitet
– tehnoloski parametar
– proizvod

***Abstract:** The contribution concerns the determination of the technological parameters limit values necessary for the planned experiment proposal, where the influence of single technological parameters will be observed. Technological parameters in mutual interaction influence the resulting quality of thermoplastics products produced through the technology of injection molding. The three distinct technological parameters that were used mainly in mutual interaction influencing qualitative characteristics of the products in manufacturing process were chosen from the technological parameters set. During experimental measurement, the value of one technological parameter was always changed. At every change, experimental samples were produced and then were measured and evaluated.*

Keywords:
– experiment
– quality
– technological parameter
– product

1. INTRODUCTION

From theoretical analysis, it is evident that the technological process of injection molding is a complicated process. The technological parameters working in mutual interaction at various levels on the qualitative characteristics of the resulting product enter into it. Evaluation of the technological parameters and their properties is a complicated process put together from mutual opening-up steps. The parameters influence the result and would cause uncertainties in the final conclusion of the classical method of evaluation. [1, 3]
From experimental work, it is shown that it is possible to progress with the classical method. Then under constant conditions, the level of only one parameter is changed and it is judged from the results of the experiment whether the researched quantity influences eventually changed and with what method. In planned experiments, it is possible also to evaluate single parameters influence on interactions, i.e. the simultaneous working of the researched parameters. The basis of this experiment is to perform the first step of judging the influence of single technological parameters in the classical way. This means that the parameters are judged separately and at the same time the limit value of the single technological parameters is determined and serves as a given value for the proposal of the planned experiment. [2, 4]

2. DESIGN AND DESCRIPTION OF THE EXPERIMENT

This experimental approach observed the influence of the chosen technological parameters upon choice of parameters of quality in injection molding of the product from thermoplastic. The researched product from thermoplastic is represented in Figure 1.

Figure 1. The analyzed product from thermoplastic

During the experiment, the influence of one choice of technological parameter on the selected qualitative parameters was always followed. The substance of this part was simultaneously used to determine the limit levels of the technological parameters for the planned experiment. The injection pressure p_3, the injection speed v_3 and the switch point V_3 were chosen from the set of parameters as the technological parameters. The diameter of the orifice for the screw $d_3$and the total mass of the product m_3 were chosen from the set of qualitative parameters. At every change of a single technological parameter (Figure 2), 6 samples were adopted. Every sample was marked in order to avoid interchange in the measurement of the single qualitative parameters.

Figure 2. Manufacturing analyzed samples

Table 1. Adjusted technological parameters at optimum manufacturing process

parameter	unit	value	parameter	unit	value
time of cycle	s	37,7	screw speed	$U.min^{-1}$	125
time of injection	s	5,78	screw resistance	MPa	1,5
time of plastification	s	22,14	screw backward	cm^3	231,22
injection pressure	MPa	90	plastification stop	cm^3	231
injection speed	$cm^3.s^{-1}$	160	melting cushion	cm^3	14,92
time of pressure process	s	3	switch point	cm^3	15
pressure process	MPa	60	time of switch	s	30
time of cooling	s	24			

Table 2. Values of single technological parameters changes during the experiment

No. of exp.	parameter	No. of exp.	parameter	No. of exp.	parameter
1	p_3 = 80 MPa	10	V_3 = 3 cm^3	20	v_3 = 20 cm^3/s
2	p_3 = 83 MPa	11	V_3 = 7 cm^3	21	v_3 = 30 cm^3/s
3	p_3 = 85 MPa	12	V_3 = 11 cm^3	22	v_3 = 40 cm^3/s
4	p_3 = 87 MPa	13	V_3 = 17 cm^3	23	v_3 = 90 cm^3/s
5	p_3 = 93 MPa	14	V_3 = 21 cm^3	24	v_3 = 110 cm^3/s
6	p_3 = 97 MPa	15	V_3 = 28 cm^3	25	v_3 = 140 cm^3/s
7	p_3 = 100 MPa	16	V_3 = 32 cm^3	26	v_3 = 170 cm^3/s
8	p_3 = 103 MPa	17	V_3 = 36 cm^3	27	v_3 = 190 cm^3/s
9	p_3 = 107 MPa	18	V_3 = 40 cm^3	28	v_3 = 206 cm^3/s

In Table 1, the values of single technological parameters adjusted in the optimum manufacturing process are represented. The technological parameters that are changed during the experiment are marked with red color. In Table 2, the values of the single technological parameter changes are represented as they are changed during the experiment.

