Characterization of Differences in Cavity Positions Orientation in the Multi Cavity Plastic Molding Process on the Product Defects

Moh. Hartono[1], Gumono[2], Hangga Wicaksono[3], and Ramadhan Araya Ismoyo[4]

[1,2,3,4] State Polytechnic of Malang, Malang 65142, Indonesia
[1]moh.hartono@polinema.ac.id
[2]gumono@polinema.ac.id
[3]hangga.wicaksono@polinema.ac.id
[4]rama.araya1@gmail.com

Abstract. When performing the injection molding process, the influence of the set parameters such as injection time, injection pressure, and other parameters used will affect the mold result. The problem that arises when doing injection molding using multi-cavity molds is the appearance of product defects. The purpose of this study focuses on finding the parameters of the injection temperature, injection pressure, injection time and optimal interactions, and the position of the cavity orientation so that the product produced from multi-cavity molds is minimally flawed. The method used is to conduct experiments on the plastic molding process and compare the results of the different cavity positions in the vertical and horizontal positions. Experimental design chosen is DOE Factorial. The results obtained that there is an influence of injection temperature, injection pressure, injection time and cavity position on the number of defects. The recommended cavity position is to adjust the horizontal position right - left, because it produces minimal product defects. The smallest chance of defects occurs when the interaction of injection temperature is 210 C, injection pressure is 42 Bar, and injection time is 4.5 seconds.

Keywords: Cavity Position Orientation, Defect Product, Temperature, Injection Pressure.

1   Introduction

Along with the rapid development of manufacturing industry technology, plastics are in great demand by the public. This is due to the nature of plastic which is light, easy to shape, recyclable, and corrosion resistant. In general, plastics are divided into 2 groups, namely thermosets and thermosetting. The difference between the two can be seen when heated, thermoset plastics will harden and cannot be recycled. While thermosetting plastic will soften when heated and can be recycled [1].

The cycles that occur during the injection molding process are plastification, injection, packing, cooling, and ejection stage. Where the plastic granular material is inserted into the hopper, then the injection cylinder will push the screw towards the

nozzle which is connected to the sprue, then the material will fill the cavity through the gate. After being fully filled, the material in the mold will be cooled, then the product is removed from the mold [2].

In the injection molding process, the influence of parameter settings such as injection temperature, injection time, injection pressure, and other parameters used will affect the mold result. The effect caused by parameter setting is 60% - 70% on the quality produced during the injection molding process [3]. As a result, it can cause various product defects such as short shots, flashing, bubbles, warpage and other defects [4].

Several studies have been conducted to see the effect of setting parameters, that as the injection temperature increases, the potential for flashing defects to appear is getting bigger [5]. Meanwhile, as the injection pressure increases, the injected material becomes denser, but the potential for defects also appears, namely flashing [6]. The assumption that arises from this research is the influence of injection temperature, injection pressure, and injection time and their interactions resulting from the injection molding process using multi-cavity molds. The purpose of this study is to find optimal parameters so that product defects produced by multi-cavity molds can be minimized.

2   Method

2.1   Selection of Tools and Materials

The method used in this research is an experimental method, by conducting experiments and observations so that the relationship between parameters or variables in a process can be recognized. The injection molding machine used is KT 105-G.

Fig. 1. The injection molding machine kt 105 – g.

While the material used in this study is polypropylene plastic material with the Masplene brand. The density of the material is 0.91 g/cm3 with a melting point of 165 °C.

Fig. 2. Material polypropylene (masplane).

The molds used are cupcake molds. The mold is a multi-cavity mold with a total of 2 cavities.

Fig. 3. Multi cavity molds.

2.2   Research Design

The data processing method used in this study is a factorial Design of Experiment (DOE). The purpose of using this method is to improve or improve quality, so as to provide a satisfactory and optimal response.

There are three variables used, namely the independent variable, the controlled variable, and the dependent variable. The selected independent variables were injection temperature (195, 210, and 225 °C), injection pressure (38, 40, and 42 Bar), and injection time (3.5, 4, and 4.5 seconds). The controlled variables used were clamping force (95 Bar), injection speed (40%), holding time (1 second), and cooling time (20 sec-

onds). While the dependent variable is the probability of product defects that arise from the injection molding results with 27 cycles with 10 replications.

