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Design Analysis of Mold Cavity and Core on Compression Molding of Composite Material

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Abstract

This study discusses the design analysis of compression molding cavity and core under 12 tons of pressure and 100ºC heat using experimental analysis and Ansys R19.2 simulation. This compression mold is used to process composite materials, mainly thermoset matrix composites. The compression product is a tensile test specimen according to the American Society for Testing and Material (ASTM) D638-4 standard. The main concern of this study aimed to analyze the stress distribution and deflection due to the compression load and heat on the cavity and core of compression molding. Hence, the die construction is safe during the operation under these loads. The analysis was carried out using Von Mises's stress of static loading criteria. The research parameter examined are stress distribution, deflection, and some critical dimensions in the cavity and core. These parameters significantly affect mold performance, product quality, and service life. Experimental analysis shows that the maximum deflection of the cavity and the core is 4.40 x10^{-4} mm and 1.53 x 10^{-4} mm, respectively. On the other hand, Simulation analysis shows the maximum deflection of the cavity and core is 4.56 x 10^{-4} mm and 7.41 x 10^{-5} mm, respectively. The error between experimental analysis and simulation is 6.87 x 10^{-5} mm and 3.32 x 10^{-5} mm for the cavity and the core, respectively. For stress analysis, the maximum value is 37.94 MPa for both cavity and core. On the other hand, simulation analysis shows 262 MPa and 256 MPa for the cavity and core, respectively. Both experimental analysis and simulation show that the result complies with the standard, less than 0,025 mm for deflection, and stress is less than 1034 MPa for maximum stress. Therefore, compression mold structure is safely used.

Keywords: cavity, core, stress, heat, simulation.

1 Introduction

Bio-composite consists of a polymer matrix and natural fiber reinforcement [1]. The brittle property of the thermoset is improved by the more ductile fiber property so that the combination of properties improves the strength, ductility elongation, stiffness, and impact strength. Compression molding is becoming essential for composite materials processing at this time [2]–[4]. This compression molding machine and its tooling have been widely developed for processing plastics and biomaterials. However, the existing machines in the industry still have limitations, one of which is the limited use of certain materials and needs. Another limitation is the complexity of use and slow production speed.

Previous studies have discussed and developed research on composite molding machines and the material mixing process. Some of them are developing machines for materials derived from natural fibers. Kim et al. (2019) developed a compression machine used in thermoset fiber composite materials. The machine processes carbon fiber with a length of 50 mm mixed with epoxy resin [5]. This study also performs simulations with finite element analysis. Wulfsberg et al. (2014) developed compression molding for thermoset composite materials [6]. In this research, molding is developed and used for thermoset fiber composites with plastic reinforcement for the aerospace industry. Fette et al. (2015) developed a mold used in the compression molding process using additive manufacturing [7]. This study used Selective Laser Melting (SLM) made with metal powder. Yang et al. (2010) developed a compression technique for thermoset resin materials with soybean oil and natural fiber reinforcement [8].

Other studies of mixing composite materials with compression techniques have also been carried out. Al-Mezrakci et al. (2021) developed a thick-walled Polyester Ether Ketone (PEEK) blending process using a compression molding instrument [9]. The calculation of the thermal conductivity modulus is carried out after the composite material has been successfully fabricated. Shamsuri et al. (2015) used combinations of four types of materials: High-Density Polyethylene (HPDE), agar biocomposite, Virgin Low-Density Polyethylene (LDPE), and woven biocomposite to fabricate containers [10]. Guleria et al. (2021) developed composite mixing to manufacture kevlar materials using the molding process [11]. The Kevlar has flexural properties, good absorption energy, and the desired hardness. Effect of Compression Molding Pressure on the Performance of Graphite Composite/Epoxy Resin Composite Plates with 20% Coconut Shell Carbon Composition. Uswah and Muslimin (2020) investigated the effect of molding pressure on the Performance of a Graphite Composite Bipolar Plate/Epoxy Resin Composition of 20% Coconut Shell Carbon [4].

The mold cavity and core are the main components of a compression molding machine [1]. A cavity is a part of the mold that determines the shape and quality of the product. While the core is sometimes called force, plunger, or core, the male part of the mold forms the inner contour of the product. The other half is called the cavity, the female part of the mold, because it forms the outer contour of the product. The cavity itself is a component that receives a heavy load due to the pressure from the hydraulic rod, so proper calculations are needed to design the cavity to function correctly and remain safe to use. The cavity must be properly designed so that the results of compression molding products meet the needs and the molding itself will last a long life.

