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# Optimization of Injection Molding Temperature and Pressure on the Quality of Polypropylene Cutting Board

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*ABSTRACT*

This study delves into the optimization of polypropylene cutting board production through injection molding. Polypropylene, derived from propylene monomers, serves as the primary material. The injection molding process often leads to flash defects due to inadequate temperature and pressure settings. The research aims to discern the individual and interactive effects of temperature and injection pressure on the weight and surface area of the cutting boards. Experimental variations encompass temperature levels of 165°C to 175°C and injection pressures ranging from 25 Psi to 35 Psi. Data collection employs experimental methods, and analysis utilizes factorial and RSM approaches. Findings reveal that the lightest cutting boards result from the lowest temperature (165°C) and injection pressure (25 Psi), with an average weight of 105.6009 grams and a surface area of 21,158.3333 mm². In conclusion, both temperature and injection pressure significantly influence the weight and surface area of polypropylene cutting boards, providing valuable insights for enhanced manufacturing processes.

**Keywords:** Polypropylene, Injection Molding, Cutting Board

## 1. INTRODUCTION

Automation is becoming more and more important in today's manufacturing sector. The research problem addressed is how to monitor mould and part quality in-process during injection moulding (IM). With the development of computing hardware and software, especially in the fields of image processing technologies, computer vision techniques for automatic tracking of tool condition started to be largely adopted in manufacturing [1], [2]. Soft tooling is a cost-effective method of tooling for injection moulding [3], [4]. [5] Instead of using the conventional metal tools, moulds produced by polymer additive manufacturing, especially vat photopolymerization, are used in injection moulding. Many injection-molded components are intended for appearance and exterior products. For example, automotive exterior and interior components, housings of home appliances, and mobile devices are injectionmolded plastic parts. Due to the demands of high surface quality and efficient polymer processing, more net-shape products are being produced without further surface finishing such as painting or coating. Various factors relating to the material property, mold design, and process setting affect the surface quality of injection-molded products. During the injection molding process, polymer melts undergo various rheological deformations and thermal histories due to high pressure and rapid temperature changes. Inhomogeneous morphology resulting from additives such as reinforcing fibers, mineral additives, and foaming agents also influence quality and anisotropy within a single part. Shrinkage and warpage due to the heat transfer and flow field in the molds, as well as the pvT (pressure, specific volume, temperature) property of the material are known to contribute to dimensional stability and surface quality[6], [7]. In addition, stress distribution and filling patterns due to the fountain flow and viscoelastic characteristics of polymer materials influence surface defects and optical quality [6], [8]

The process of injection molding mainly includes three stages: three processes of filling, filling and holding. During the plasticizing stage of the injection process, the screw conveys the plasticized material forward at a certain speed. As the screw groove of the screw becomes shallower, the material is compacted and continuously conveyed forward. The head is continuously accumulating, waiting for the arrival of the injection instruction, and at the same time, the screw will continuously retreat as the back pressure of the injection machine increases during the injection process. When the injection is started, the screw moves forward, and the material continuously fills the mold. At the same time, as the pressure in the mold increases, the screw moves while injecting. When the material is filled in the mold, the injection machine injects the material into the mold by the action of back pressure. With the temperature of the material continues to decrease, the pressure in the mold cavity begins to decrease. When the injected material can be safely molded without being damaged, the injection mold is opened, and the product is ejected through the mold structure [9], [10].