Table 1. Data recording.

No	Inj Temp	Inj Press	Inj Time	Cycle	Prob
1	195	38	3,5	1 - 10	N
N	n	n	n	1 - 10	N
27	225	42	4,5	1 - 10	N

The data recording table facilitates the identification process in the process of observing product defects that arise. When the product is successful, the code number 0 is given and the defective product is given the code number 1. Then the probability of the defective product is calculated.
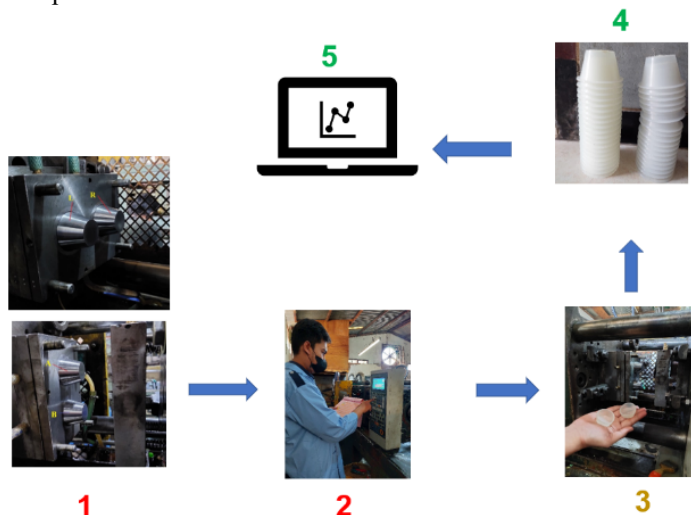

Fig. 4. Research flow.

The experiment was carried out 2 times, namely the installation of molds with vertical (up-down) and horizontal (right-left) orientations/positions. The next process is the adjustment or setting of the parameters used to adjust the variables that have been selected. Next, carry out the injection process according to the mapping of Table 1. After obtaining the injection molded product, then the process of visually identifying defects is carried out and for data processing using statistical software. To verify, it is also supported by injection molding software analysis to see the effect of setting variable.

3   Result and Discussion

From the observations made during the study, it was found that the number of defects that emerged from each cavity, both vertical (top-bottom) and horizontal (right-left) settings.

Table 2. Observation results for defective products with vertical cavity position orientation (up - down).

No	Product Defects	Cavity Position	Number of Defects
1	**Flashing**	AB	**22**
		A	**2**
		B	**109**
	Number of Flashing Defects		**133**
2	**Splay**	AB	**52**
		A	**7**
		B	**77**
	Number of Splay Defects		**136**
3	**Bubbles**	AB	**4**
		A	**2**
		B	**3**
	Number of Bubbles Defects		**9**
4	**Short Shot**	AB	**8**
		A	**1**
		B	**0**
	Number of Short Shot Defects		**9**
5	**Warpage**	AB	**5**
		A	**3**
		B	**5**
	Number of Warpage Defects		**13**
Total product defects that appear			**300**

Table 3. Observation results for defective products with horizontal cavity position orientation (left-right).

No	Product Defects	Cavity Position	Number of Defects
1	**Short Shot**	RL	**13**
		R	**10**
		L	**0**
	Number of Short Shot Defects		**33**

		RL	95
2	**Flashing**	RL	0
		L	0
	Number of Splay Defects		95
3	**Bubbles**	RL	41
		RL	2
		L	8
	Number of Bubbles Defects		51
Total product defects that appear			169

From the results of observations, the identification of the number of product defects that occurred the most was in the vertical cavity position (top-bottom (Experiment 1), the defect area resulted in the most product defects in the lower cavity. While the results of observing the horizontal cavity position (right-left) fewer defects.