Based on the need for the safe construction of mold, this study aims to analyze the stress distribution in the mold cavity under 12-ton hydraulic pressure and 100ºC heat using experiment computation and software analysis.

2 Research Methods

Compression molding is the most common manufacturing process for thermoset and thermoplastic polymer composite. It can produce many useful thermosets and thermoplastics products, such as furniture and high-strength automotive components. Asim et al. (2017) classify compression molding into two basic processes: cold and hot [12]. In the cold process, only pressure is implemented, and the curing process takes place at room temperature. However, in the hot process, both pressure and temperature are required. In hot process, the curing process is initiated by heat.

In thermosetting-matrix based, a Bulk Molding Compound (BMC) and a sheet molding compound are the typical types of product. In contrast, a Glass Mat Thermoplastic (GMT) is normally utilized for thermoplastic. Polyester is a thermoset material often used as molding compound (intermediated semi-cure) composites because of its more affordable and good mechanical properties. In common, compression molding of fiber with thermoset-matrix such as BMC and SMC needs 2.4 MPa to 17 MPa pressure and 121ºC to 177ºC at 30 s to many minutes, as shown in Table 1.

Table 1. General Processing of Fiber Reinforced Compression Molding [12]

Fiber-Reinforced Compound	Molding Pressure (MPa)	Molding Temperature (ºC)	Cycle time (second)
BMC (Thermoset)	2.7 - 17	121 - 177	30 s to many minutes
SMC (Thermoset)	3.4 - 17	121 - 171	30 s to many minutes
GMT (Thermoplastic)	10 - 14	25 - 70	30-60 s

Compression molding structure consists of the upper-heated platen, lower-heated platen, upper mold half (core), lower mold half (cavity), base plates, moving plate, hydraulic unit, slide rods, and ejector unit, as shown in Fig. 1 [1]. The temperature range of electric heaters in common is 150–200°C. However, the temperature can be lower, and it prefers to use hot oil for higher temperatures.

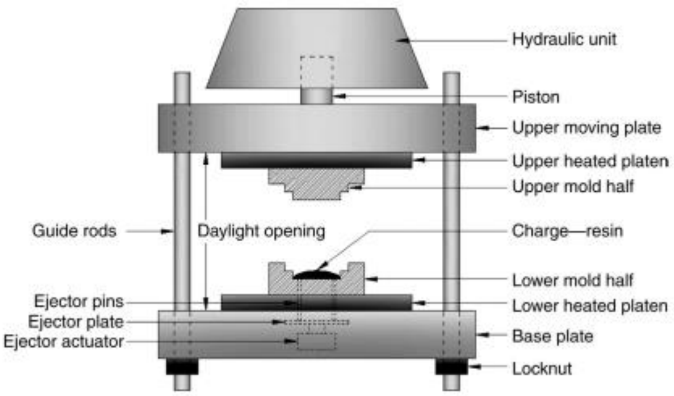

Fig. 1. Schematic view of the major components of a typical compression press

The compression molding process consists of four main steps: loading of charge into the mold, compaction in a heated mold, curing of part inside the cavity, and Removal of solidified part from the mold, as shown in Fig. 2.