As one of the most important components, the injection system is mainly composed of three parts: the plasticizing part, the injection part and the pressure driving part. Its functions are as follows: (1) Plasticizing- under the combined action of the screw and the heating ring, the material is melted and plasticized uniformly; (2) injection one under the action of the screw, the plasticized material is injected into the mold cavity at a set pressure and speed; (3) the pressure is maintained- one molten material is injected into the cavity. Inside the cavity, the screw stays still to replenish a part of the molten material into the cavity to eliminate shrinkage caused by cooling, ensure product quality, and prevent material from flowing back. The injection part is mainly composed of a pressurizing device and a driving device. When the melt in the metering section reaches the required amount, the screw stops rotating and remains stationary. Then, under the action of the injection cylinder, the molten material in the metering chamber is injected into the closed mold cavity under the setting of the injection process parameters, and the injection ends. The pressure device mainly provides power to make the screw exert pressure on the material. There are mainly two power sources: hydraulic pressure and mechanical force. At present, most of them use hydraulic pressure, and use self-sufficient hydraulic system to supply pressure. [11], [12] applied highly oriented homo polypropylene (PP) as the reinforcement and a PP-based thermoplastic elastomer as the matrix, and firstly prepared SPC pellets (5 mm × 5 mm) by film lamination method and cutting, and finally added the SPC pellets into the injection molding machine to produce SPC parts. The results showed that the processing temperature window was expanded to 90 ◦C due to the addition of the PP elastomer. However, the elastomer and the cut fibers decreased the improvement of the mechanical strength of the PP SPC parts. [13] combined co-extrusion and injection molding methods to prepare PP SPCs. The processing temperature window of 33 ◦C was realized. However, the method is not the best solution in terms of high mechanical properties due to the short fibers and their anisotropic distribution. [14] Applied injection-compression molding for the production of PP SPC parts. The weft-knitting technique was conducted to prepare plain knitted textile fabrics as the reinforcement. Before the injection-compression molding, the fabrics should be fixed in the mold. The short cycle time could be achieved by this method in comparison with compression molding. Unfortunately, they mainly discussed the processing temperature and the effects of homo-PP and block-PP and did not discuss the effects of other processing parameters. Moreover, the tensile strength of the prepared PP SPCs was not improved. A similar approach for preparing SPCs by insert injection molding was proposed using PP and polyethylene (PE) as models [15].The method has a relatively high production efficiency with a molding cycle on the order of seconds. The processing temperature window for PP SPCs and PE SPCs achieved 80 and 40 ◦C, respectively. A sandwiched structure with a middle fabric for PP and PE SPCs was also realized by the insert injection molding method [16], [17].This method can realize a better appearance because the fabric was set in the middle of the parts. However, the fiber volume fraction was low, which influenced the improvement of the mechanical properties of the SPC parts. [18], [19] applied the same method in the preparation of poly(ethylene terephtahalte) (PET) SPCs. The presented results confirm that the proposed concept of using the overmolding technology for the preparation of SPCs has the potential for industrial implementation. However, the improvement in the tensile strength of the SPCs was also limited. [20], [21] has also studied the influence of temperature on the properties of the insert injection molded PET SPCs. They pointed out that a thorough knowledge of how temperature influences the SPCs is required. A melt sequential injection molding process [22], [23].

The injection machine usually consists of an injection system, a mold clamping mechanism, a hydraulic system, an electrical control system, a heating part and other auxiliary parts such as a cooling part and a feeding part [24]. Increasing the temperature of the plastic melt will speed up the movement of the internal molecular chains and thereby achieve a better relaxation. The interaction energy between molecular chains will be reduced, the internal stress will be better released, and the internal stress will be smaller after the product is cooled. The degree of shrinkage and deformation is low, which makes the surface of the injection molded part smoother and shiny. For example, [25], [26] studied the residual stress of thin-walled parts and found that the mold temperature had a greater effect on the residual stress of the surface layer and the core region, and the pressure had a smaller effect on the residual stress. [27], [28] found that birefringence is related to the residual stress of the transparent material itself and the product. Since the melt flow during the filling stage and the shrinkage abnormality is caused by the temperature and pressure difference during the injection molding process, the molecular orientation will cause the component generate internal stress. For example, [29], [30] used the injection molding simulation method to analyze the melt flow during injection molding, and analyzed the effects of various process parameters and mold sizes on the injection molding process. Under the condition that the mold temperature is low and the size ratio of the part is the same, for the par with a smaller thickness, it will normally require a greater maximum pressure and a longer injection time during injection. When the mold temperature is high and the size ratio of the part is the same, for the part with a smaller thickness, the maximum pressure required for injection does not change significantly, but a longer injection time is required. The maximum pressure required for injection molding also does not change significantly, and the maximum pressure is smaller when the injection time is short.

## 2. RESEARCH SIGNIFICANCE

Injection molding machine, also known as plastic injection molding machine or injection machine, is used to add granular or powdery polymer raw materials to the injection molding machine barrel, melt and plasticize into polymers with good fluidity under the action of external heating and mechanical shear the melt, followed by the plunger or screw, quickly enters the mold cavity with a lower temperature, and is cooled and solidified to form a plastic product consistent with the shape of the mold. The following mainly introduces the injection system, mold clamping mechanism, hydraulic and electrical control systems.