2.1. Characteristic and description of researched samples material

The analyzed samples were manufactured from the thermoplastic polypropylene with the manufacturing marking Borealis Polypropylene BC 142 MO by adding 2 % pigment. The material is supplied into the works for working into the shape of pellets. BC 142 MO is characterized by high impact strength, high hardness, excellent workability, good flow properties and low deformation. In terms of other properties, we should mention its physical properties as a being of a density 0,905 $g.cm^{-3}$, with a melt flow rate index (test conditions - 230°C and 2,16 kg) of 5 $g.10min^{-1}$. The working (melting) temperature 230 - 260 °C, die temperature 13 - 30 °C and high injection speed come under the process characteristics. Their application is used in the manufacture of containers, transports, engineering parts etc.

2.2. Characteristics and description of machineries employed in the manufacture and evaluation of researched samples

Samples necessary for experimental measurements were produced on the machine for injection molding of thermoplastics DEMAG EXTRA 120-430 that is represented in Figure 2. Measurements of qualitative parameters were performed by the length measuring instrument Mitutoyo Absolute Digimatic CD 15-DC with PC compatibility. For measuring total mass, the digital balance Mettler Toledo PL 1502-S (also PC-compatible) was used.

2.3. Drawing diagrams and their interpretation

On the basis of single measurements, the diagrams of individual technological parameters dependencies of quality parameters were drawn. The total mass m_3 and the orifice diameter d_3 were acquired as qualitative parameters.
Changes of single technological parameters and drawing functional dependences were performed in this order:

- change of the injection pressure p_3 and its influence on the resulting quality of the product,
- change of the switch point V_3 and its influence on the resulting quality of the product,
- change of the injection speed v_3 and its influence on the resulting quality of the product.

Change of the injection pressure p_3 and its influence on resulting quality of the product

Figures 3 and 4 represent the influence of the injection pressure p_3 change on the total mass m_3 and the diameter d_3 of the orifice. The optimum injection pressure at which the given product is produced is 90 MPa. The total mass of the product is not changed considerably (69,0 - 69,2 g) in the range of pressures 85 - 100 MPa as we can see in the Figure 3.

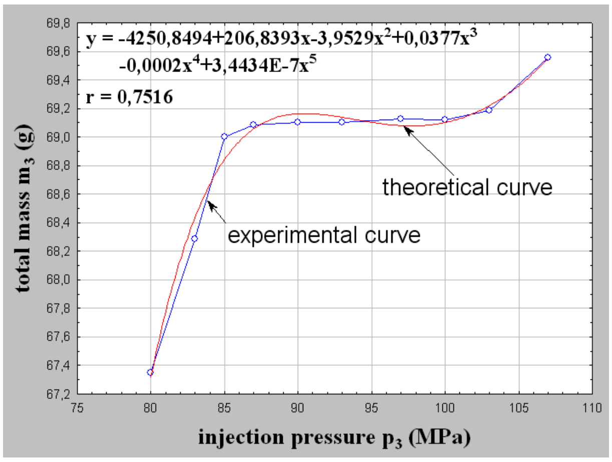

Figure 3. Influence of the injection pressure p_3 change on total mass m_3 of the product

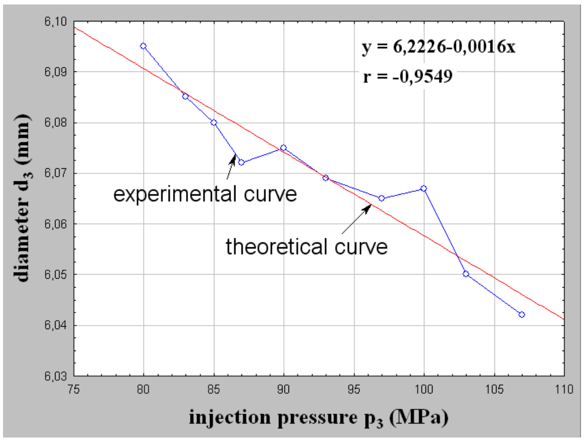

Figure 4. Influence of the injection pressure p_3 change on diameter d_3 of the product

