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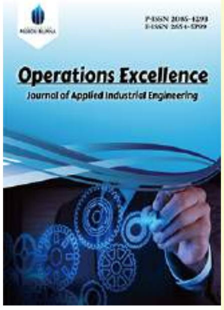

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Optimization of plastic injection molding process parameters for cowl B (L/R) sink mark defects by using Taguchi methods and ANOVA

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Abstract. *The plastic injection molding process on Cowl B (L/R) products that have been carried out has sink mark defects. The defects that arise occur because the composition of injection molding parameter values is not optimal in the variables of melt temperature, mold temperature, packing time, packing pressure, and cooling time. The purpose of this study is to find the optimal composition of parameter values for each variable, to minimize sink mark defects in the product. The analysis process begins with the preparation of an orthogonal array matrix to determine the design parameters to be simulated on Autodesk mold flow. These results are evaluated with a signal-to-noise ratio to determine the effect of each parameter value composition on the results of the analysis process. The Analysis of Variance (ANOVA) method is used to estimate the contribution of each independent variable to all response measurements (the dependent variable). The optimization results for sink mark defects in the sink mark index value of 1.4494%, volumetric shrinkage of 0.5053%, and sink mark estimate of 0.0608 mm are found in the composition of the parameter values of melt temperature 200°C, mold temperature 80°C, packing time 30 seconds, packing pressure 80 MPa and a cooling time of 13,365 seconds. This data is used as a reference in determining parameters before production is carried out on plastic injection molding machines so that the time and cost of testing the injection molding process are optimal.*

Keywords: ANOVA, injection parameters, sink mark, Taguchi

1. Introduction

Plastic injection molding is a method of forming plastic-based products that is carried out by injecting molten material into a mold (Wibowo et al., 2019). Plastic injection molding is commonly used in various modern industries because this method can produce large quantities of products in a short time and at economical operating costs (Lozano et al., 2022; Hadisaputra & Hasibuan, 2022). In addition, the resulting shape is more varied, the color is more attractive and the physical properties are increasing (Wibowo et al., 2021). Even so, an optimal process is needed to ensure the quality of the products produced is maintained (Wibowo et al., 2020; Zhao et al., 2022).

Products produced from the injection molding process are inseparable from defects caused by several factors, one of the causes of which is the process parameters (Moayyedian, 2019; Ogorodnyk & Martinsen, 2018). Parameters of the injection molding process generally include temperature, pressure, time, and speed (Ja'afar et al., 2020). If one of these parameters is ignored, there will be potential for non-optimal product print results, such as incomplete product shape, shrinkage non-uniformity, product dimensions not intolerance and plane cracks after ejection. (Kerkstra & Brammer, 2018; Valero, 2020).

Research on AC components to identify effect of print parameters injection plastic to disabled weld lines and sink marks using L27 orthogonal array normalized by Gray Relational Analysis (GRA) obtained parameters that are capable of optimization reduce wide weld line of 56.4% and depth sinkmark of 68.9 (Sreedharan & Jeevanantham, 2018). The sinkmark defect on the GeNose 19 T-Valve product was 1.10%, decreased by 0.06% by optimizing the parameters of holding time, melt temperature and mold temperature (Setya Hutama & Nicolas Axel Reyhan, 2022). In addition, the Taguchi method was used to identify the influencing parameters and the response surface methodology was used to describe the sinkmark effect on the surface from 0.0088 down to 0.0080 (Anwarullah & Kumar, 2019). The simulation process with mold flow analysis is used to predict possible defects that may occur in automotive components, so that product quality can be optimal (Bhatagalikar & Adewar, 2020). In this study, the Taguchi orthogonal array method was used to identify influential parameters with the addition of ANOVA which was used for weighting the parameters from the most influential to those that had less effect on the causes of product defects, thus making a difference to previous studies.