## 3. RESEARCH METHODS

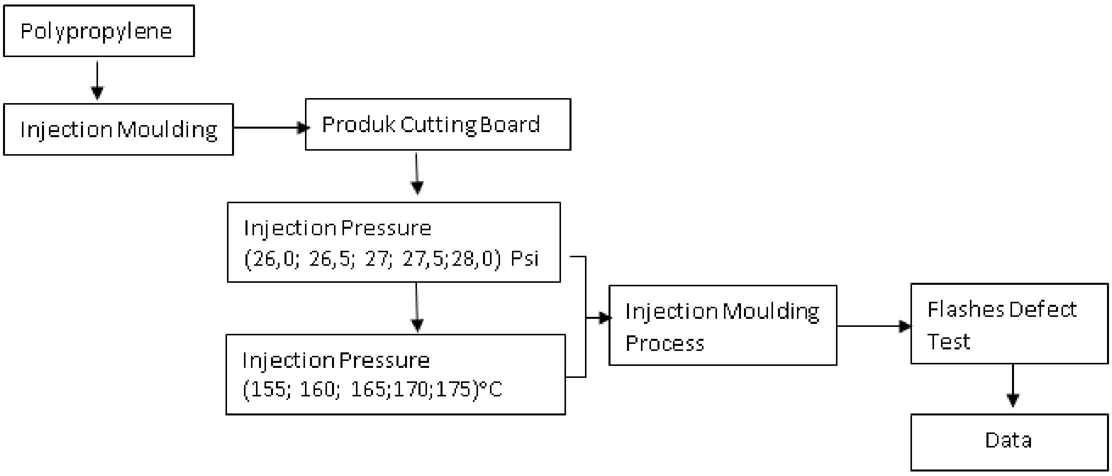


**Figure 1** Research Conceptual Framework

In this research, the independent variables include temperature (165°C, 167.5°C, 170°C, 172.5°C, 175°C) and injection pressure (25 Psi, 27.5 Psi, 30 Psi, 32.5 Psi, 35 Psi) during the injection molding process. These variations allow for a detailed examination of the quantitative influence of both factors on the final product's characteristics. The systematic exploration of temperature and pressure levels ensures a comprehensive understanding of their impact on the polypropylene cutting board's properties.

Controlled variables encompass holding time, back pressure, injection time, open mould, close mould, and cooling time. Managing these variables is crucial to maintaining consistent and optimal conditions throughout the injection molding process. This approach facilitates a direct assessment of the effects of temperature and injection pressure variations on the final product. Essential tools utilized in the study include the injection molding machine, molds, digital scale, camera, scissors, knife, calipers, and a laptop. Each tool plays a critical role in ensuring accurate and efficient experimental execution. Polypropylene serves as the primary material, chosen for its properties that significantly influence the cutting board's quality and strength.

In this study, the authors used an observational experimental design research method (Observations on artificial conditions). Artificial conditions are set and made based on actual circumstances. The purpose of this study is to determine the effect of injection temperature and injection pressure on the defects of injection molding plastic products. The data processing method used in this research is factorial anova which is to determine the effect of variations in injection temperature and pressure on flashess defects in products. And using the RSM (Response Surface Method) method to find out the optimal results of the anova process.

**Figure 2** Analytical Balance Testing

## 4. RESULTS AND DISCUSSION

This research produces two discussions, namely product weight and product surface area. Data obtained from testing is then processed, then displayed in graphical form.

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Model | 5 | 6206,17 | 1241,23 | 76,70 | 0,000 |
| Linear | 2 | 3022,43 | 1511,21 | 93,38 | 0,000 |
| TEMPERATUR | 1 | 2702,67 | 2702,67 | 167,00 | 0,000 |
| TEKANAN | 1 | 319,76 | 319,76 | 19,76 | 0,000 |
| Square | 2 | 3119,80 | 1559,90 | 96,39 | 0,000 |
| TEMPERATUR*TEMPERATUR | 1 | 2614,21 | 2614,21 | 161,53 | 0,000 |
| TEKANAN*TEKANAN | 1 | 505,59 | 505,59 | 31,24 | 0,000 |
| 2-Way Interaction | 1 | 63,94 | 63,94 | 3,95 | 0,051 |
| TEMPERATUR*TEKANAN | 1 | 63,94 | 63,94 | 3,95 | 0,051 |
| Error | 69 | 1116,67 | 16,18 | | |
| Lack-of-Fit | 19 | 802,91 | 42,26 | 6,73 | 0,000 |
| Pure Error | 50 | 313,76 | 6,28 | | |
| Total | 74 | 7322,84 | | | |

