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THE DETERMINATION OF THE OUTSIDE MOLD DIMENSION FOR OPTIMIZATION OF THE CLAMPING FORCE OF THE PLASTIC INJECTION MACHINE

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Abstract
Injection molding is widely used for plastic manufacturing due to its high efficiency, yet the critical relationship between mold outer dimensions and machine capacity is often overlooked. An oversized mold base forces companies to use higher-tonnage machines, unnecessarily increasing production costs. This study aims to optimize the outside mold dimensions to perfectly align with the clamping force and available space of the selected injection machine. Using a high-density polyethylene (HDPE) rail pad as the research object, the methodology included calculating product weight, cycle time, tie-bar distance, and minimum mold height. Based on a two-cavity design to meet an order quantity of 50,000 pieces per month, calculations determined a total shot weight of 224.6 grams and a required clamping force of 110 tons. Consequently, the Nissei 110 FN injection machine was selected. To ensure compatibility with this machine's specifications, the mold design required modification, specifically increasing the mold height from 194 mm to 223 mm. The findings demonstrate that optimizing mold dimensions is a crucial guide for selecting the most cost-efficient machine and preventing financial waste.

Key words: clamping, injection molding, machine, mold, plastic

INTRODUCTION

Plastics offer several advantages, including being lightweight, strong, easy to mold, and easy to color (Malloy, 2010). In Indonesia, plastics manufacturing is a significant business sector, ranking fifth among the top industries contributing to national revenue. To produce these plastic products, injection molding has been the most popular method due to its high productivity, efficiency, and manufacturability. Compared to modern alternatives like 3D printing, injection molding remains superior in terms of price efficiency and speed, ensuring that the future of the injection molding industry is highly promising(Idris & Masood, 2024).

The main tools in the injection molding process are the mold and the injection machine. The mold is installed by securing it to the clamping area, meaning everything related to the mold size must perfectly fit within the available space on the machine. However, the critical relationship between the mold's outer dimensions and the machine's capacity is often overlooked. So, the relation dimension mold must fit the machine. Nomenclature injection machine, see Figure 1. A common issue occurs when the required clamping force is small, but the outer size of the mold base is designed too large.

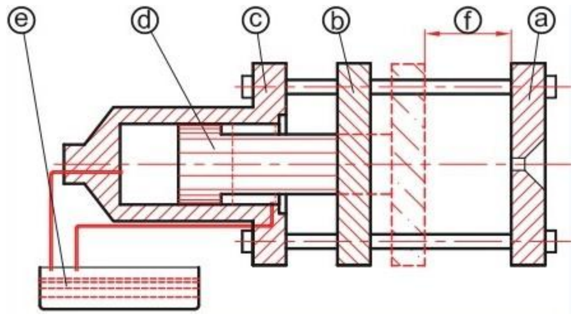

Figure 1. njection machine, a fixed plate, b moving plate, c hydraulic system, d piston, e oil tank, f minimum clamp

The mold is installed by securing it to the clamping area. Therefore, everything related to the mold size must fit within the available space on the injection machine. Mold nomenclature is Figure 2.

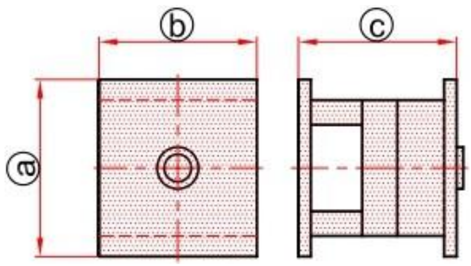

Figure 2. Molding plastic, a vertical dim, b horizontal dim, c length

In Indonesia, plastics manufacturing is one of the business sectors with a significant contribution to revenue. Plastics production has ranked fifth among the top industries over the last 10 years, following base metals, motors, chemicals, and food (Kementerian LHK, 2022).

Plastic products are formed using molds. Molds are cavities that create the shape of the product (Krishnappa et al., 2025). The process of filling liquid plastic into a mold using an injection machine. In the screw barrel heats the material, closes the mold, pushes the liquid plastic into the mold cavity, holds the mold closed during the filling process, cools the mold, opens the mold, and pushes the product out of the mold cavity (Wang & Lee, 2023).

This dimensional mismatch directly impacts production costs. Clamping force is a key parameter in determining both product pricing and the required investment for an injection molding machine. If the outer mold size is determined incorrectly (too large), companies are forced to use a machine with a higher tonnage than technically required. Using an injection machine with a tonnage higher than necessary increases hourly operating costs and is considered a significant waste of resources, putting the company at a financial disadvantage (Patil et al., 2021), (Ke & Huang, 2020).

