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Heat distribution analysis of cartridge heater in core and cavity of compression mold for bio-composite roof tile fabrication

Muslimin*, Maulidya Rahman, Dhiya Luqyana

Manufacturing Study Program, Department of Mechanical Engineering, Politeknik Negeri Jakarta, Depok, 16425, Indonesia

*Corresponding author: muslimin@mesin.pnj.ac.id

Abstract

Bio-composite roof tiles use polypropylene matrix material and rice straw fiber as reinforcement processed by compression molding to create innovative and sustainable building products. This research aims to analyze heat distribution from the cartridge heater in the mold core during the compression molding process for fabricating bio-composite roof tiles. The research employs Finite Element Analysis (FEA), and laboratory experiments to measure temperature distribution and heating efficiency. The results showed that even heat distribution on the mold core is crucial to ensure optimal final product quality. Manual calculation estimated a heating time of 170.78 seconds to reach the desired temperature. Simulations conducted using Ansys R19.2 software shows that the temperature variation on the surface of the mold core can be minimized with the optimal placement of the heater cartridge. The simulation results obtained a time of 10 seconds to reach a temperature of 200°C gradually. Laboratory experiments support the simulation results by showing that good heat distribution improves bio-composite tile materials' mechanical strength and homogeneity. This research significantly contributes to the design and optimization of mold cores for bio-composite applications. It offers practical guidance to the industry in improving the efficiency of the production process.

Keywords:

Composite, compression molding, fabric, rubber.

1 Introduction

Bio-composite tile is made from a composite of polymer matrix material and natural fiber reinforcement. Bio-composite is developed from composite materials to utilize natural fibers. Using natural fibers is an effort to reduce environmental impact because natural fibers are easily decomposed in the environment [1]. Natural fibers have several advantages, such as being readily available, abundant, and renewable. This biocomposite uses Polypropylene (PP) as a matrix and rice straw as reinforcing fiber. Polypropylene has the advantages of high-temperature resistance and good mechanical properties [2]. The manufacture of bio-composite roof tiles has become an attractive alternative in the building industry due to its environmentally friendly and durable properties. The bio-composite roof tile fabrication process used is compression molding. Compression molding is a popular forming method used in the manufacturing industry, especially for composite products that require pressure and heat to shape the material according to the mold. Compression molding is a diverse method of manufacturing composite products, as well as a closed molding method. The principle of this process is to apply pressure

to the mold; then, the machine connects heat from the heater to form a material compatible with the pressed mold [3]. The main components in a compression molding machine are the cavity and core (Fig. 1). Heat distribution is critical in compression molding for quality product results [4]. Uneven heat distribution can cause deformation, material damage, or even failure in the product-forming process. Heating elements that help spread heat in compression molding are cartridge, tubular, and coil heaters.



Fig. 1. Compression molding [5].

Arief and Muslimin (2019) explored a Small and Medium Enterprises (SME) scale compression molding machine. It previously used a tubular heater as a heating element in a compression molding machine mold for biocomposite products [5]. The maximum temperature of the tubular heater reaches 450°C, and the power specification is 1,500 watts. The weakness of using tubular is the lack of heat generated when heating the mold. This research uses a cartridge heater heating element. A cartridge heater is a bullet-shaped electric heating element, or cartridge, with two terminals on one side of the cylindrical cross-section. The cartridge heater is usually made of SS-304 stainless steel, and its dimensions are adjusted to the mold of the compression molding machine. The cartridge heater is used to heat the mold before the product molding process. Previous research discussed the design analysis of the mold cavity and core on a compression molding machine for composite material using the tubular heater. This research analyzes the heat distribution generated by the heater in the core and cavity. Heat distribution analysis uses the finite element analysis method with Ansys software. Finite Element Analysis (FEA) is an experimental analysis method derived from complex mechanical phenomena of an object, which is then visualized or virtually modeled using Computer-Aided Engineering (CAE) software [6].

2 Material and Methods

The research process was conducted with meticulous attention to detail, ensuring the reliability and accuracy of the findings. Finite element analysis, a computational method for analyzing the behavior of physical products under loads and boundary conditions, was the cornerstone of our study. This method, one of the most common for solving Partial Differential Equations (PDEs) that describe physical phenomena, was applied with precision and care. Engineering problems that can be effectively solved through FEA include structural mechanics, heat transfer, and electromagnetics [7], [8]. The research steps were conducted as shown in Fig. 2, reflecting the thoroughness and rigor of our approach.