Upon a decrease of an injection pressure under 85 MPa, concretely at the values 83 and 80 MPa, the total mass of the product decreases quickly under an allowable tolerance as is the case for the conditions 69,0 ± 0,5 g. At an injection pressure of 83 MPa, the total mass of the product is 68,3 g and at a decrease in pressure to 80 MPa, the total mass is 67,35 g.

Figure 5. Uninjection of the products

Upon a decrease in the pressure on 83 MPa that follows on to 80 MPa, the result is an uninjection of products (Figure 5) and in relation to it a quick lowering of total mass.
At an increase of the injection pressure on 103 MPa and eventually on 107 MPa, it comes out in the products as fine overinjections that are barely observable and eventually lead to considerable visible overinjections in the regions of the product.
We see in the diagram that with a change of injection pressure, the diameter of orifice also increases because at low pressure the machine doesn't push into this place the demanded quantity of melt. On the contrary, at a high pressure, the diameter of the orifice narrows because the machine deposits a larger quantity of the melt. Overall, the value of the diameter changed within the range of 6,045 - 6,095 mm, which is a difference of 0,5 mm.

Change of the switch point V_3 and its influence on resulting quality of the product

At the switch point, the total mass of the product falls in transferring from injection pressure to pressure process. The optimum switch point adjusted to the production of the product is 15 cm^3.

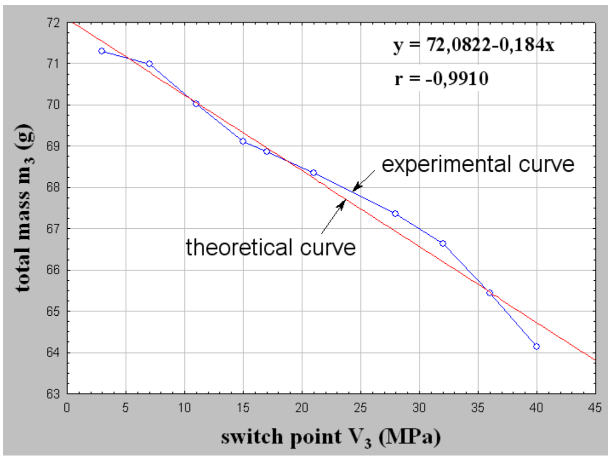

Figure 6. Influence of the switch point V_3 change on total mass m_3 of the product

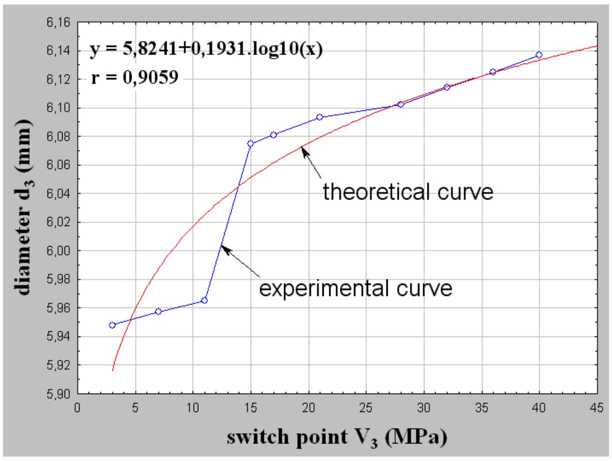

Figure 7. Influence of the switch point V_3 change on diameter d_3 of the product

We can see in Figure 6 that the total mass of the product changes linearly with a change of the switch point that has an expressive influence on the resulting mass of the product. At the optimum switch point, the total mass of the product has the value 69,1 g. At the value of the switch point 3 cm^3, it results in an over-injection of products on borders as is also the change observed in injection pressure occurring over 100 MPa. At a lower switch point under 3 cm^3, injection systems remain in die. At an increase of the switch point, it results in the growth of mass, and at values of 36 cm^3 that eventually reach 40 cm^3, it ends in fine uninjections and eventually leads to considerable uninjections of products (Figure 8) and as a consequence of this, the machine does not follow through to inject the demanded dose into die.