Companies would be at a significant disadvantage if, due to a mistake in determining the outer mold size, they were forced to use a machine with a higher tonnage when, upon further investigation, the mold could have been designed for a lower tonnage.

To prevent these financial disadvantages, optimizing the mold size to maximize efficiency in machine selection is undoubtedly more economical. Therefore, the objective of this research is to determine the optimal outside mold dimensions to perfectly suit the available space and clamping force capacity of the plastic injection machine. This optimization serves as a vital guide for designing the minimum allowable mold dimensions to align perfectly with the most efficient machine choice, thereby minimizing production costs.

Literature review

Previous studies on plastic product manufacturing have primarily focused on optimizing other process variables. For instance, several methods like LEAN and KAIZEN have been utilized, and various studies have investigated cycle time efficiency, product quality, and defect reduction. However, a specific analysis regarding the optimization of the outer mold dimensions is still lacking. This study addresses that critical gap by presenting the effect of the mold's outside dimension on selecting a suitable injection molding machine, ensuring manufacturing process efficiency and competitive pricing (Romero & Sanchez, 2019).

When designing products and tools adjustments to the shape are made including determining the parting line, gate location, ejector pin position, and draft angle to facilitate removal from the mold cavity. This requires mutual understanding between the product designer and the tool designer.

The order quantity and turnaround time determine the number and layout of mold cavities. More mold cavities will result in greater size variations. Using software to predict deviations can help address this issue. However, in practice, deviations will still occur due to factors such as the quality of the machined surface, the coordinates of the guide posts, and the deviations of individual parts during mold assembly (Mahshid et al., 2021).

One of the mold design stages is determining the mold base size. The mold base structure of a top plate (include locating ring), cavity plate, core plate, support plate, intermediate plate, ejector plate, and bottom plate. The inner size of the mold base must be sufficient to accommodate the mold cavity and mold mechanism. Meanwhile, the outer size must be able to fit into an injection machine with the appropriate tonnage. If the required clamping force is small but the outer size of the mold base is too large, this is considered a waste of the injection machine's tonnage. Fig. 3 shows the arrangement of the mold base plates especially top plate and botoom plate. Unigraphics software is used to simplify the mold design process and perform simulations, including barrel heat, injection speed, injection pressure, filling time, cooling time, flow in the mold cavity, and other analyses (Jamsheed et al., 2015).

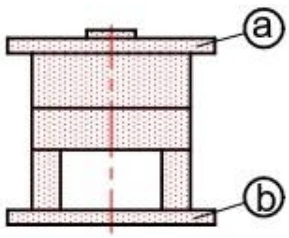

Figure 3. Mold base, a top plate, b bottom plate

The ideal cavity layout should be symmetrical and equidistant from the injection molding nozzle tip. This isn't always possible under certain conditions, especially in multi-cavity molding. Symmetrical cavity layouts are more advantageous than asymmetrical ones. This impacts the efficiency of the molding force and the resulting product quality (Huang et al., 2018).

Draft angle refers to the slope of the mold cavity walls, which facilitates product removal. This

Table 1. Injection machine specification

BRAND AND TYPE	Max clamp press	Max daylight	Clamp stroke	Mold height	Tie bar distance	Eject stroke	Max inject vol
	Ton	mm	mm	mm	mm	mm	mm^3
Mitsubishi 550 MGIII-110	550	1600	1200	400	860x860	150	1940
Mitsubishi 450 MGIII-80	450	1400	1050	350	810s810	150	1640
Nissei FHX 460-160A ESD	460	1320	1025	295	820x820	150	1610
Nissei FHX 360-160A ESD	360	1240	970	315	700x700	120	1010
Nissei FHX 360 S140 ANE	360	1025	710	315	700x700	150	1585
Mitsubishi 290 MS V-40	290	1060	760	300	660x660	125	1030
Mitsubishi 190 MS V-30	190	900	630	270	570x570	100	461
Mitsubishi 130 MS V-10	130	850	610	240	510x510	100	283
Nissei FS120 S25 ANE	120	700	400	170	410x410	85	179
Nissei 110 FN 2000	110	720	520	200	420x420	85	226
Nissei FS80 S18 ANE	80	685	350	160	375x375	75	132
NisseiS40 PNX	40	680	470	210	310x310	60	49
Nissei 40 ANE	40	500	300	200	310x310	60	42

slope depends on the position of the parting line, which is the boundary between the two molds forming the cavity. If there is no slope, friction will occur, making the product heavy when removed (Chen et al., 2025).