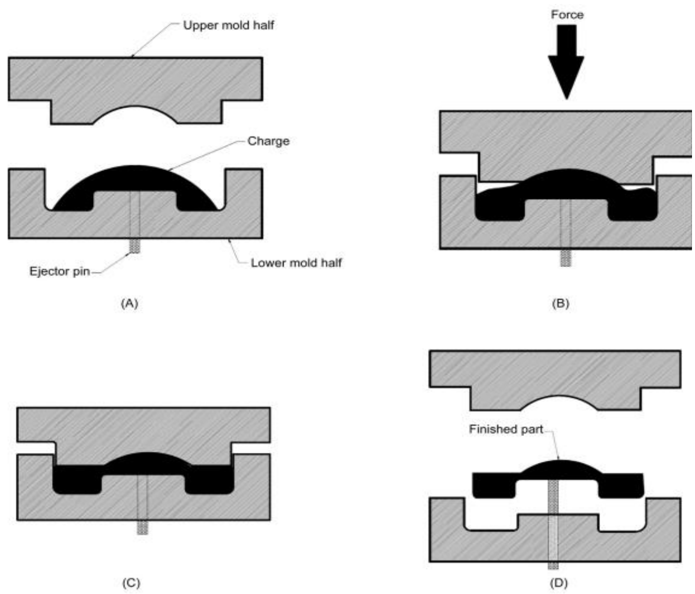

Fig. 2. The compression molding process as described by a implified, four-step procedure. (A) Loading of charge into mold. (B) Compaction of charge in heated mold. (C) Curing of part inside mold cavity. (D) Removal of solidified part.

2.1 System Design

The mold was designed using the Solid work 2018 software. The mold and cavity design was then simulated by static loading to determine the stress distribution using manual and Ansys R19.2 Software. The parameters involved in this analysis were material properties, load, and support in the cavity. Loading is carried out simultaneously with the requirement of temperature input. The data was inputted into the software and simulated how the stress distribution occurs. The results are then analyzed and compared with manual computation.

The main objective of this design is to get a safe structure with a long-life service mold with a good quality product. In this case, the product's shape is a tensile testing specimen. The product release uses two ejectors, which can facilitate the product release process. It is used to streamline the whole process. Second, the cavity design shaped like a dog's bone will make the product suitable and can be directly given a tensile test according to the ASTM D638-4 standard.

The compression mold design in this research is shown in Fig. 3. The main components of mold are a core, cavity, heater, and insulation plate. In addition, the others are ejector springs, ejector plates, ejector profiles, ejector pins, top plates, bottom plates, and base plates. The ejector pin is used as a tool that pushes the compressed product. The ejector pin is placed on the ejector plate, penetrates, and is connected to the ejector profile. The ejector spring is placed at the bottom of the compression molding machine. The ejector spring helps push back the ejector plate so it can be used again immediately.

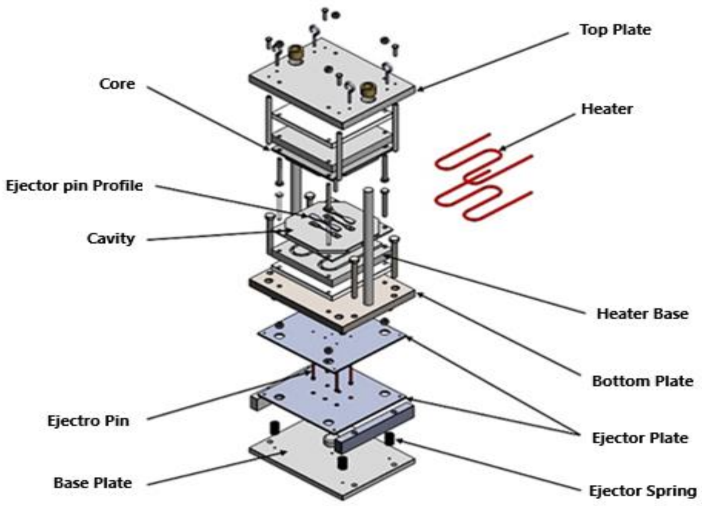

Fig. 3. Compression Molding for Composite

The material is selected based on its mechanical properties requirements. The material requirements for molding are strength, good wear-resistant, good thermal conductivity, good machinability, and affordable prices [13][14]. The material used for the core and the cavity is SKD 61, which is rigid and robust properties, while the others used SS400 rolled steel. The mechanical properties of SKD61 (JIS G 4404) and SS400 (JIS G 3101) are shown in Table 2.

Table 2. Mechanical properties [15]

Material	Elastic Modulus (GPa)	Yield point (MPa)	Tensile strength (MPa)	Elongation (%)	Hardness (HRB)
SS400	206	205-245	400-510	17-23	160
SKD61	190-210	1034	1158	15	335

2.2. Target Design

In this work, this compression molding machine was designed to produce a product in the form of tensile test specimens from composite material. This specimen is designed according to the ASTM D638-4 standard, as shown in Fig. 4. The design has a shape resembling a dog's bone because, in the tensile test process, the two heads from the end of the product will be clamped during the tensile test. The design is 115 mm long and 19 mm wide. The specimens also have specific radii with a length of 33 mm in the middle. Therefore, this machine can produce tensile test specimens from various composite materials.