3.1   Experimental Statistical Data Processing 1

Installation of the mold cavity in experiment 1 in a vertical position (up-down). The data collection process is carried out according to the specified cycle. After the product comes out of the mold, it is then given a special code using numbering.
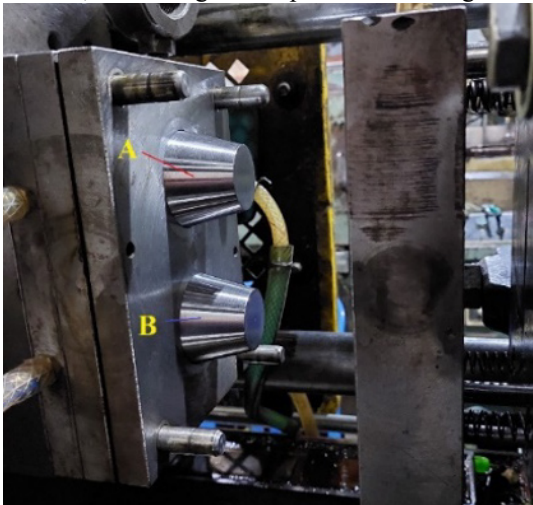
Fig. 5. Vertical cavity mounting (up-down).

he product defect identification process uses statistical software, so that the data analysis process can be maximized. The following are the results of data processing:

Table 4. Anova of experiment 1.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	26	40,867	1,57179	18,19	0,000

Linear	6	24,044	4,00741	46,37	0,000
Tempt.Inj	2	19,489	9,74444	112,76	0,000
Press.Inj	2	3,200	1,60000	18,51	0,000
Time.Inj	2	1,356	0,67778	7,84	0,001
2-Way Interactions	12	14,711	1,22593	14,19	0,000
Tempt.Inj*Press.Inj	4	12,044	3,01111	34,84	0,000
Tempt.Inj*Time.Inj	4	1,022	0,25556	2,96	0,021
Press.Inj*Time.Inj	4	1,644	0,41111	4,76	0,001
3-Way Interactions	8	2,111	0,26389	3,05	0,003
Tempt.Inj*Press.Inj*Time.Inj	8	2,111	0,26389	3,05	0,003
Error	243	21,000	0,08642		
Total	269	61,867			

Table 5. Model summary

S	R-sq	R-sq(adj)	R-sq(pred)
0,293972	66,06%	62,42%	58,09%

From the results of data processing using statistical software in Table 4, it was found that the P-value of each independent variable and its interactions showed the number < value (α) 0.05. So that H0 in this study is rejected, and H1 is accepted.

For the coefficient of determination R-sq from Table 5 is 66.06% so that the influence of each independent variable and its interaction affects product defects by that value. While the remaining 33.94% is influenced by variables out of control (error). For the value of the product defect standard deviation of 0.29.

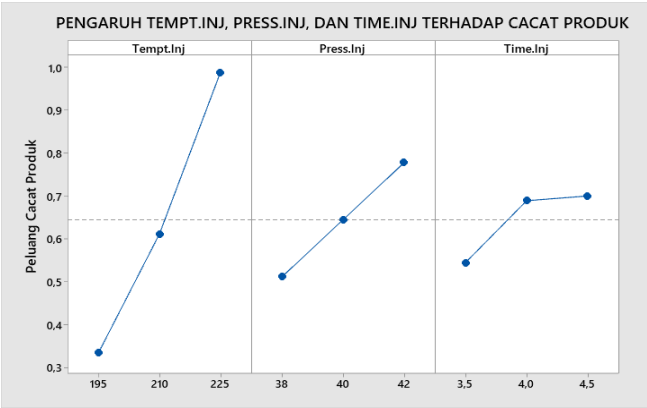The following is a factorial plot graph using statistical software:

Fig. 6. Plot graph in experiment-1.

Fig. 7. Flashing defect.

