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Quality by design of optimum parameter to minimize the weight of plastic products

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Abstract. The research aims to control product quality off-line (quality by design) in producing lightweight plastic products for food packaging. The lightweight product is very profitable for the producers due to the efficient production costs. Quality by design was done by designing controlled parameters in the plastic molding process which includes clamping force, holding time, injection pressure, injection speed and injection temperature and their interactions. The plastic material that is made observable is Polypropylene (PP). The response parameter in this study is the weight of the product. The parameter design method used was Factorial Experiment Design with 5 independent variables with different levels of variation. The results showed that the combination of injection temperature and holding time had a significant effect on product weight. To produce heavier products that are in the area above the holding time of 0.4 seconds at any injection temperature. Meanwhile, to produce a lightweight product (under 43 grams) is at a combination of injection temperature below 263 C and holding time of about 0.3 seconds. The standard weight of the product on the plain bucket food packaging for this yogurt container is 42.5 gram.

1. Introduction

Nowadays, objects made of plastic are increasingly being encountered, starting from household appliances, food wrappers, electronic equipment and others. Without realizing it, this plastic object has replaced products made of other materials such as wood, metal, bamboo, glass and so on. In general, the properties of plastics are less stiff and strong when compared to metals, however, the ratio of strength to weight and stiffness to weight ratio is better than metal [1].

According to the industry ministry, the consumption of plastic products is still quite high in various manufacturing sectors, such as the food and beverage product packaging industry, the cosmetics industry, the electronics industry and the automotive industry. Throughout 2018, the plastic industry grew by 6.92%, an increase from 2017's growth of 2.47%. The number of plastic industries currently reaches 925 companies with the ability to produce various kinds of plastic products. The total production of this sector in 2018 reached 7.23 million tons. Meanwhile, the demand for plastic products has increased by an average of 5% in the last five years [2]. One example of a demand for plastic products is for packaging food containers. But on the market there are many unhygienic food container products because they are made of non-food grade plastic material.

In an effort to maintain and improve the quality of plastic products, companies face the problem of selecting and determining the physical attributes of the products that affect quality, which are better known as quality characteristics. Recently, quality control methods have shifted to quality by design methods [3]. Initially, the quality control method was carried out by quality control which was carried



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out after the product was finished. Then the method is improved by conducting an inspection while the production process is in progress. In this quality control method, it is known as online quality control because it is carried out simultaneously both during the actual production process and shortly after being produced, many losses are borne by the company, including losses in scrap costs, products and materials dispose and loss of processing time. Until finally the quality control method was refined again into a quality by design method, which is an off-line quality control and implemented when the product has not been made and has not entered the actual production process, because it is still a prototype. However, there are many advantages, including the efficiency of raw material costs, the existence of a mature production process planning and anticipating all possibilities that can improve product quality [4].

Plastics are generally classified into 3 (three) types, namely: thermoplastics, thermo-setting and elastomers. Thermoplastics (thermo-plastics) are a type of plastic that will soften when heated and harden when cooled. Examples of thermoplastic materials include: polyethylene, polypropylene, and PVC (polyvinyl chloride). Thermosetting plastic will harden when heated and cannot be recycled (recycled). Examples of thermo-setting plastics are: bakelit, silicon, epoxy and others, while elastic (elastomer) is a very elastic material. an example of an elastic material is synthetic rubber [5].

Injection molding is the process of forming an object or product from a plastic material with a certain shape and size that requires a mold or mold. In principle, plastic molding is a tool used to make components from plastic materials by means of a plastic molding machine. The product forming process begins with inserting plastic material in the form of granules into the machine hopper. Then the material will enter the barrel where the barrel is hot then pushed by a screw mechanism through the engine nozzle and the sprue bushing enters the mold cavity which is already closed. After a few moments of cooling, the mold will be opened and the product will be ejected by an ejector mechanism. In the injection molding process, there are several parameters that affect the quality of injection molding products and can affect the optimal amount of production, including injection temperature, injection pressure, injection time, holding time, cooling time, injection speed, and clamping force [6].

2. Methods

In this research, there are 5 (five) parameters observed in this experiment, namely injection temperature (temperature zone-1 (C)), injection pressure (bar), injection speed (% of cm/sec), holding time (sec) and clamping force (KgF). While the response variable is product weight (grams). The aims of the experiment are make a product made from Polypropylene that is as light as possible. The product made is a plain bucket, which is a yogurt container made of plastic cans, with an outer diameter of 115 mm and an inner diameter of 112 mm and a white bottom with a diameter of 93 and 135 mm. In this experiment, the weight of the product is designed to be as light as possible in order to increase efficiency in product delivery to consumers. For this purpose, this experiment will observe the effect of each parameter of the plastic molding process which contributes to the weight of the product. In this experiment, using a factorial experimental design with 5 factors and each with 3 factor levels and 3 replications each so that the number of experimental runs was 729 runs. The production process and experiments are carried out at the Production Workshop of the Department of Mechanical Engineering, State Polytechnic of Malang, which also serves orders from outside the campus. The machine used is still Maya Jieli MJM-JLB198-HQ Plastic Injection Molding Machine and the standard of the specified product weight is 42.5 ± 0.5 cm as in Figure 1.