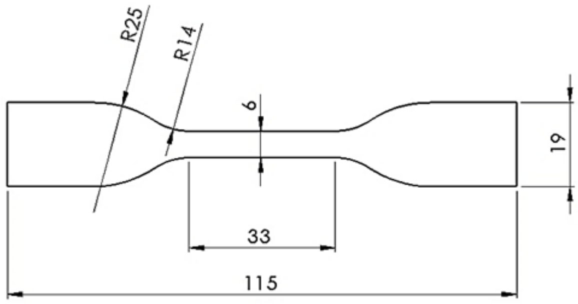

Fig. 4. Tensile test specimen ASTM D638 – 4 standards

Mold design consists of a core or a male part and a cavity or female part. In a mold, two tensile test specimens are formed as compression mold products. Therefore, the external load is distributed on both of the products. The cavity and core design with two products attached is shown in Fig. 5.

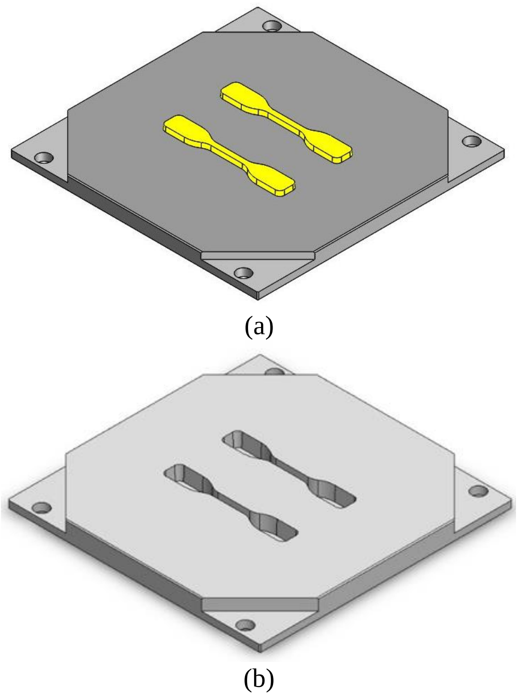

Fig. 5. (a) Core design and (b) Cavity design

Pressure P_m on the cavity and the core based on the load and product area can be calculated using the following Eq.1:

$$P_m = \frac{F_{hydraulic}}{A_{product\_area}} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

where $F_{hydraulic}$ is the external load (hydraulic) that works in Cavity and Core when compression molding is implemented. $A_{product\_area}$ is an area of product perpendicular to the load direction.

Fig. 6 shows the location of the product on the mold cavity, which is the fulcrum of the cavity in receiving maximum pressure. While the minimum stress occurs at the angular ends of the cavity, this part does not come into direct contact with the core, so the stress received is not as significant as other parts. Stress distribution on the mold core is a similar pattern to the cavity.

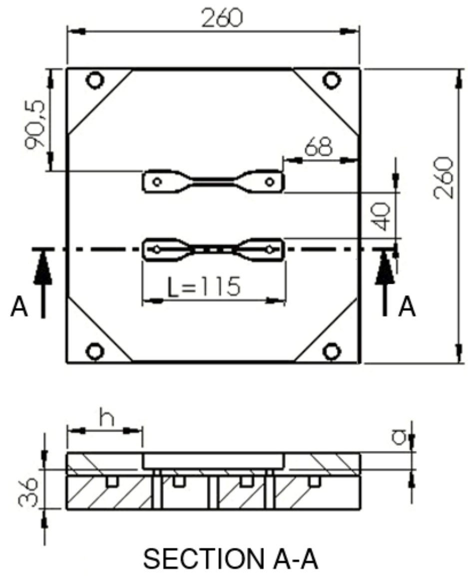

Fig. 6. Detail design of cavity

2.2 Cavity and core computation

2.2.1 Deflection

Deflection is a change in the beam shape in the horizontal direction due to the vertical loading applied to the beam or rod as shown in Fig. 7. The beam deformation can be explained very obviously by the deflection from its position before and after loading. Deflection is measured from the initial neutral surface to the neutral position after deformation occurs. The assumed configuration with neutral surface deformation is known as the elastic curve of the beam. If deflection occurs in the mold, it will accelerate mold damage, and the resulting product does not comply with specifications.