This research discusses the manual comparison of heater heat transfer on the core and simulation using Ansys Student R1 software. It begins with a 3D design in SolidWorks software. Eq. 1 and Eq. 2 can be used to determine image dimensions.

$$H = \sqrt[3]{F_{total} \#} \quad (1)$$

$$W = 1.25 \times H \# \quad (2)$$

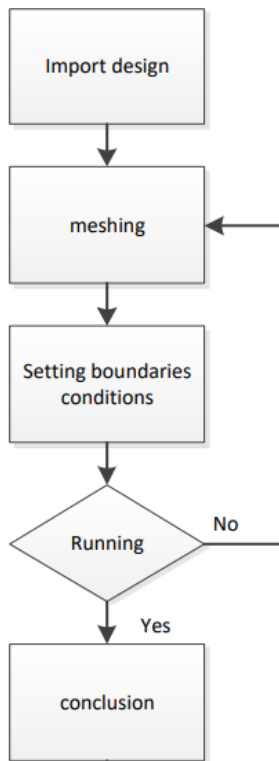


Fig. 2. Flowchart.

Based on the calculation results, the core dimensions are $30 \times 260 \times 260$ mm. Fig. 3. shows the appearance of the core design that has been made.

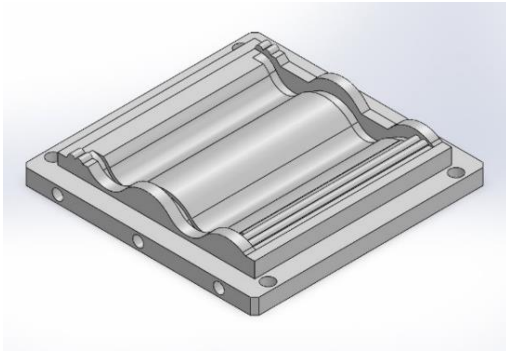


Fig. 3. Mold core.

The dimensions of the mold cavity are determined using equations (1) and (2) with the final dimensions of $35 \times 260 \times 260$ mm. The mold cavity can be seen in Fig. 4.

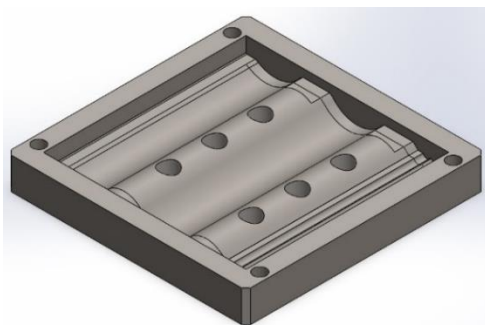


Fig. 4. Mold cavity.

Mold core and cavity using SS400 material, which has the advantages of high strength, low price, easy availability, and low elasticity [9]. Table 1 shows the mechanical properties of SS400.

Table 1. Mechanical properties SS400

Mechanical properties	Value
Tensile strength, MPa	400 – 550
Yield strength, MPa	250
Elongation, %	20
Modulus of elasticity, GPa	200
Bulk modulus, GPa	140
Poissons ratio	0.260
Shear modulus, GPa	79.3

The heating element used in this study is a cartridge heater with a power of 1500 watts, shown in Fig. 5.



Fig. 5. Cartridge heater.

The next step is to import 3D images previously designed in Solidworks software into Ansys Student R1. Next, create a mesh to convert complex geometric shapes into more straightforward elements such as triangles, quads, and tetrahedrons, making it easier to analyze. After creating the mesh, the boundaries condition is set, which is a set of boundaries or conditions applied to the model for simulation. These conditions provide detailed instructions on how the model should interact with the surrounding environment during analysis. Running is done when the boundaries condition has been set; if the running is successful, it will continue to make conclusions, while if the running fails, it must return to pay attention to the mesh that has an error. Mold heating time is compared by calculating mold heat. Heat calculation can be calculated based on Eq. 3. Mold heating time can be calculated using Eq. 4.