Based on the results of the experiment in experiment 1, the higher the injection temperature, the greater the chance for defects to appear. Some defects that appear when setting the highest injection temperature are flashing, bubbles, warpage, and splay. The emergence of flashing defects is caused by the low viscosity of the material due to the influence of the injection temperature used above the melting point of the specification of the material used, so that the plastic melt will easily pass through the mold gap, this statement is in accordance with research conducted [5].
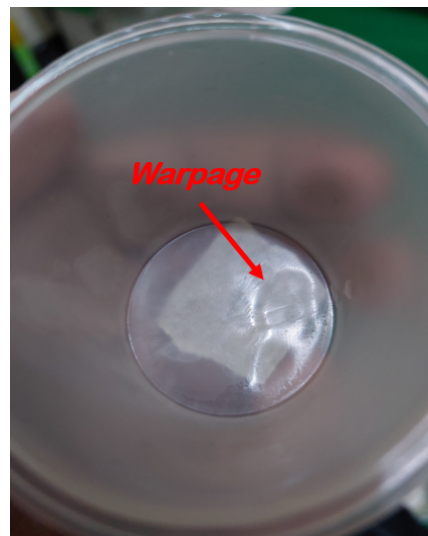
Fig. 8. Warpage defect.

Meanwhile, warpage defects also arise due to the high injection temperature setting. The effect that occurs results in an increase in the fluidity of the melt which causes the cavity to be filled easily and experience a buildup of material in the gate section [7].


Fig. 9. Splay defect.

Not only that, the influence of high injection temperature will cause display defects [4]. The effect that occurs when setting the injection temperature parameter is above the melting point of the material used, it will cause thermal degradation. As a result, the air contained in the material used is trapped so that it is trapped on the surface, resulting in the appearance of white lines (splay).

The effect of injection pressure can be seen in Fig. 6, that the greater the injection pressure, the greater the product defects that arise. The tendency of the defect to occur is flashing as shown in Fig. 8, it is caused when the applied injection pressure is large and the plastic material melts in high fluidity. From this influence it will push the melt easily, so that when the injection pressure setting is too large, the material will exceed the cavity. As a result, the material will overflow between the mold gaps and flashing defects will appear [6].

While the effect of setting the injection time is the longer the injection time, the greater the chance of product defects. This is because the longer the injection time is given, the greater the amount of material injected, so that the melted material overflows beyond the cavity volume, resulting in flashing defects [8].

3.2   Statistical Data Processing in Experiment-2
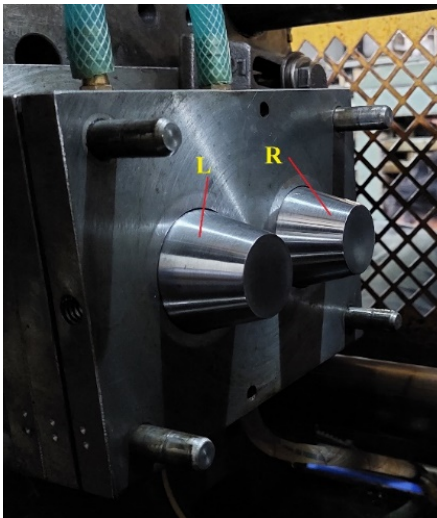
The installation of the mold in the 2nd experiment positioned the cavity horizontally (right–left). The goal is to see the difference in product quality produced by molds with different cavity positions. The following is data processing with statistical software :

Table 6. Anova of experiment-2

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	26	57,8667	2,2256	67,60	0,000
Linear	6	43,4222	7,2370	219,82	0,000
Tempt.Inj	2	33,8667	16,9333	514,35	0,000
Press.Inj	2	8,8667	4,4333	134,66	0,000
Time.Inj	2	0,6889	0,3444	10,46	0,000
2-Way Interactions	12	12,5556	1,0463	31,78	0,000
Tempt.Inj*Press.Inj	4	10,5333	2,6333	79,99	0,000
Tempt.Inj*Time.Inj	4	0,7778	0,1944	5,91	0,000
Press.Inj*Time.Inj	4	1,2444	0,3111	9,45	0,000
3-Way Interactions	8	1,8889	0,2361	7,17	0,000
Tempt.Inj*Press.Inj*Time.Inj	8	1,8889	0,2361	7,17	0,000
Error	243	8,0000	0,0329		
Total	269	65,8667			

Table 7. Model summary of experiment-2.