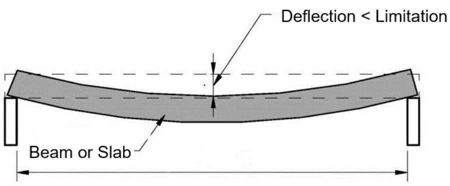

Fig. 7. Deflection of beam

2.2.2 Deflection and critical dimension in Cavity side

The deflection and minimum dimensions of h and b of the cavity are essential parameters in compression molding, as shown in Fig. 8.

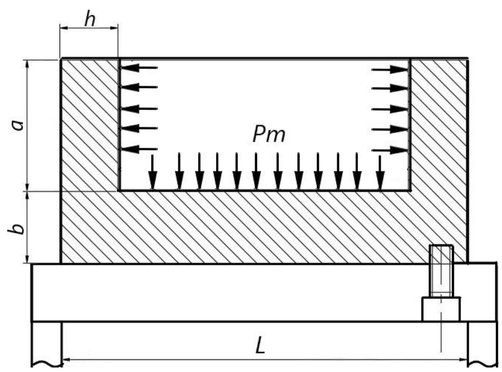

Fig. 8. The solid structure of the mold cavity

Assume uniformly distributed load, Deflection, δ_{Max} on cavity is calculated using the following Eq. 2:

$$\delta_{Max} = \frac{P_m.a.L^4}{384.E.I} \quad ....(2)$$

The minimum dimension of h and b is calculated using the following Eq. 3-4:

$$h = \sqrt[3]{\frac{c.P_m.a^4}{E.\delta_{max}}} \quad .... (3)$$

and

$$b = \sqrt[3]{\frac{5.P_m.w.L^4}{32.E.W.\delta_{max}}} \quad .... (4)$$

where P_m is mold pressure in kgf/mm^2, a is the depth of product space in mm, L is the length of the product in mm, E is the modulus of elasticity in kgf/mm^2, I is the moment of inertia of the section in mm^4, w is the width of the product in mm, W is the width of cavity plate (mold) in mm, and c is the coefficient of the ratio of width to depth of cavity.

2.2.3 Deflection and critical dimension in Core side

Deflection, δ_{Max} on the Core side, is calculated based on Fig. 9 using the following Eq. 5:

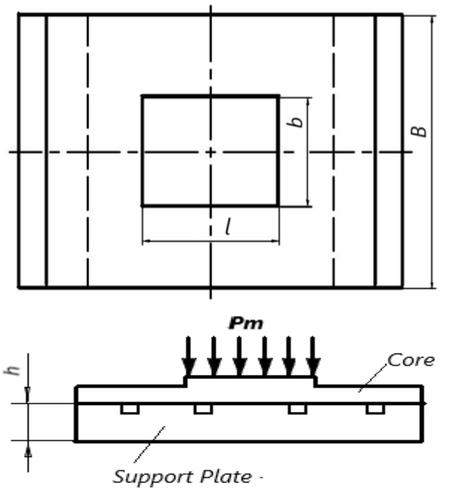

Fig. 9. The solid structure of the mold core

$$\delta_{Max} = \frac{5.P_m.b.l^4}{384.E.I} \quad .... (5)$$

The minimum dimension of h is calculated using the following Eq. 6:

$$h = \sqrt[3]{\frac{5.P_m.b.l^4}{32.E.B.\delta_{max}}} \quad .... (6)$$

Where P_m is mold force in kgf/mm^2, b is the width of mold pressure in mm, B is the width of the support plate in mm, l *is* the length of the product in mm, L is the length Core plate in mm, and I *is the* moment of inertia of the section in mm^4.

2.2.4 Software Simulation

The simulation is implemented to define the cavity and core stress and deflection using Ansys R19.2 software. The parameter used is stress and thermal in the toolbox related to real condition. The next step is to enter the *material properties* data into the *software*. In this work material used is SKD 61 for mold and SS400 for other components. Then static loading derived from the hydraulic rod is carried out by a maximum of 12 tons on the upper surface of the *cavity*, while on the lower surface, it is determined as the fulcrum. Loading is carried out simultaneously with the provision of temperature input from the *heater* of 100° C. Data inputted in the *software* is then simulated on analysis of the stress distribution, and deflection occurs both in the cavity and the core. The result of manual computation and software simulation result is then compared and analyzed.