A gate is a small hole through which molten plastic flows to fill the mold cavity. Gates are kept small to minimize product appearance and are easy to cut. If the gate is too large, the product will look unattractive. Gate position is crucial for the success of the filling process. For small, symmetrical products, it's easy to guess the ideal gate position. However, for asymmetrical or complex products, the mold cavity may not be filled if gate placement is not carefully considered (Zhai et al., 2005).

After the molten plastic is injected from barrels into the mold cavity, it proceeds to the cooling stage, which aims to lower the plastic's temperature from the melting point to its freezing point. The success of the cooling process is determined by how quickly it reaches the freezing point. This is done so that the mold is ready to be removed from the mold cavity (Deepika et al., 2020). Because damage will occur if it is forcibly removed before it is sufficiently frozen. It is important to ensure even cooling across each part of the plastic (Rosli et al., 2015).

The injection mold machine spesification shown at table 1. Description: A is clamping force, B is maximum daylight, C is clamps stroke, D is mold height, E is tie bar distance (horizontal x vertical), F is ejector stroke, G is maximum injection weight. Data source from manual book Mitsubishi and Nissei each type.

METHODS

The proposed methodology for determining the outside mold is as follows in Fig. 4. A straight line represents a direct relationship. A strip line indicates a relationship, but it's indirect. Arrows indicate the direction of data processing.

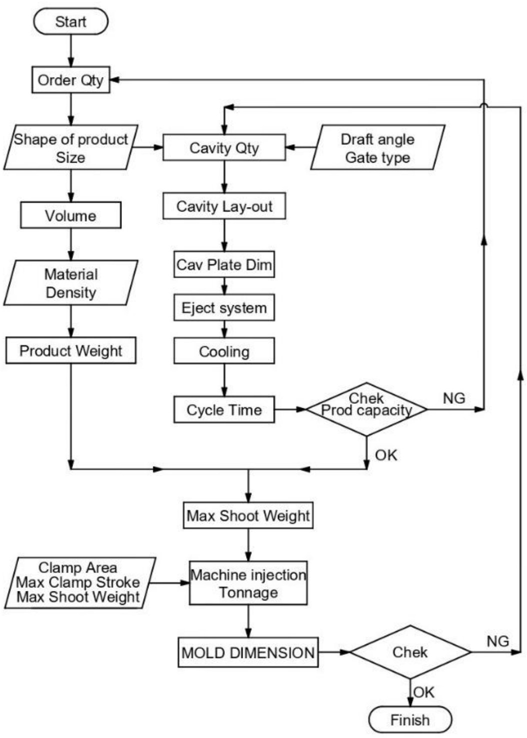

Figure 4. Flow diagram

It begins with the customer providing order data, including the shape, size, and type of material used. Shape and size determine volume. The type of material determines the specific gravity used to calculate the product's weight.

Volume can be calculated using Equation 1:

$$V = L \times W \times t \qquad \ldots\ldots (1)$$

Where V is volume (mm^3), L is length (mm), W is width (mm), and t is thickness (mm).

Product weight can be calculated using equation 2:

$$W = \rho \times V \qquad \ldots\ldots (2)$$

Where W is weight (gram), ρ is density ($gram/mm^3$) and V is volume (mm^3).

In addition to calculating the volume of the shape, it also serves as a parameter for considering the parting line. After determining the parting line location, the draft angle, gate location, and type are determined. Next, the appropriate channel and filler hole (runner and sprue) shapes are determined.

The customer has data on the order quantity and completion time for a specific quantity. This data is used to calculate the number of mold cavities. These results will be recalculated after the final cycle time estimate is obtained.

Production capacity can be calculated using Equation 3:

$$Cap = \frac{3600}{Ct} \times 24 \text{ hours } \times 25 \text{ days} \qquad \ldots\ldots (3)$$

Where Cap is capacity (pc/month)

Duration of work can be calculated using Equation 4:

$$T = \frac{Q}{Cap} \qquad \ldots\ldots (4)$$

Where T= Duration of work (month) and Q is order quantity.

The number of cavities determines the mold cavity layout. Ideally, it should be symmetrical. However, this isn't always possible. It depends on the product shape and order quantity. Next, the length, width, and thickness of the cavity plate, ejecting system, and cooling channel layout are determined, respectively.

Once the cooling channel design is complete, the cycle time can be estimated. This figure is then compared with the capacity and order quantity requested by the customer. If it meets the requirements, the process will proceed. If not, all related parameters will be adjusted.

Next, the mold base is determined, which is related to the size of the injection machine, including the clamping area, maximum stroke, and maximum injection weight. This data determines the tonnage. Furthermore, tonnage is also calculated for: Projection area can be calculated by using equation 4:

$$A = L \times W \qquad \ldots\ldots (4)$$

Where A is the projection area (mm^2), L is the length (mm), and W is the width (mm).