Figure 1. The product and production process for plain buckets.

3. Results and discussion

Table 1. Anova and model summary.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	349,15	43,644	770,08	0,000
Linear	4	275,70	68,924	1216,13	0,000
TEMP.ZONA 1(C)	2	29,06	14,529	256,35	0,000
HOLD.TIME(S)	2	246,64	123,320	2175,91	0,000
2-Way Interactions	4	73,46	18,364	324,02	0,000
TEMP.ZONA 1(C)*HOLD.TIME(S)	4	73,46	18,364	324,02	0,000
Error	720	40,81	0,057		
Lack-of-Fit	234	10,01	0,043	0,68	1,000
Pure Error	486	30,79	0,063		
Total	728	389,96			

Model summary			
S	R-sq	R-sq(adj)	R-sq(pred)
0,238066	89,54%	89,42%	89,27%

From Tables 1 and 2, it turns out that of the 5 independent variable parameters observed, there are only 2 independent variables that have a significant effect on product weight. The two variables are injection temperature (Zone-1) and holding time (Holding time). Likewise, the interaction or combination of injection temperature and holding time also has a significant effect on product weight. It can be seen from the P-value whose value is $< \alpha$ of 0.05. From the summary model (Model Summary), it is found that the coefficient of determination is 89.54%. This value shows that the model of the influence of the variable injection temperature, injection pressure, injection speed, holding time and clamping force has an effect on the variation of product weight by 89.54%. While the remaining 10.46% is influenced by other factors that have not been observed and experimental errors.

Table 2 below shows the regression equation coefficients generated from the RSM Box Behnken method. To display the coefficient of this regression equation using the Stepwise method so that only those shown in the table have a significant effect (P-value < 0.05). The choice of the Stepwise method is to be efficient in displaying tables.

Table 2. The regression equation model influence of independent variables (injection temperature, injection pressure, injection speed, holding time and clamping force) on product weight variables.

$$\begin{aligned} \text{Weight (g)} = & 43,6556 - 0,1770 \text{ TEMP.ZONA 1(C)}_{260} - 0,1021 \text{ TEMP.ZONA 1(C)}_{265} \\ & + 0,2790 \text{ TEMP.ZONA 1(C)}_{270} - 0,7597 \text{ HOLD.TIME(S)}_{0,3} + 0,1066 \text{ HOLD.TIME(S)}_{0,4} \\ & + 0,6531 \text{ HOLD.TIME(S)}_{0,5} - 0,5239 \text{ TEMP.ZONA 1(C)*HOLD.TIME(S)}_{260 \ 0,3} \\ & + 0,2444 \text{ TEMP.ZONA 1(C)*HOLD.TIME(S)}_{260 \ 0,4} + 0,2794 \text{ TEMP.ZONA 1(C)*HOLD.TIME(S)}_{260 \ 0,5} \\ & - 0,0481 \text{ TEMP.ZONA 1(C)*HOLD.TIME(S)}_{265 \ 0,3} + 0,0313 \text{ TEMP.ZONA 1(C)*HOLD.TIME(S)}_{265 \ 0,4} \\ & + 0,0169 \text{ TEMP.ZONA 1(C)*HOLD.TIME(S)}_{265 \ 0,5} + 0,5720 \text{ TEMP.ZONA 1(C)*HOLD.TIME(S)}_{270 \ 0,3} \\ & - 0,2757 \text{ TEMP.ZONA 1(C)*HOLD.TIME(S)}_{270 \ 0,4} - 0,2963 \text{ TEMP.ZONA 1(C)*HOLD.TIME(S)}_{270 \ 0,5} \end{aligned}$$

The above equation is used to make a prediction or weight estimation model of the product using the parameters of the equation above. To make predictions, the following parameters are converted:

Factor level: Injection Temperature 260,265 and 270 are replaced by level -1, 0 and 1

Holding time 0,3, 0,4, and 0,5 are replaced by level -1, 0 and 1

So that if the regression equation above is replaced with the following numbers:

$$\begin{aligned} \text{Weight} = & 43,6556 - 0,1770*(-1) - 0,1021*(0) + 0,2790 * (1) - 0,7597*(-1) \\ & + 0,1066*(0) + 0,6531*(1) - 0,5239*(-1) * (-1) + 0,2444*(-1)*(0) \\ & + 0,2794*(-1)*(1) - 0,0481*(0)*(-1) + 0,0313*(0)*(0) \\ & + 0,0169*(0)*(1) + 0,5720*(1)*(-1) - 0,2757*(1)*(0) \\ & - 0,2963*(1)*(1) \end{aligned}$$

Weight = 43,8528 gram

It appears that the prediction results are still close to the expected weight.

