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Analysis of Temperature Spread Distribution on Mold of Manual Injection Molding Machine Double-Stages 5 TF Capacity

Valen Yudha Prawira[a], Muslimin[a,*], Muhammad Prasha Risfi Silitonga[a], Almahdi[b]
[a] Manufacturing Engineering Technology Study Program, Department of Mechanical Engineering, Politeknik Negeri Jakarta, Depok, Indonesia 16425
[b] Mechanical Engineering Study Program, Department of Mechanical Engineering, Politeknik Negeri Jakarta, Depok, Indonesia 16425
* Email of corresponding author: muslimin@mesin.pnj.ac.id

Abstract

This study analyzes the temperature spread distribution in the core and cavity design of a manual double-stage injection molding machine with a 5 tons force (TF) capacity. The injection mold is utilized to process polypropylene (PP) material into an injection product in the shape of the PNJ logo. This research aims to examine the temperature spread distribution resulting from a 100-watt cartridge heater located on the support plate of the mold, with a focus on the core and cavity temperatures. Manual calculations using heat transfer conduction principles and finite element analysis (FEA) simulations using software were conducted in this study. The parameters investigated include the temperature values across the support plate mold, core, and cavity. The results of the manual calculations indicate that the temperatures on the support plate mold, core, and cavity are 58.96°C, 57.34°C, and 57.34°C, respectively. The simulation analysis yielded maximum temperatures of 89.53°C for the support plate mold and 88.11°C for both the core and cavity. The manual calculations and simulation analysis produced accurate and reliable results, confirming that the standard mold temperature range for processing polypropylene is between 20°C and 90°C. This analysis demonstrates that the identified temperature levels are safe for polypropylene processing, providing high confidence in the validity of the research findings.

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Introduction

Plastic waste, including polypropylene (PP), is a problem that can damage nature, especially the ocean and ecosystems. Various methods of handling PP waste have been carried out, one of which is reusing and recycling plastic waste into other products. The recycling process is done by converting plastic waste into plastic pellets (resin). Processing resin into more valuable products has many methods; one of the processing methods is injection molding.

Injection molding is a manufacturing method where the resin material is heated until it melts, and then the injection process is carried out into the mold [1][2]. Injection molding consists of two parts, i.e., the injection unit and the clamping unit [3]. The injection unit functions to heat the resin until it melts, and the injection process into the mold [4][5]. The clamping unit is where the process of opening and closing the mold and dispensing the product results occurs [4][6]. The injection molding process consists of the following main stages: the mold is closed tightly, then the plastic seeds are put into the hopper (feeding), the plastic seeds are heated until they melt in the stages, then the injection process is carried out into the mold, the cooling process (cooling) the mold to lower the mold temperature, and finally the ejecting process removes the product from the mold [7][8].

A mold is part of an injection molding machine that produces a tailored product shape. The mold consists of two parts, namely the core and cavity [9]. The mold core is the part of the mold that forms the details of the product, commonly called the male, which will form the lower product, while the mold cavity is the part of the mold that will form the upper product, called the female. Mold is made of material with good heat conductivity and strength [10] [11]. Polypropylene is a plastic material among the lightest thermoplastics with a 0.9 – 0.91 g/cm^3 density and excellent flow properties—the shrinkage ratio of polypropylene changes based on the temperature of the mold.

The heat transfer in the mold during cooling is the transfer of conductive heat from the molten plastic in the mold cavity with a higher temperature to the mold wall with a lower temperature [7]. The mold is equipped with a cooling system either in the form of fluid flow through the mold or air cooling by blowing into the mold to lower the mold temperature after the liquid plastic injection process. The temperature difference between the liquid plastic and the molded wall is set not to be too high but can still result in the heat transfer process. Mold temperature has an important role in producing good quality products and maintaining the mold's life so that it lasts for a long time. Mold temperature is one of the parameters of the molding injection process. Therefore, heat transfer analysis in the mold is critical to determine the effectiveness of cooling in the molding process. In this study, the temperature distribution in the support plate mold, core, and cavity, which is one assembly mold, was analyzed to obtain temperature results on the mold in accordance with PP material standards. This study aims to determine the temperature spread produced by a cartridge heater with a power of 100 Watts found in the support plate to the core and cavity.