The clamping force be calculated using the projected area of product and the injection pressure of the specific material (Li, 2018) Using equation 5:

$$C = P_{inj} \text{ x } A_{proj} \qquad \ldots\ldots (5)$$

Where C is clamping force (ton), P_{inj} is injection pressure (ton/mm^2), and A_{proj} is projection area (mm^2).

RESULTS AND DISCUSSION

The object of this research is a rail pad, a component of railway track installation. It functions as a base for the rail's undercarriage, and is then clamped with a locking mechanism. It functions to dampen train vibrations as it travels on it. The shape and dimensions are as shown in Fig. 5, and the technical data are in Table 1.

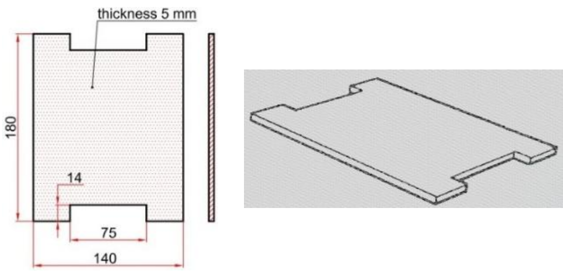

Figure 5. Rail pad

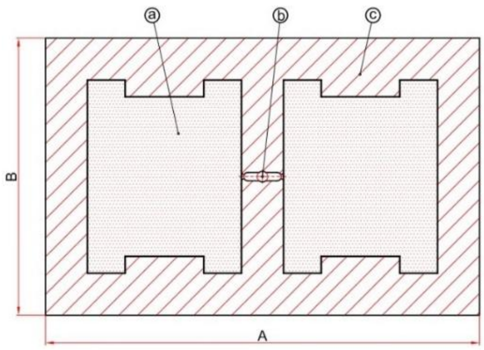

Figure 6. Cavity layout, A length, B width, a cavity, b runner and gate, c cavity plate

Table 2. Product data

Item	Nominal	Unit
Length	180	mm
Width	140	mm
Thickness	5	mm
Material	HDPE	-
Color	Black	-
Order quantity	50000	Pcs/month

a. Refer to Fig. 4, Table 2, and Equation 1 to calculate product volume:

$V = \{(180\times140) - 2\times(14\times75)\} \times 5$

$V = 115500 \text{ mm}^3$

Refer to Table 2, product data material HDPE from technical specification, density 940-965 kg/m^3, average 952.5 kg/m^3 (Emblem, 2012).

$W = 115500 \text{ mm}^3 \times 0.9525 \text{ gram/mm}^3$

$W = 110.01375$ grams

Conclusion 1: Use Nissei FS80 S18, with a maximal inject weight of 132 grams and a clamping force of 80 tons.

b. Refer to Table 1, order quantity 50000 pcs/month, plan to use two cavities, weight (Ws):

$W = 110.01375$ grams × 2 cavities

$W = 220.0275$ grams

Refer to Fig. 1 and the number of cavities created to lay out the mold, as shown in Fig. 5. The drawing includes the parting line, gate type, and location. Runner and sprue detail dimension, see Fig. 7.

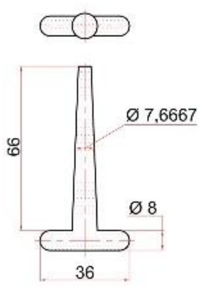

Figure 7. Runner and sprue

Volume runner $= \pi \times 4^2 \times 36$

$= 1808.64 \text{ mm}^3$

Weight runner $= 1808.64 \text{mm}^3 \times 0.0009525 \text{ kg/mm}^3$

$= 1.7227$ grams

Volume sprue $= \pi \times 3.8^2 \times 66$

$= 2992.54 \text{ mm}^3$

Weight sprue $= 2992.54 \text{mm}^3 \times 0.000952 \text{ kg/mm}^3$

$= 2.8504$ grams

Weight shoot = (2 x product) + runner + sprue

= 220.0275 + 1.7227 + 2,8504

= 224.6006 gram

Conclusion 2: Use Nissei 110 FN, maximal inject weight 226 grams, clamping force 110 tons.

Order quantity 50000 pcs per month, check capacity calculated by cycle time prediction 85 seconds using equation 3.

Cap={(3600/85)×2cav}×24hours×25 days

= 50823 pcs per month

c. Check by projection area, refer to equations 4 and 5, then see Fig. 5 cavity layout.