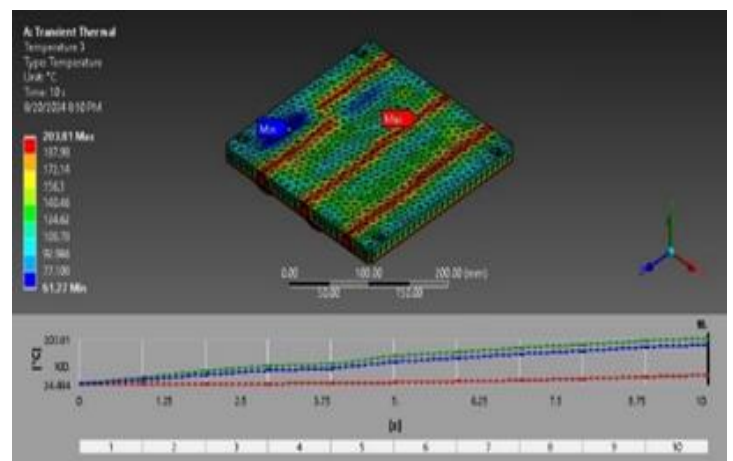
$$Q_{mold} = m C_p \Delta T \# \quad (3)$$

$$Q_{total} = P_{heater} \times t_{mold} \# \quad (4)$$

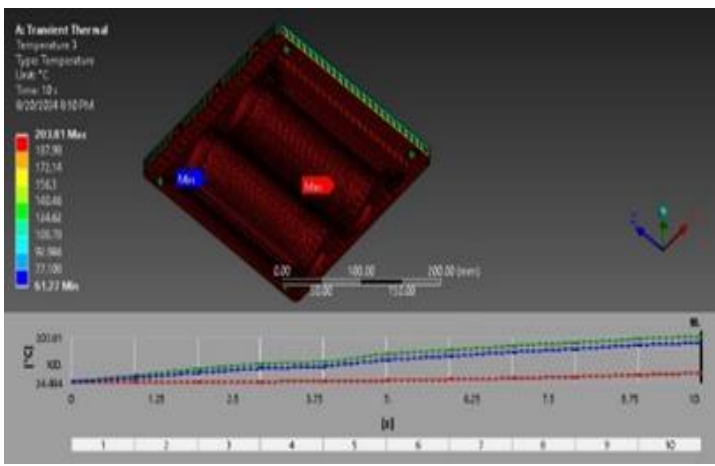
Where m is the mass of the object (kg), C_p is the specific heat (J/kg°C), and ΔT is the temperature change (°C). Based on the calculation results, the mold's heat is 256,175.286 Joules, and the time required to heat the mold is 170.78 seconds.

3 Results and Discussion

Von Mises criteria are used to model and calculate the mold core and cavity. The design results are applied in simulation and calculation. The 3D design results of the mold core and cavity are shown in Fig. 3 and Fig. 4. Furthermore, numerical calculations and simulations were performed using Ansys 2024 R1 Student software. The material used is SS400. The heater cartridge is placed in the mold core with a maximum temperature of 200°C. The simulation results with Von Mises criteria can be seen in Fig. 6.



(a)



(b)

Fig. 6. Temperature distribution analysis results for mold core, (a) top view, (b) bottom view of mold.

Fig. 6 shows the temperature distribution simulation, with the maximum temperature generated being 203.8°C. The picture shows the temperature is evenly distributed in Fig. 6(b). However, the temperature is still uneven in the contour part of the mold and the top of the mold due to the heat resistance, which is still unevenly seen in Fig. 6(a). Some parts are still 61 C. The time required for heating is 10 seconds.

The transient thermal analysis performed on the mold cavity using Ansys software showed that the temperature distribution on the object varies from a minimum temperature of 70.312°C to a maximum temperature of 200.71°C. The highest temperature is in the area shown in red, while the lowest temperature is in the blue area, indicating good cooling in that area. The analysis was conducted over 10 seconds, and the graph at the bottom shows that the temperature increased gradually over that period. The maximum temperature rises significantly to about 200°C within 10 seconds, while the average and minimum temperatures increase more slowly. These results indicate uneven heat distribution, possibly related to the cooling system design or material characteristics. Optimization of high-temperature areas for more even heat distribution is recommended to improve the system, either through redesigning the cooling channels or selecting materials with better thermal conductivity.