2.3 Failure criterion

The analysis uses the principal stresses as follows Eq. 7:

$$\sigma_{1,2} = \frac{\sigma_x - \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x + \sigma_y}{2}\right)^2 + \tau_{xy}^2} \quad .... (7)$$

The failure analysis using Von Misses criteria is as follows Eq. 8:

$$(\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2) \leq \sigma_y^2 \quad .... (8)$$

where σ_x, σ_y are stresses caused by axial force in MPa, τ_{xy} is shear stress in MPa, $\sigma_{1,2}$ is principal stress in MPa, and σ_y is yields strength of the material.

In this work, the deflection criterion is not higher than 0.025 mm. This deflection is often used in the molding industry.

3 Results and Discussion.

The design cavity is analyzed to optimize the mold system of the developed compression machine. This machine is a downstroke type of compression molding machine. A source of the compressive force of this downstroke compression molding comes from an upward direction so that the cavity will still accept the load. At the same time, the punch or core will move down, pressing the cavity.

The Cavity dimension is 260 mm x 260 mm x 20 mm. The cavity receives 12 tons of pressure from the hydraulic rod. This load is the optimum pressure that can be applied to the composite molding process on this machine [11]. The heating temperature received from the heater is 100° C. The *cavity* and core design are then analyzed using manual computation and Ansys R19.2 software.

3.1 Experimental Computation of Cavity and Core

- Internal Stress

Stress on both Cavity and Core is calculated by using Eq. 1. If the external load is 12-ton, hydraulic pressure $\left(F_{hydraulic} = 12\ ton\right)$, by using g=9,81 $\frac{m}{s^2}$, $F_{hydraulic}$ is equal to $117{,}720\ N$. A product area ($A_{product\_area}$), regarding Fig. 4 and by using Solid work software, is $1551.49\ mm^2$. Because of two cavities $A_{product\_area}$ becomes 3102.98 mm^2. Therefore, maximum internal pressure (P_m) by using Eq. 1 is 37.94 MPa or equal to 3.87 kgf/mm^2. Suppose the load is only compression (Eq. 7-8), therefore principal stress is equal to compression stress (37.94 MPa). The yield strength of SKD 61 Steel is 1034 MPa. Therefore, the mold is safely used for this structure.

Cavity computation

- Maximum deflection

Based on Fig. 6 and Fig. 8, if internal pressure (P_m) is 3.87 kgf/mm^2, cavity length l is 115 mm. The depth of cavity a is 14,4 mm, modulus elasticity E_{SKD61} is 210 GPa (2.14 x 10^4 kgf/mm^2) and moment of inertia $I_{Cavity\ SW} = 2{,}696{,}704.77$ mm^4, then maximum deflection is calculated using Eq. 2 $\left(\delta_{Max} = \frac{P_m.a.L^4}{384.E.I}\right)$ is 4.40 x 10^{-4} mm. Therefore, the maximum deflection is lower than deflection criteria (0.025 mm).

- Dimension of h minimum

Dimension of h minimum of the cavity for unification mold construction as shown in Fig. 8. Assume dimension b is fixed, and for $\frac{l}{a} = 7.981$, c *is* 0.244. Choose a maximum deflection δ_{max} is 0.025 mm as the standard of safe deflection on mold. Using Eq. 3,

$\left(h = \sqrt[3]{\frac{c.P_m.a^4}{E.\delta_{max}}}\right)$, the dimension of the h minimum is 4.24 mm. The design's minimal distance is 40 mm (distance between cavities). Therefore, the structure is safe.

- Dimension of *b* minimum

Suppose the assumed dimension of *h* minimum is fixed. In that case, width *w* is 19 mm (for two products, width w becomes 38 mm), and *W* is 260 mm for the cavity with unification mold construction, as shown in Fig. 8. Dimension *b* minimum is calculated using Eq. 4, $\left(b = \sqrt[3]{\frac{5.P_m.w.L^4}{32.E.W.\delta_{max}}}\right)$, which is 30.69 mm. The design's minimal distance *b* is 36 mm (back plate). Therefore, the structure is safe.