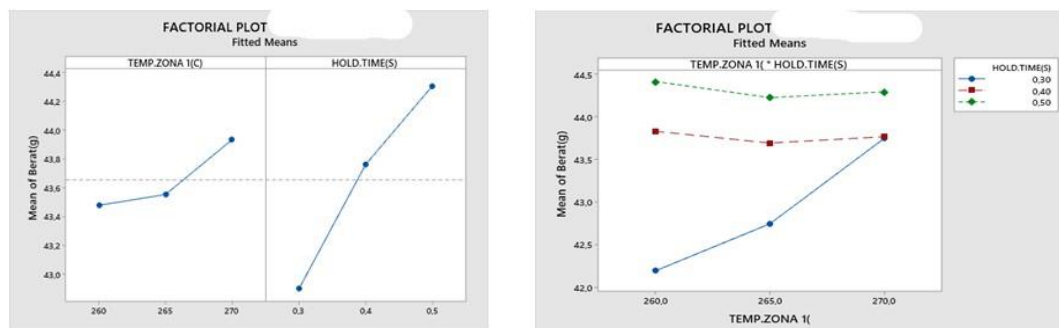


Figure 2. Main effect plot and interaction plot of injection temperature and holding time against product weight.

In accordance with Table 2, the graph in Figure 2 reinforces the significant effect of injection temperature and holding time on product weight. In this experiment, the increase in injection temperature and holding time can increase the weight of the product

In the graph above, it also can be seen that the combination of injection temperature and holding time has a significant effect on product weight, especially the combination of level 1 (temperature 270) injection temperature and level -1 holding time 03 which gives an increase in product weight. This is also in accordance with the magnitude of the regression coefficient above with a contribution of 0.5720 which is the largest contribution than the other coefficients. In the graph above, it can also be shown that the holding time level 0 and level 1 (0.4 and 0.5) has a greater effect on product weight. However, the combination with the increase in injection temperature is not very significant.

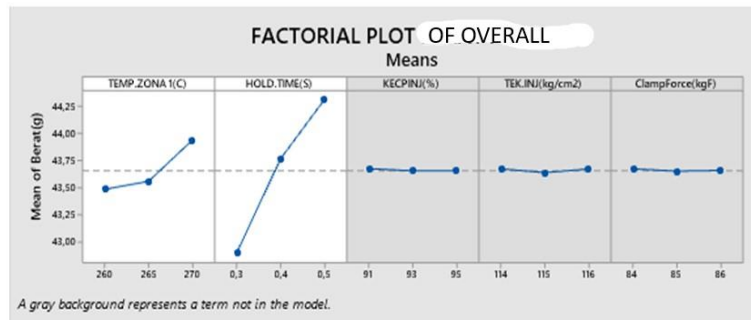


Figure 3. Effect of other factors on product weight.

In the graph above, it can be seen that for the factors of velocity, injection pressure and clamping force the three of them do not have a significant effect on product weight.

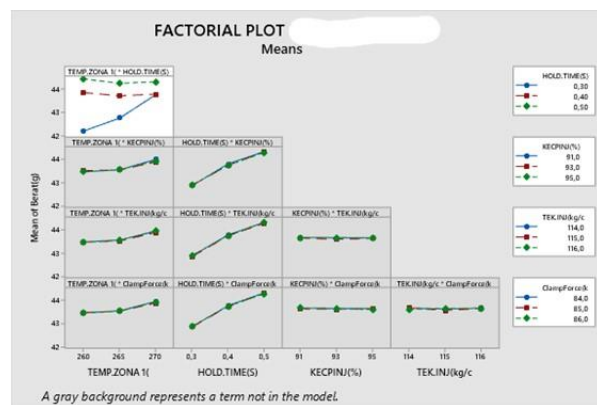


Figure 4. Effect of various interactions of independent variables on product weight.

From the graph above, it can be seen that the interaction of various factors that shows a significant effect is only those related to the holding time and injection temperature. For a combination involving injection temperature and holding time, it always results in an increase in product weight, from insignificant to significant increases.