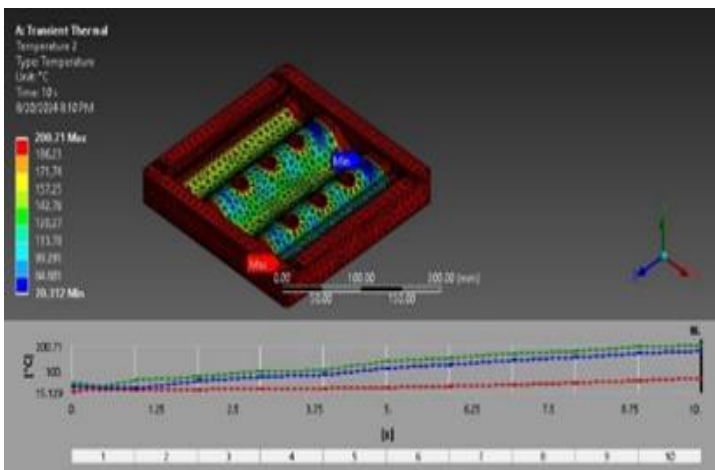


Fig. 7. Temperature distribution analysis results for mold cavity.

Fig. 8 shows the results of a transient thermal analysis using Ansys 2024 R1 software, which evaluates the temperature distribution on a component for 10 seconds. This analysis notes that the maximum temperature reached was 201.81°C, while the minimum temperature was 70.312°C. The temperature distribution is shown through color variations, with red areas signifying high temperatures and blue signifying low temperatures. The graph at the bottom of the figure shows the increasing trend of the

temperature at three different points during the process, where the temperature starts at around 15°C and continues to increase for up to 10 seconds. These results are essential for understanding the heat distribution and cooling efficiency of components and help in thermal design optimization to improve the performance of the product or system.

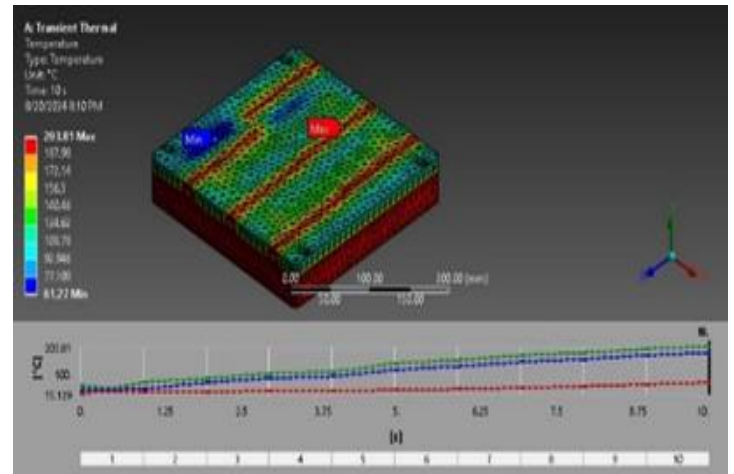


Fig. 8. Temperature distribution analysis results for mold core and cavity assembly.

The minimum temperature obtained is 70.312°C, which will cause uneven heat in the cavity and mold, resulting in product defects. Uneven heat can be seen in Fig. 9, which shows the results of roof tile products.



Fig. 9. Product results with uneven heating.

The difference obtained from manual calculation with simulation is enormous. The results of manual time calculations used to heat the cavity and core in making bio-composite roof tiles for 170.78 seconds are shown in Fig. 10. The results of heating the mold for the core and cavity obtained bio-composite roof tiles are in accordance with SNI 03-2095-1998 standards by visually checking for dimensions of 200 mm × 200 mm.



Fig. 10. Bio-composite roof tile.

4 Conclusion

This study found that the heat distribution of the cartridge heater in the core compression molding process is significant for bio-composite roof tile fabrication. Optimal heat distribution can improve the quality and strength of the roof tiles. Analysis of the heat distribution of the cartridge heater in the core compression molding mold obtained a time of 10 seconds to heat the mold, while in the manual calculation, a time of 170.78 seconds was obtained to heat the mold.

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