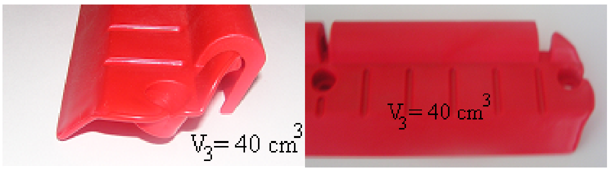

Figure 8. Uninjected products at a lowering switch point

With a sinking switch point (Figure 7), the diameter of the product diminishes on account of the machine pushing a larger dose of melt into die. Measured values are in the stated tolerance because the demanded diameter of the orifice is 6 mm with a tolerance ± 0,1 mm. At an increase of the switch point, the diameter of the orifice increases on account of the machine not pushing the necessary quantity of melt into die.

Change of the injection speed v_3 and its influence on the resulting quality of the product

Figure 9 represents change of injection speed v_3 influence on total mass m_3 of the products. From the diagram, it is evident that with an increase of injection speed, the total mass of the product increases. At the injection speed 20 - 110 $cm^3.s^{-1}$, total mass grows by 0,5 g. At a further increase of speed, the total mass changes minimally.

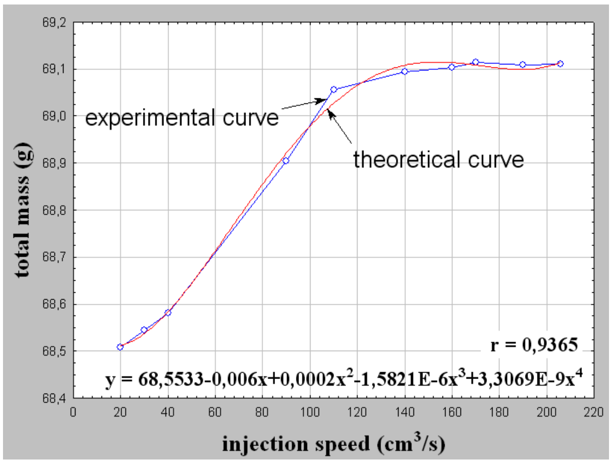

Figure 9. Influence of the injection speed v_3 change on total mass m_3 of the product

From it follows that injection speed influences the total mass of the product when lowered under the value 110 $cm^3.s^{-1}$ only. In products, it does not lead to visible changes. It is evident also from measured values of total mass.

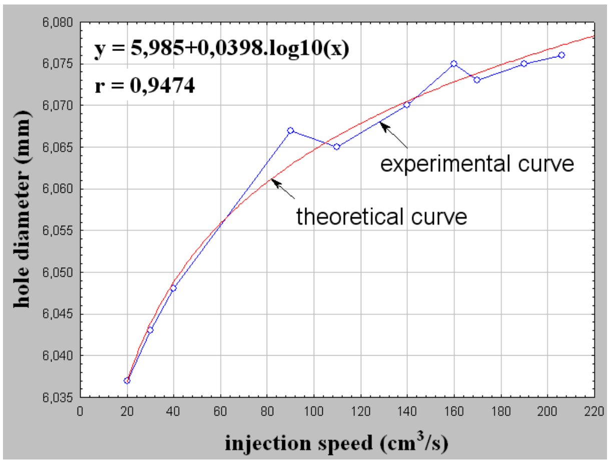

Figure 10. Influence of the injection speed v_3 change on diameter d_3 of the product

Lowering injection speed leads to moderate diminishing in diameter (Figure 10). At a lowering of the injection speed to 20 $cm^3.s^{-1}$, the diameter diminishes to 6,037 mm; this is, however, within demanded tolerance. At an injection speed 90 - 210 $cm^3.s^{-1}$, the diameter of the orifice changes within a range of 0,01 mm., although this is visibly unperceivable.