Projection Area A=(Productx2) + Runner + Product

$= \{((180\times140) - 2\times(14\times75))\times2\} + (8\times36)$

$= 46488 \text{ mm}^2$

Clamping force is calculated by using equation 5, HDPE pressure injection height precision 500 kg/cm^2 (Nikoohemmat et al., 2022).

Clamping force C= $46488 \text{ mm}^2 \times 0.5 \text{ kg/mm}^2$

= 23244 kg

Conclusion 3: Use Nissei 40ANE clamping force 40 ton, but this machine's maximum injection weight is 42 grams only because it needs a minimal 224.6006 grams. Not suitable.

d. Mold base layout.

Mold base layout makes all the mold mechanisms included in the area, for example, guide pillar/bush, bolt area, springs, ejecting stroke, and all parts for support. See Fig. 8; C is 384 mm in width and D is 534 mm in length. Seeking a tie bar distance of at least 384 × 534 mm. For Nissei FS80 S18, 375 × 375 mm is only too little. For Nissei 110FN distance 420 × 420 mm, it's OK. See Figure 9.

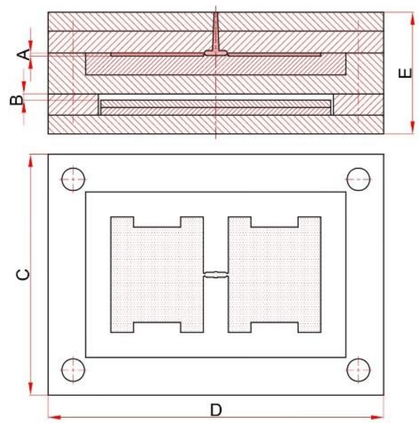

Figure 8. Mold base layout, A product thickness, B ejector stroke, C width, D length, E height.

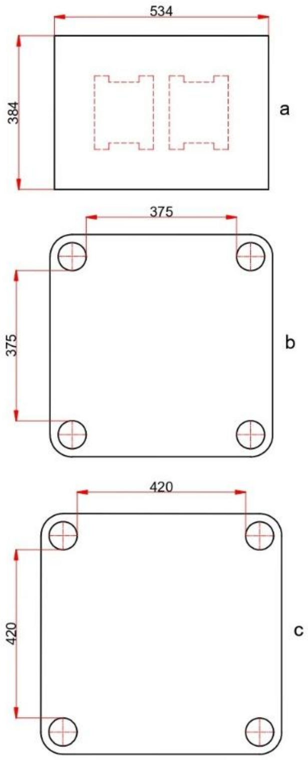

Figure 9. Dimention area a.mold dimention, b.clamp area Nissei FS80, c.clamp area Nissei F110

In Fig. 8, the mold base layout A has a product thickness of 5 mm, so the B area to be ejected is 10 mm. Total height E is 194 mm. Check the Nissei 110FN minimal mold height 200 mm. Modifications are needed to increase the mold height to more than 200 mm. Therefore, the steps are as shown in Fig. 10.

Increase the ejector stroke area from 10mm to 34mm by increasing the spacer height from 34mm to 58mm. Several other plates are also added to facilitate the creation of cooling paths. Finally, the height of the F mold is 223 mm.

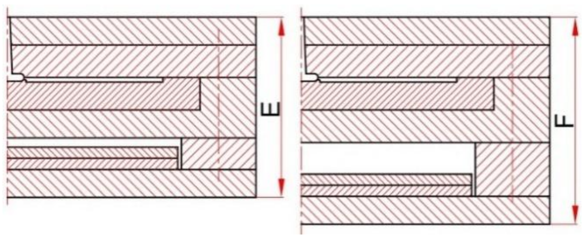

Figure 10. Modification of mold height

To increase the height of the spacer, St. 37 plates dimension 58 cm x 80 x 384 cm quantity 2 pcs are required. With a specific gravity of 7.85 grams/cm^2, the material weighs 28 kg. If the price per kg is IDR 40,000, the cost required is IDR 1,120,000.

CONCLUSIONS

The research object has been carried out using various methods of calculating the size of the machine to be used. The calculation of the volume and weight of the product obtained a weight of 110.01375 grams using Nissei FS80 S18, with a maximum inject weight of 132 grams, and a clamping force of 80 tons.
Based on the order quantity, two cavities were designed with a cycle time of 85 seconds, resulting in a capacity of 50823 pieces per month.

Changing the number of cavities required a recalculation, resulting in a shot weight of 224.6006 grams using the Nissei 110 FN, a maximum injection weight of 226 grams, and a clamping force of 110 tons. Because it uses a 110-ton injection machine, the mold height is adjusted from 194 mm to 223 mm.

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