S	R-sq	R-sq(adj)	R-sq(pred)
0,181444	87,85%	86,55%	85,01%

From this, it can be seen that the P-Value of each independent variable and its interactions has a value of < (α) 0.05, so H1 is accepted and H0 is rejected. For the residual value/R-sq from Table 5 which has a large enough effect compared to experiment 1, which is 87.85% and the remaining 12.15% is an out of control variable. By looking at the value of the independent variables that affect the dependent variable is very significant. Not only that, the standard deviation value in experiment 2 (0.1814) is smaller than the standard deviation of experiment 1 (0.2939) so that the error factor that occurs can be reduced. The following is a graph of the factorial plot due to the influence of the independent variable on the dependent variable:
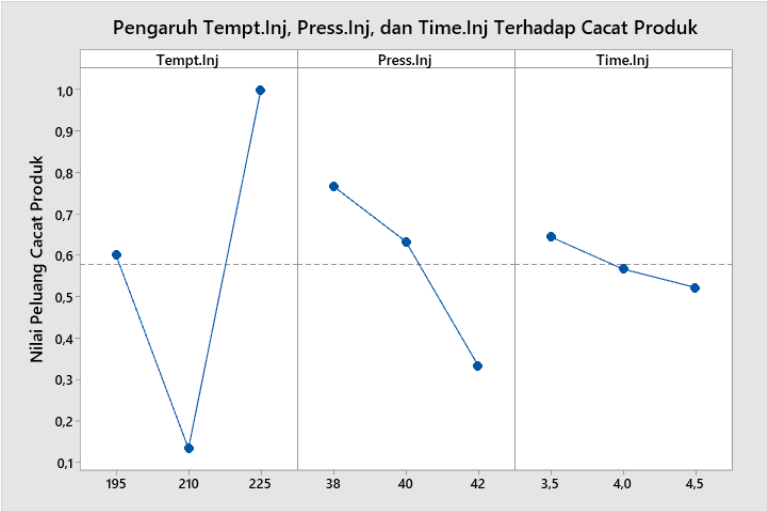
Fig. 10. Factorial plot graph in experiment-2.

Based on the results of the 2nd experimental study, the higher the injection temperature setting, the greater the chance of product defects. However, at 210 °C the probability of product defects is very low. This shows that at this temperature the material reaches the optimal temperature. The effect of the injection temperature being too low can cause the molten material to have a high viscosity so that the material does not completely fill the cavity (short shot) [4]. So that to reduce the occurrence of short shots, increasing the injection temperature will suppress these defects optimally, these results are in accordance with research conducted, where short shot defects are reduced by increasing the injection temperature setting [6].

Meanwhile, bubbles defects that appear at a temperature of 195°C, due to the temperature setting above the recommended melting point (165°C) it is certain that bubbles will appear, although only slightly. These results are in accordance with statement [9], where the size of the cell density increases and the air is trapped in the melted material. Not only that, bubble defects appear when the injection temperature parameter is above the recommended burst point for plastic materials [10]. Meanwhile, if the injection temperature is at a temperature of 225 °C, it will cause flashing defects because the molten material has a low viscosity so that it easily flows through the mold gap [5].

For setting the injection pressure, the greater the injection pressure given, the smaller the chance of defects. Injection pressure with a value of 38 Bar has a tendency to appear short shot product defects, this is due to the lack of injection pressure given so that the material is not able to fill the cavity completely [4][11]. This statement is in accordance with previous research that the higher the injection pressure, the smoother the flow of material to fill the cavity.

While the effect of the injection time is set, if the injection time given is 3.5 seconds, the indication that appears is a short shot defect. This is because the injected material has not completely filled the cavity. So that the longer the injection time is given, the greater the material injected [8]. In another study the indication of the longest injection time will provide a minimal and optimal product [12].