The Cowl B (L/R) product is a component that functions to protect the fuel tanks located on the left (L) and right (R) sides of the motorcycle tank. However, this product has sink mark defects after being simulated using Autodesk Moldflow software (Munankar et al., 2019). The injection molding simulation, which was carried out 27 times, showed that 89% of the sink mark values were unacceptable, with a sink mark value of more than 0.03 mm. If the desired surface is glossy, then sink marks with a value greater than 0.03 will appear. However, on non-glossy products, a sink mark with a value of more than 0.05 mm will be visible directly to the eye (Inui et al., 2018). Sinkmark with a value of less than 0.05 mm can be controlled by optimizing the processing parameters, namely by increasing the pressure and holding time (Zhao et al., 2022). In other experiments, this defect was anticipated with the right combination of parameters including melt temperature, injection pressure and holding time (Budiyantoro, 2016). Mold temperature, packing pressure and holding time combined with injection molding process parameters can minimize sinkmark defects in automotive components (Kumar, 2019). Non-uniform shrinkage in food packaging products causes sink marks to be minimized by adjusting the melt temperature and mold temperature (Ja'afar et al., 2020). The purpose of this study is to obtain the optimal composition of injection molding process parameters for Cowl B (L/R) products so as to produce optimal product quality.

2. Method

The research begins with the collection of supporting data such as product data, materials, and machines. Determination of test parameters is used to ensure that the parameters used have a significant effect on the results. Next, an orthogonal array matrix is arranged from the parameter data. The analysis process was carried out to obtain the results of each parameter combination using Computer Aided Engineering (CAE), namely product modeling which was analyzed with Autodesk Moldflow (Munankar et al., 2019) and ended with an analysis of process parameter optimization using the Analysis of Variance (ANOVA) method (Oliaei et al., 2016).

Product

Cowl B (L/R) has specifications of length = mm, width = 472 mm and height = 170 mm, with an average wall thickness of 2.3 mm and a mass of 384 gr. Figure 1 shows cross-section Cowl B (L/R) products. Cowl B (Left & Right) can be seen in Figure 1

Figure 1 Cowl B (Left & Right).
Source: (PT. Astra Honda Motor, 2019)

Materials

The plastic material used in this product is Acrylonitrile Butadiene Styrene (ABS) with the trademark Nippon A&L GA-501 ABS. Table 1 shows the specifications for this material.

Table 1 Plastic Material Data Nippon A&L GA-501 ABS

Data	Mark	Unit
Melt Density	0.93	g/cm ^{3}
Solid Density	1.04	g/cm ^{3}
Mold Shrinkage	0.4 – 0.6	%
Melt Flow Rate	32	cm3 $^{/}$ 10m
Yield Strength	42	MPa
Melt Temperature	200–260	°C
Mold Temperature	40 – 80	°C
Ejection Temperature	101	°C

Machine

The machine used is adapted to the actual conditions in the field in the plastic injection molding process for the product using a hydraulic type with the following specifications can be seen Table 2

Table 2 Toshiba EC1300SX i78 Specifications

Specification	Mark	Unit
Screw Dia	120	mm
Shot Weight	5200	g
Injection Pressure	138	MPa
Injection Speed	150	mm/s
Plasticizing Capacity	580	kg/h
Clamping Force	1300	tf
Distance Tie Rods	1400 x 1400	mm
Clamp Strokes	1500	mm
Open Daylight	2800	mm
Machine Dimension	12.8 x 3.2 x 3.2	m

Stages of Research

The stages of research begin with the preparation of the L27 orthogonal array matrix to determine the composition of the test parameters. The Taguchi method is used to find factors that affect the quality of a product by setting combination parameters based on orthogonal arrays so that pattern testing is carried out efficiently. After that, these parameters are simulated with Moldflow to find out the results. Based on these results, the ANOVA method is used to determine the optimal parameter conditions to obtain the minimum sink mark value. Based on some previous research literature, there are parameters that influence sink mark defects. These parameters are grouped according to the independent variables used, namely: melt temperature (A), mold temperature (B), packing pressure (C), packing time (D) and cooling time (E) (Budiyantoro, 2016; Li et al., 2016; Sun et al., 2019; Hartono et al., 2020; Lin et al., 2022;). The research variable scheme consists of fixed variables, independent variables and dependent variables written in Table 3 as follows.

Table 3 Variable Study

Fixed Variables	Independent Variable	Dependent Variable
Injection pressure	Melt temperature (A)	Sink mark index (X)
Screw Diameter	Mold temperature (B)	
Engine injection speed	Packing pressure (C)	Volumetric Shrinkage (Y)
Machine grip style	Packing time (D)	
Injection temperature	Cooling time (E)	Sink marks Estimate (Z)

Determining the value of the independent variable consists of 5 parameters, each of which has 3 levels on each parameter, while the determination of these levels is obtained from the specifications of the plastic material used. The purpose of this leveling is to make it easier to determine the optimal parameters of a series of processes in the Anova method. Table 4 shows the values of each level and the units of these parameters.