**Model Summary**

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 4,02289 | 84,75% | 83,65% | 82,39% |

**Figure 3** Anova and Model Summary of Weight

The presented figure illustrates the outcomes of statistical analysis using the Response Surface Regression method, aiming to optimize the response variable (in this case, weight) based on the factors (in this case, temperature and pressure).

The analysis suggests that the Response Surface Regression method effectively optimizes the weight response based on temperature and pressure factors. The high R-Squared values indicate a reliable model. However, it's recommended to supplement this analysis with contour or three-dimensional plots to visualize the response surface shape for identifying optimal factor combinations. Additionally, validation tests, such as residual plots, are crucial to ensure the model's assumptions, including normality and independence of errors.

**Factor Information**

| Factor | Levels | Values |
|---|---|---|
| Temperatur (oC) | 5 | 165,0; 167,5; 170,0; 172,5; 175,0 |
| Tekanan (Psi) | 5 | 25,0; 27,5; 30,0; 32,5; 35,0 |

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Model | 24 | 274563762 | 11440157 | 32,94 | 0,000 |
| Linear | 8 | 229212429 | 28651554 | 82,51 | 0,000 |
| Temperatur (oC) | 4 | 27648056 | 6912014 | 19,90 | 0,000 |
| Tekanan (Psi) | 4 | 201564373 | 50391093 | 145,11 | 0,000 |
| 2-Way Interactions | 16 | 45351333 | 2834458 | 8,16 | 0,000 |
| Temperatur (oC)*Tekanan (Psi) | 16 | 45351333 | 2834458 | 8,16 | 0,000 |
| Error | 50 | 17363488 | 347270 | | |
| Total | 74 | 291927250 | | | |

**Model Summary**

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 589,296 | 94,05% | 91,20% | 86,62% |

**Figure 4** Anova and Model Summary Product Area

The analysis employs a general factorial regression, focusing on "Surface Area" and "Pressure" as factors influencing an unspecified response variable. To enhance clarity, it is advisable to specify the nature or name of this response variable, see figure 4.

The regression model used is a two-factor, three-level general factorial regression, expressed as $y=\beta0+\beta1x1+\beta2x2+\beta12x1x2+\epsilon$, where y represents the response variable, x1 and x2 are the factor variables, and $\beta0$, $\beta1$, $\beta2$, $\beta12$ are the regression coefficients, with $\epsilon$ denoting the random error.

The analysis of variance results indicates a highly significant F-ratio and a very low p-value, underscoring the model's capacity to substantially explain the variance in the response variable. The elevated R-squared and adjusted R-squared values further signify the model's accuracy in predicting the response.

However, noteworthy is the significant interaction identified between surface area and pressure. This implies that the impact of surface area on the response variable is contingent on the pressure value and vice versa. To visually convey this interaction effect, it is recommended to include interaction plots depicting the relationship between the two factors and the response variable.

## 5. CONCLUSIONS

The research examines product weight and surface area, analyzing data using Anova and Response Surface Regression for weight and a general factorial regression for surface area. For weight, linear effects of temperature and pressure are significant, with high R-Squared values indicating model reliability. It's suggested to use contour or 3D plots for a clearer understanding of the response surface. Validation tests like residual plots are advised. For surface area, the model shows significant F-ratio and low p-values, with high R-squared values indicating accurate prediction. Interaction between surface area and pressure is noted, suggesting their combined impact on the response. Incorporating interaction plots is recommended for better visualization.

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## 7. AUTHOR CONTRIBUTIONS

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- Data curation: Ramadhana Luhur Prabangkara
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- Validation: Sugeng Hadi Susilo.
- Visualization: Ramadhana Luhur Prabangkara
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- Writing – review & editing: Ramadhana Luhur Prabangkara

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