3.3   Best Recommendations

The proposal from the chosen experiment is the 2nd experiment, this is because the influence of the independent variable on the dependent variable is very high compared to the results of experiment 1. Not only that, the horizontal cavity position (right-left) is able to reduce warpage and splay defects that appear when the vertical cavity (top-bottom). In addition, the product produced by experiment 2 has better visuals with clear colors without being contaminated with display defects. So that the proposal given to the cavity position printing industry also has an impact on product quality, and it is hoped that it can be implemented so that product quality improvement can be achieved.

Allegations that arise are the influence of gravity during injection molding with a vertical cavity position (up-down). It is proven from the results of recording the data in Table 2 that the most defects appear in the lower cavity area. Not only that, the indications of the emergence of the most product defects during experiment 1 were also proven using injection molding analysis software as follows:
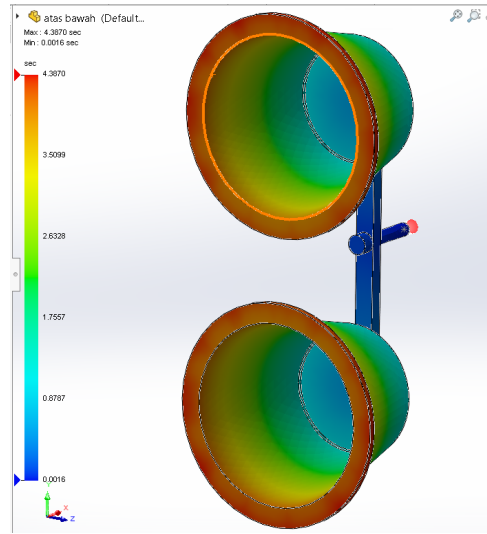
Fig. 11. Simulation on experiment-1.

Variable settings are also equated with appropriate conditions such as at the research location. From the results of Fig. 11 it can be seen that the filling time is 4.3870 seconds, so during that time the material has filled the entire cavity.
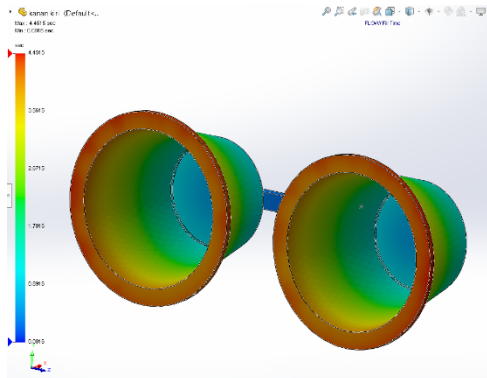

Fig. 12. Simulation on experiment-2.

The simulation results with the horizontal cavity position (right–left) show that the cavity filling time is 4.4515. From the two simulations, the filling time for the vertical cavity (up-down) is shorter with the horizontal cavity (right-left) for 4.3870 seconds, which is smaller than 4.4515 seconds. So when using the vertical cavity position (up-down) there is still more time left for the material to be injected. Therefore, supported by the influence of gravity and a longer time remaining, it indicates the number of defects that arise when using the vertical position (up-down). In another study, an indication of the position of the lower cavity occurred that there was a lot of material accumulation with an indication of warpage defects that appeared [13].

4   Conclusion

The results of the study can explain the characterization that in the 2nd experiment with a horizontal cavity position (right-left), it shows that the resulting product has a better product quality (minimum defects) than the 1st experiment with a vertical cavity position (top-bottom). The highest injection temperature setting (225 °C) has the largest defect probability with a value of 1. While the smallest defect opportunity occurs when the injection temperature is 210 °C with a product defect probability value of 0.15. When setting the highest injection pressure (38 Bar), the largest probability of product defects is 0.788. The smallest chance of defects occurs when the injection pressure is 42 Bar with a value of 0.37. For setting the injection time, the greatest chance of defects with a value of 0.677 occurs when the injection time is 3.5 seconds. While the greatest chance of defects occurs when the injection time is 4.5 seconds with a value of 0.544. For optimal parameter interaction with a flawless/successful product, it occurs when the injection temperature setting is 210 °C, injection pressure is 42 Bar, and injection time is 4.5 seconds.

Acknowledgment

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