Table 4 Independent Variable Levels

Test Parameters	Levels			Unit
	1	2	3	
Melt temperature (A)	200	230	260	°C
Mold temperature (B)	40	60	80	°C
Packing pressure (C)	60	70	80	MPa
Packing time (D)	10	20	30	s
Cooling time (E)	5.104	8,274	13,365	s

3. Results and Discussion

Taguchi method

The Taguchi method was applied in this research to find the optimal parameters in order to get the minimum sink mark value. The sink mark values are presented in Table 5 and the S/N ratio responses in Tables 6, Table 7 and Table 8. The S/N ratio is a simple quality indicator that can be used to evaluate the effect of a combination of parameters on the results of the analysis process (Budiyantoro, 2016; Kumar, 2019; Ja'afar et al., 2020). In this study, " smaller is better " is used to calculate the S/N ratio, where S/N with the highest value indicates an optimal parameter, while S/N with the lowest value indicates a parameter that is not optimal (Oliaei et al., 2016; Solanki et al., 2021). Table 5 shows the results of test number 9th with the lowest Sink mark, index (X), Volumetric Shrinkage (Y) and Sink marks Estimate (Z) values among the other tests. So that, it produces the highest S/N ratio value among the others. The 9th test consisted of composition A1 with a value of 200 °C, B3 with a value of 80 °C, C3 with a value of 80 MPa, D3 with a value of 30 seconds and E3 with a value of 13.365 seconds. Table 5 only shows the best parameters for the overall response. The data has not shown the effect of each parameter on each response. The effect of each parameter on the response is presented in detail in Table 6, Table 7 and Table 8.

Table 5 Sinkmark Value and S/N Ratio

Run	Independent variables					x(mm)	Y(mm)	Z(mm)	S/N X	S/N Y	S/N Z
	A (°C)	B (°C)	C(MPa)	D(s)	E(s)						
1	200	40	60	10	5.104	2.5269	0.8917	0.0907	-8.0518	0.9956	20.8479
2	200	40	60	10	8,274	2.5269	0.8903	0.0907	-8.0518	1.0093	20.8479
3	200	40	60	10	13,365	2.5269	0.8888	0.0907	-8.0518	1.0239	20.8479
4	200	60	70	20	5.104	2.0290	0.6320	0.0769	-6.1456	3.9857	22.2815
5	200	60	70	20	8,274	2.0290	0.6315	0.0769	-6.1456	3.9925	22.2815
6	200	60	70	20	13,365	2.0290	0.6311	0.0769	-6.1456	3,9980	22.2815
7	200	80	80	30	5.104	1.4494	0.5054	0.0608	-3.2238	5.9273	24.3219
8	200	80	80	30	8,274	1.4494	0.5054	0.0608	-3.2238	5.9273	24.3219
9	200	80	80	30	13,365	1.4494	0.5053	0.0608	-3.2238	5.9290	24.3219
10	230	40	70	30	5.104	2.6858	0.6243	0.0904	-8.5815	4.0921	20.8766
11	230	40	70	30	8,274	2.6858	0.6242	0.0904	-8.5815	4.0935	20.8766
12	230	40	70	30	13,365	2.6858	0.6240	0.0904	-8.5815	4.0963	20.8766
13	230	60	80	10	5.104	2.6541	1.0410	0.0950	-8.4783	-0.349	20.4455
14	230	60	80	10	8,274	2.6541	1.0388	0.0950	-8.4783	-0.330	20.4455
15	230	60	80	10	13,365	2.6541	1.0366	0.0950	-8.4783	-0.312	20.4455
16	230	80	60	20	5.104	2.2475	1.1044	0.0860	-7.0340	-0.862	21.3100

Run	Independent variables					x(mm)	Y(mm)	Z(mm)	S/N X	S/N Y	S/N Z
	A (°C)	B (°C)	C(MPa)	D(s)	E(s)						
17	230	80	60	20	8,274	2.2475	1.1041	0.0860	-7.0340	-0.860	21.3100
18	230	80	60	20	13,365	2.2475	1.1038	0.0860	-7.0340	-0.857	21.3100
19	260	40	80	20	5.104	3.6677	1.0789	0.1254	-11,287	-0.659	18.0340
20	260	40	80	20	8,274	3.6677	1.0784	0.1254	-11,287	-0.655	18.0340
21	260	40	80	20	13,365	3.6677	1.0779	0.1254	-11,287	-0.651	18.0340
22	260	60	60	30	5.104	3.5823	1.3618	0.1269	-11,083	-2,682	17.9308
23	260	60	60	30	8,274	3.5823	1.3617	0.1269	-11,083	-2,681	17.9308
24	260	60	60	30	13,365	3.5823	1.3615	0.1269	-11,083	-2,680	17.9308
25	260	80	70	10	5.104	3.5160	1.8779	0.1274	-10,921	-5,473	17.8966
26	260	80	70	10	8,274	3.5160	1.8750	0.1274	-10,921	-5,460	17.8966
27	260	80	70	10	13,365	3.5160	1.8723	0.1274	-10,921	-5,447	17.8966