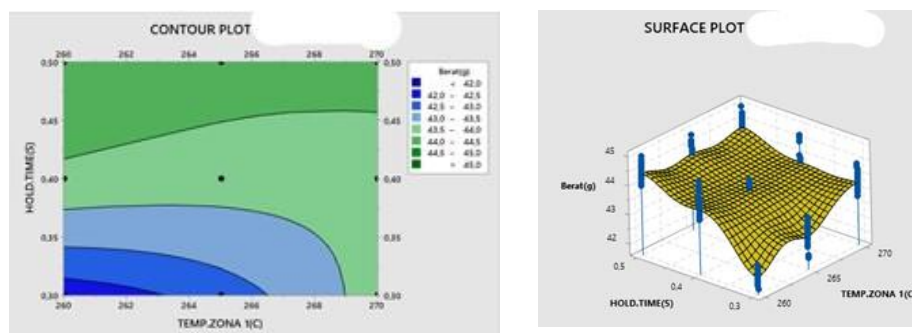


Figure 5. Contour plot and surface plot for the effect of injection and holding temperature time to product weight.

Figure 5 shows a contour plot for the combination of injection temperature and holding time for product weight. To produce a heavier product be in the area above the holding time of 0.4 seconds at any

injection temperature. Meanwhile, to produce a light product (under 42 grams), it is at a combination of injection temperature below 263 °C and holding time of about 0.3 seconds.

In Figure above, we also can see the surface plot for the combination of injection temperature and holding time for product weight. To produce a heavier product be in the area above the holding time of 0.4 seconds at any injection temperature. Meanwhile, to produce a light product (under 42 grams), it is at a combination of injection temperature below 263 °C and holding time of about 0.3 seconds.

The results of this study are consistent with what has been done by Oktem et al [7] who have examined the plastic molding process for producing thin products. From the results of this research, it turns out that the holding time factor is also a determining factor in producing a thin product. Also the injection pressure factor contributes to the production of quality product characteristics for these thin dimensions. The difference with this study is in the aspect of injection temperature. In this research, the target is to produce a lightweight product so that the parameters that determine are the holding time and injection temperature parameters.

The results of this study are relevant to the research conducted by Fitriyanto et al [8] with the title "Analysis of PS 135 Rearview Products with Injection Time Parameters for Polypropylene Plastic Material (PP) in the Injection Molding Process". In this study, using the black PP material type Globalene 7533 with injection time independent variables and various variations. And the dependent variable is a mold temperature of 50 °C, a melt temperature of 230 °C, a maximum machine injection pressure of 85 MPa, a machine clamp open time of 7 s. With the dependent variable shot volume, total part weight, confidence of fill, and quality prediction. The results of this study indicate that the increase in injection time variation causes an increase in the total part weight. The increase in total part weight is due to the long injection time duration so that the plastic molecules injected into the mold become solid so that the product weight increases [8].

In another similar research conducted by Hassan [9] with the title "An Experimental Work on The Effect of Injection Molding Parameters on The Cavity Pressure and Product Weight". This study used 2 types of materials, namely LDPE and PS. And there are 4 independent variables in this study, namely, cooling time, injection pressure, packing pressure, and injection temperature. With 2 dependent variables, namely cavity pressure and product weight. The results of this study indicate that injection pressure and injection temperature have a significant effect on product weight compared to the other two independent variables [9].

Research on plastics regarding product weight is closely related to product defects because improper composition of independent variables can cause product defects. At low temperatures there will be a short shoot defect and too high a temperature there will be a flash defect. This is evidenced by previous research, namely [10]. On the independent variable holding time has a significant effect. Significant results are obtained because the longer the time to inject the plain bucket packaging product will increase the product weight and reduce shrinkage product defects because the product is stronger and denser. So, defects in packaged products can be minimized. This is evidenced by Wahyudi [11]. So it can be explained that the higher the injection temperature, the decrease in the weight of the plain bucket product and the increasing the holding time, the product weight increases.

In addition, the longer the holding time, the denser the plastic molecules that are injected into the cavity, this happens because the air trapped in the cavity is small due to the large injection pressure during the product manufacturing process. And if the holding time is shorter, the density of plastic molecules injected into the cavity will also decrease. This happens because there is air trapped in the cavity which is caused by too short a holding time so that there is still air trapped causing product defects.

4. Conclusion

To be able to minimize the product weight (bucket plain) which is also a quality product criterion, the significant parameter settings are holding time and injection temperature. The longer the holding time, the heavier the product. Likewise, the injection temperature. For food packaging products (bucket plain), the holding time is set at 0.3 seconds and the injection temperature is at 260-262.5 °C.

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