On the basis of the measured data and drawn function, the dependences limits of single technological parameters were stated as follows in Table 3.

Table 3. Limit values of technological parameters for planned experiments

technological par.	top limit value	lower limit value
injection pressure	107 (MPa)	80 (MPa)
injection speed	200 (cm^3/s)	40(cm^3/s)
switch point	40 (cm^3)	3 (cm^3)

3. DESIGN AND DESCRIPTION OF THE PLANNED EXPERIMENTS

In this section on the planned experiment, technological parameters will be shown as factors due to utilization of this term in the theory of planned experiments. Likewise, here three technological parameters (further factors only) yield an injection pressure p_4, injection speed v_4, and a switch point V_4. For the statistical evaluation of factors, a three level planned-three factors experiment of the type 3^3 was used. The coding factors by levels with ordered real values are stated in Table 4. With the help of 27 experiments (Table 5) with five repetitions, the influence of the factors was evaluated based on the chosen qualitative parameters. Initially, products particularly from the first and second cavity were judged and finally products from both cavities were judged as a whole. This was in accordance with the qualitative parameters (Fig. 11) obtained from the distance of the axes between the two diameters l_4, the hole diameter d_{4A}, the hole diameter d_{4B} and the total mass m_4.

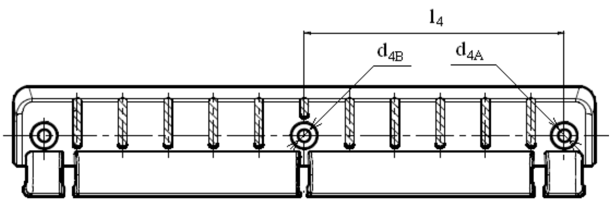

Figure 11. Followed qualitative parameters in planned experiments

4. CONCLUSION

The contribution describes the determination of the limit values of the technological parameters for the design of the planned experiment with the technology of injection molding. Tables 4 and 5 represent the condition for planned experiments design based on these advanced measurements.

Table 4. Coding factors by levels with ordered real values

Factors				Levels of factors		
No. of factor	marking	name	unit	-1	0	1
1	x_1	injection speed (v_4)	cm^3/s	40	113	200
2	x_2	injection pressure (p_4)	MPa	80	93,5	107
3	x_3	switch point (V_4)	cm^3	3	21,5	40

Table 5. Coded conditions of experiments

No. of exp.	coded conditions of experiments			typical conditions of experiments		
	x_1	x_2	x_3	(v_4)	(p_4)	(V_4)
1	-1	-1	-1	40	80	3
2	-1	-1	0	40	80	21,5
3	-1	-1	1	40	80	40
4	-1	0	-1	40	93,5	3
5	-1	0	0	40	93,5	21,5
6	-1	0	1	40	93,5	40
7	-1	1	-1	40	107	3
8	-1	1	0	40	107	21,5
9	-1	1	1	40	107	40
10	0	-1	-1	113	80	3
11	0	-1	0	113	80	21,5
12	0	-1	1	113	80	40
13	0	0	-1	113	93,5	3
14	0	0	0	113	93,5	21,5
15	0	0	1	113	93,5	40
16	0	1	-1	113	107	3
17	0	1	0	113	107	21,5
18	0	1	1	113	107	40
19	1	-1	-1	200	80	3
20	1	-1	0	200	80	21,5
21	1	-1	1	200	80	40
22	1	0	-1	200	93,5	3
23	1	0	0	200	93,5	21,5
24	1	0	1	200	93,5	40
25	1	1	-1	200	107	3
26	1	1	0	200	107	21,5
27	1	1	1	200	107	40

5. LIST OF SYMBOLS

injection pressure	p_3,	MPa
switch point	V_3,	cm^3
injection speed	v_3,	cm^3/s
total mass	m_3,	g
hole diameter	d_3,	mm
injection pressure	p_4,	MPa
switch point	V_4,	cm^3
injection speed	v_4,	cm^3/s
total mass	m_4,	g
hole diameter	d_{4A},	mm
hole diameter	d_{4B},	mm
distance of axes between two diameters	l_4,	mm

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