Theory

A. Double-Stages Molding Machine

A double-stage molding machine consists of an extrusion unit and an injection plunger [12]. Double Stages is a unique configuration on an injection molding machine that combines two main mechanisms in one system. The machine is designed to provide better control over the defrosting of the material and the injection into the mold. The purpose of the extrusion stage in the injection molding process is to melt and prepare plastic or polymer materials before being injected into the mold. Extrusion is the first step in several molding machines, including double-stage machines. At the extrusion stage, plastic materials in pellets or granules are heated until they melt and are ready for further processing. Meanwhile, in the plunger injection stage, the liquid material in the reservoir is injected into the mold using a plunger (piston) that applies high pressure directly to ensure that the material fills all the mold cavities perfectly. The comparison of double stages to single stages is shown in Table 1 below [12]

TABLE 1. COMPARISON OF DOUBLE STAGE AND SINGLE STAGE MACHINES

Aspects	Single Stage	Double Stages (Extruder and Plunger)
Function	Screw melting and injection	Extruder melting, plunger injection
Material Quality	Less consistent	More consistent
Material Capacity	Limited	Greater
Injection Pressure	Pressure can fluctuate	Stable pressure
Application	Small to medium products	Large and complex products
Aspects	Single Stage	Double Stages (Extruder and Plunger)

B. Polypropylene (PP)

Polypropylene is the lightest thermoplastic material, with a density of 0.9 – 0.91 g/cm³ and excellent flow properties—the shrinkage ratio of polypropylene changes based on the mold's temperature. Polypropylene has excellent bending resistance and high tensile strength. Pressure injection of polypropylene material is 600 – 1400 kg/cm². The mechanical properties of polypropylene can be seen in Table 2 [13] .

TABLE 2. MECHANICAL PROPERTIES OF POLYPROPYLENE PLASTICIZER

Plastic Materials	***Shrinkage* (%)**	***Density***	***Cylinder Temperature* (°C)**	***Mold Temperature* (°C)**	***Injection Pressure* (kgf/cm²)**
Polypropylene (PP)	1.0 – 2.5	0.9 – 0.91	180 – 300	20 – 90	600 – 1400

B. Heat Transfer in Mold

Figure 1 shows the cartridge heater with a power of 100 Watts installed on the support plate. The heat generated by the cartridge heater will then propagate conductively to the core and cavity.

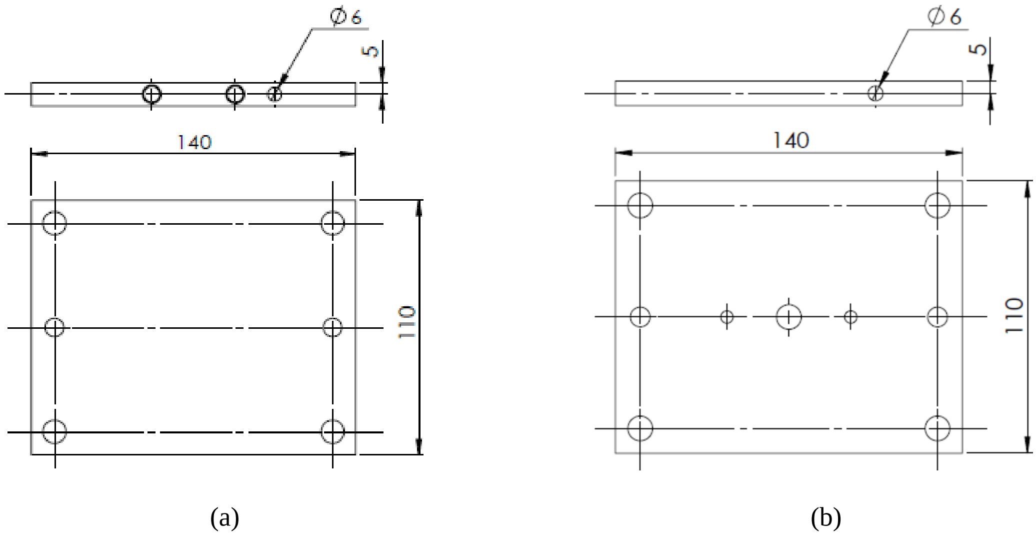

Figure 1. (a) Details of the design of the support plate core, (b) Details of the design of the support plate cavity