Tables 6, Table 7 and Table 8 show the influence of each parameter against the response sink mark index, volumetric shrinkage and sink mark estimate. These results consistently show that the greatest value is found at the melt temperature while the smallest value is found at the time of cooling.

Table 6 S/N Ratio Response to Sinkmark Index

Levels	Melt temperature (°C)	Mold temperature (°C)	Packing pressure (MPa)	Packing time (s)	Cooling time (s)
			Sink mark, index		
Level 1	-5.8071	-9.3070	-8.7230	-9.1504	-8.3119
Level 2	-8.0313	-8.5691	-8.5494	-8.1558	-8.3119
Level 3	-11.0974	-7.0596	-7.6633	-7.6295	-8.3119
Difference	5.2903	2.2474	1.0597	1.5209	0

Table 7 S/N Ratio Response to Volumetric Shrinkage

Levels	Melt temperature (°C)	Mold temperature (°C)	Packing pressure (Mpa)	Packing time (s)	Cooling time (s)
			Volumetric Shrinkage		
Level 1	3.6432	1.4827	-0.8440	-1.5938	0.5526
Level 2	0.9677	0.3267	0.8752	0.8254	0.5594
Level 3	-2.9324	-0.1309	1.6472	2.4468	0.5664
Difference	6.5765	1.6135	2.4912	4.0406	0.0138

Table 8 S/N Ratio Response to Sink Mark Estimate

Levels	Melt temperature (°C)	Mold temperature (°C)	packing pressure (MPa)	Packing time (s)	Cooling time (s)
			Sink mark Estimate		
Level 1	22.4838	19.9195	20.0296	19.7300	20.4383
Level 2	20.8774	20.2193	20.3516	20.5419	20.4383
Level 3	17.9538	21.1762	20.9338	21.0431	20.4383
Difference	4.5300	1.2567	0.9042	1.3131	0

Analysis of Variance (ANOVA)

ANOVA is used to estimate the contribution of each independent variable to all response measurements or the dependent variable (Ja'afar et al., 2020; Wibowo et al., 2020). ANOVA used in parameter design is useful to help identify the contribution of independent variables so that the accuracy of estimates can be determined (Ja'afar et al., 2020). Table 9 presents the percentage contribution of each parameter to the sink mark index, volumetric shrinkage and sink mark estimate. Based on these results, the most dominant parameter for sinkmark defects is melt temperature.

Table 9 Percentage of Each Parameter to the Dependent Variable

Parameter	Sink mark, index %	Volumetric Shrinkage %	Sink mark estimate %
Melt temperature (A)	84,61	62,78	89,20
Mold temperature (B)	10,24	9,16	4,18
Packing pressure (C)	1.37	6.50	1.87
Packing time (D)	3.78	21.56	4.75
Cooling time (E)	0	0	0

Based on the results of the analysis, the sink mark estimate is dominated by the influence of melting pressure. Melt temperature has a big effect because it gets a percentage distribution of 89.20%, followed by packing time of 4.75%, mold temperature, and packing pressure (Budiyantoro, 2016; Li et al., 2016).

4. Conclusions and Suggestion

Plastic injection molding parameters for Cowl B R/L products optimal with sink mark index 1.4494%, volumetric shrinkage 0.5053% and sink mark estimate 0.0608mm, namely in the composition melt temperature 200°C, mold temperature 80°C, packing pressure 80 MPa, packing time 30 seconds, and cooling time 13.365 seconds. The most dominant parameter influencing sink mark defects is the melt temperature. This research method is important to do at the beginning of designing a plastic product to predict potential defects. In addition, it is also used to anticipate potential defects by setting optimal composition parameters for plastic injection molding. This research can also be the basis for the development of further analysis on more complex plastic product defects with more complete parameter and condition data considerations to adapt to actual conditions during testing on injection molding machines.

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