Heat calculation on the support plate that propagates conductively using the illustration seen in Figure 2.

Figure 2. Illustration of heat calculation on the support plate

The conduction propagation temperature of the support plate based on the heater power, the thermal conductivity of the material, and the area of the heat-affected part can be calculated using Equation 1 [14]:

$$Q = \left(\frac{4.\pi.R}{1-\frac{R}{2h}}\right).k.\Delta T \qquad (1)$$

where:

Q = heat transfer rate [J/s]
R = radius of heat source [m]
k = thermal conductivity [W/mK]
ΔT = temperature difference [K]
h = distance of the heat source to the surface [m]

The mold consists of a core and a cavity. It will produce the Jakarta State Polytechnic logo merchandise. The temperature generated from the cartridge heater is distributed on the mold. The design of the core and cavity equipped with the support plate can be seen in Figure 3.

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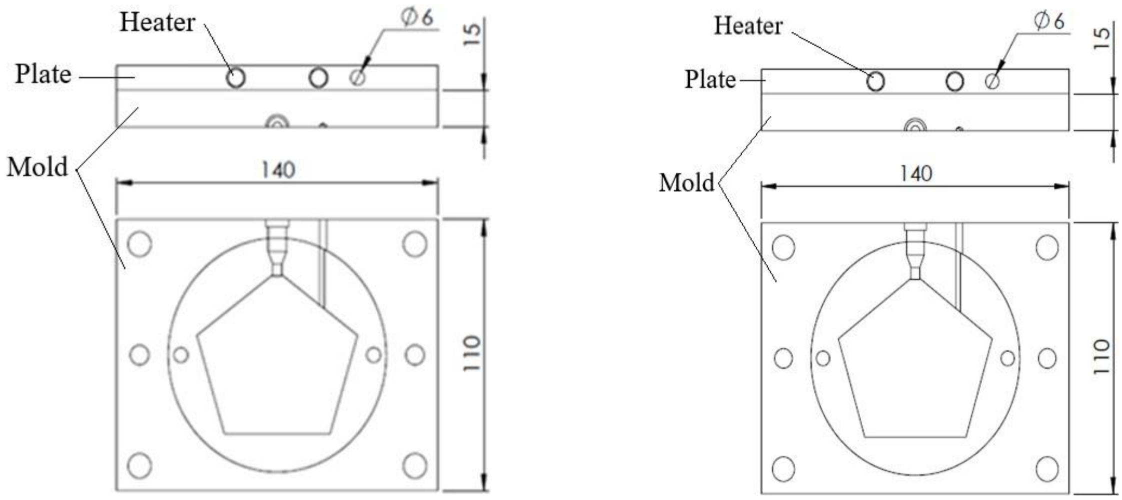

(a) (b)

Figure 3. (a) Core design with support plate, (b) Cavity design with support plate

Figure 4 shows how heat can be calculated on the conductive propagating part of the mold.

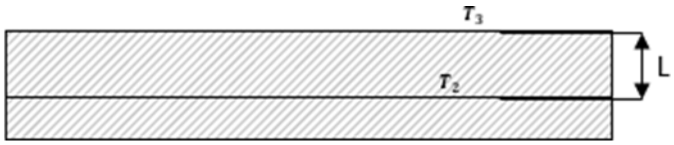

Figure 4. Illustration of heat calculation on the *support plate* with *core* and *cavity*

The temperature of propagating conductively from the support plate to the section Mold based on the temperature calculated on the surface support plate, the thermal conductivity of the material, and the area of the part exposed to heat can be calculated using Equation 2 [14]:

$$Q = \frac{k.A.\Delta T}{L} \tag{2}$$

where:

Q = heat transfer rate [J/s]
A = surface area [m2]
k = thermal conductivity [W/mK]
ΔT = temperature difference [K]
L = thickness of the object [m]

Research Methods

A. System Design

The mold is designed using Solidworks 2020 Software. The core and cavity design is then simulated with temperature to determine the temperature distribution using manual calculations and simulation of Solidworks Software. The parameters involved in this study are the thermal conductivity of the material and the power used in the cartridge heater. The simulation is carried out simultaneously with the temperature input. The data is fed into the software, and the temperature distribution is simulated. The results are then analyzed and compared with manual calculations. The primary purpose of this study is to determine the temperature distribution produced by the cartridge heater with a power of 100 watts contained in the support plate to the core and cavity of the mold, then obtain a safe temperature to be applied to the production process. The resulting product is merchandise in the form of the Jakarta State Polytechnic logo, which uses polypropylene. The design of the print in this study can be seen in Figure 5. The main components of the mold are the support plate, cartridge heater, core, and cavity.

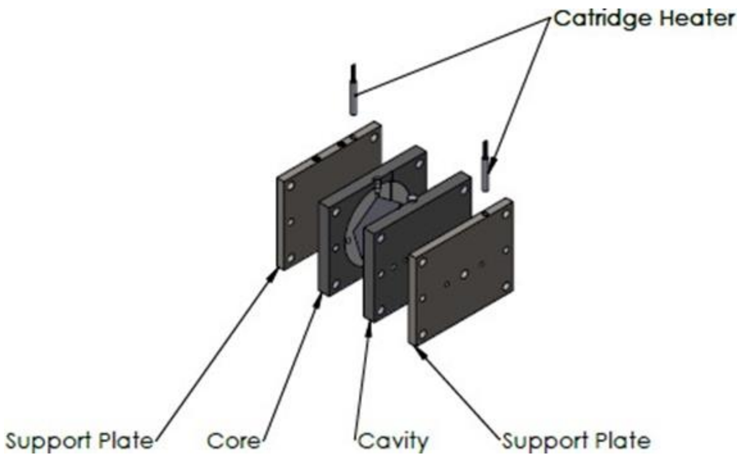

Figure 5. Mold design

The material used is based on the requirements of its mechanical properties. The material requirements for printing are strength, good thermal conductivity, and affordable price [15]. The support plate, core, and cavity materials are SS400 grade steel [16]. The mechanical properties of SS400 (JIS G 3101) are shown in Table 3 [15].

TABLE 3. MECHANICAL PROPERTIES OF SS400 STEEL

Material	Elastic Modulus (GPa)	Yield Point (MPa)	Tensile Strength (MPa)	Elongation (%)	Thermal Conductivity (W/mK)
SS400	206	205 – 245	400 – 510	17 – 23	57 – 60

B. Simulation Software

Simulations are implemented to determine the temperature distribution using Solidworks 2020 Software. The parameters used are temperature and power related to actual conditions. The next step is to insert the object's material into the software. In this simulation, the material used is SS400 for the mold and support plate. The simulation was carried out by providing an input temperature from a cartridge heater of 90°C and a power of 100 Watts. The data input in the software is then simulated in finite element analysis, and there is a temperature spread in the mold and support plate. The results of manual calculations and software simulations are then compared and analyzed.

Results and Discussion

A. Conduction on Support Plate

The conduction on the support plate is calculated using Equation 1. The heating temperature applied from the heater is 90°C, with a heater power of 100 Watts, a heater diameter of 6 mm or 0.006 m, the distance from the heater to the surface in contact with the mold of 5 mm or 0.005 m can be seen in Figure 1. The thermal conductivity of the material used in the support plate, SS400, is 60 W/mK, which can be seen in Table 2. Referring to the illustration in Figure 2, the conduction calculation on the support plate based on Equation 1 is:

$$Q = \left(\frac{4.\pi.R}{1-\frac{R}{2h}}\right).k.\Delta T$$
$$100 = \left(\frac{4x\pi x0.003}{1-\frac{0.003}{2x0.005}}\right)x60x(90-T_2)$$
$$T_2 = 58.96^oC$$

The temperature at T_2 was obtained at 58.96°C. This temperature will then be used to calculate conduction displacement in the core and cavity.

B. Conduction in Core and Cavity

The conduction in the core and cavity is calculated using Equation 2. The initial temperature used based on the T_2 temperature is 58.96°C, with the dimensions of the mold length of 140 mm or 0.14 m, the width of the mold is 110 mm or 0.11 m, and the thickness of the mold is 15 mm or 0.015 m (L) can be seen in Figure 3. The heater power is 100 Watts, and the thermal conductivity of the material used in the core and cavity, namely SS400, is 60 W/mK, which can be seen in Table 2. Based on the illustration in Figure 4, the calculation of conduction in the cavity and core based on Equation 2 is:

$$Q = \frac{k.A.\Delta T}{L}$$
$$100 = \frac{60x(0.14\ x0.11).(58.96-T_3)}{0.015}$$
$$T_3 = 57.37^oC$$

The temperature at the core and cavity was 57.34°C. Table 1 discusses the mechanical properties of polypropylene material; a standard temperature is used for molds, which is 20°C – 90°C. It was concluded that the temperature in the core and cavity obtained from the calculation was 57.34°C, safe to use because it was still within the standard temperature range.

C. Simulation

Finite element analysis was used in this study to determine the heat distribution in the support plate and the Mold Core and cavity [7][17]. The simulation was carried out by inputting data on the mechanical properties of materials used in the support plate, the mold core, and the cavity, namely SS400. Then, an input power heater is carried out at 100 Watts at a temperature of 90°C produced by a cartridge heater in the section support plate. Data is inputted into the software. Then, simulations are carried out to find out how temperature distribution occurs.

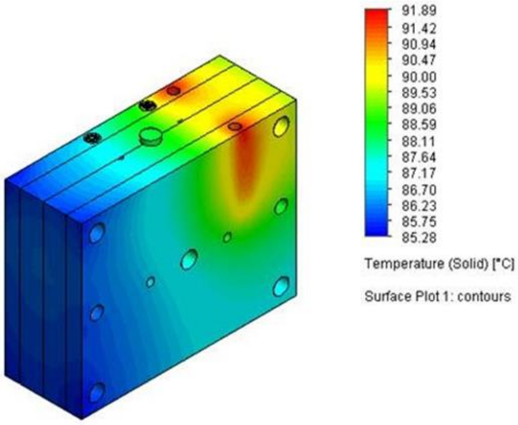

Figure 6. Simulation results

TABLE 4. TEMPERATURE SPREAD IN CORE AND CAVITY

Part	Manual Calculation	Simulation *Solidworks*	*Standard mold temperature*	Conclusion
Core	57.43°C	88.11°C	20°C – 90°C	Safe
Cavity	57.43°C	88.11°C		Safe

Table 4 shows the temperature distribution results in the core and cavity with manual calculation and simulation analysis. Based on the results of manual calculations, the temperature in the core and cavity was 57.34°C, respectively. Meanwhile, the simulation analysis shows that the core and cavity are 88.11°C, respectively. The results of manual calculations and simulation analysis, it was concluded that the temperature contained in the core and cavity is safe to use because it is still within the minimum standard range of temperature, which can be seen in Table 1.

Conclusion

The analysis of the temperature spread based on the results of manual calculations using the concept of conduction in heat transfer found that the temperature in the core and cavity was 57.43°C. The results of the analysis of finite elements using Solidworks Software obtained the temperature in the core and cavity was 88.11°C. The results of manual calculations and Solidworks simulations of the temperature in the core and cavity parts concluded that the temperature is still within the minimum standard range, so it is safe to use.

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