Core computation

- Maximum deflection

Based on Fig. 9, if internal pressure (P_m) is 3.87 kgf/mm^2, core length *l* is 115 mm The length of *b* is 19 mm (for two products, *b* becomes 38 mm), modulus elasticity, E_{SKD61} is 210 GPa (2.14 x 10^4 kgf/mm^2) and $I_{Cavity\ SW} = 2{,}696{,}704.77\ \text{mm}^4$, and then maximum deflection δ_{Max} is calculated using Eq. 5, $\left(\delta_{Max} = \frac{5.P_m.b.l^4}{384.E.I}\right)$ is 1.53 x 10^{-4} mm. Therefore, maximum deflection is lower than deflection criteria (0.025 mm).

- Dimension of *h* minimum

Dimension of *h* minimum of the core for unification mold construction as shown in Fig. 9. *B* is 260 mm. Choose a maximum deflection, $\delta_{max}$is 0.025 mm as the standard of safe deflection. Using Eq. 6, $\left(h = \sqrt[3]{\frac{5.P_m.b.l^4}{32.E.B.\delta_{max}}}\right)$, the dimension of the h minimum is 30.67 mm. In the design, the size of the h minimum is 40 mm. Therefore, the structure is safe.

3.2 Simulation Computation using Ansys R19.2

Cavity and Core computation

The computation determines the element to define the cavity in the software by selecting thermal - stress in the toolbox. The next step is to enter the SS400 *material properties* data into the *software*. Then static loading derived from the hydraulic rod is carried out by a maximum of 37.94 MPa (3.87 kgf/mm^2) on the upper surface of the *cavity*, while on the lower surface, it is determined as the fulcrum. Loading is carried out simultaneously with the provision of temperature input from the *heater* of 100° C. Data inputted in the *software* is then simulated on how the stress distribution occurs.

Fig. 10 and 11 show the stress distribution in the cavity and core, respectively. Based on both Fig.s, the dark blue color (number 1) is the surface that is exposed to the minimum stress (9.7323 x 105 Pa) as well as the gray color (number 2) with a stress value is 1.2838 x 108 Pa, and the Cyan color (number 3) with the stress value is 9.7323 x 10-5 Pa. Based on the color in both Fig. 10 and Fig. 11, the maximum stress distribution is 2.6274x108 Pa (262.74 MPa) (indicated by cyan color) in the center of the mold cavity and 2.5579x108 Pa (255.79 MPa) (indicated by cyan color) in the center of mold core. Therefore, the maximum stress on the cavity is 2.62x108 Pa (262 MPa or 26.72 kgf/mm2). While maximum stress on the core base Fig. 11 is 2.56x 108 Pa (256 MPa or 26.10 kgf/mm2).

Fig. 10 and 11 show the location of the most significant stress on the cavity's mold and cavity respectively, which are the fulcrum of the cavity in receiving maximum pressure. While the minimum stress occurs at the angular ends of the cavity, this part does not come into direct contact with the core, so the stress received is not as significant as other parts. Based on Von Mises' failure theory, the maximum pressure in the cavity is still under the criteria (yield strength of SKD 62 steel, 1034 MPa). The deflection that occurs is lower than criteria (0.025 mm), so the cavity is safe to use.

Fig. 12 and 13 show the maximum deflection in the cavity and core, respectively. Both Fig.s shows the deflection distribution on the cavity's surface when pressure is applied, which is indicated by a different color. The red color (number 1) indicates the maximum deflection on the surface with a value of 4.5862x10^{-5} mm. The brown color (number 2) indicates deflection on the surface is 4.0766x10^{-5} mm, while the yellow (number 3) deflection is 3.5671x10^{-5} mm and the green color is 3.0575x10^{-5} mm. Based on the color distribution, the maximum value of deflection is 4.5862 x10-5 mm below the requirements commonly used by industry, at most 0.025 mm.

Based on the results of manual and software calculations, it can be compared that the deflection results are not too different. This is because the mold construction includes a backplate (thick enough), so the deflection is small. The stress distribution for all elements can only be shown by software simulation results, as shown in Fig. 7 and Fig. 8. The stress distribution is small in all bode elements, both in the cavity and core, because the dimension is sufficient to withstand the internal stress. The result is tabulaed in Table 3.

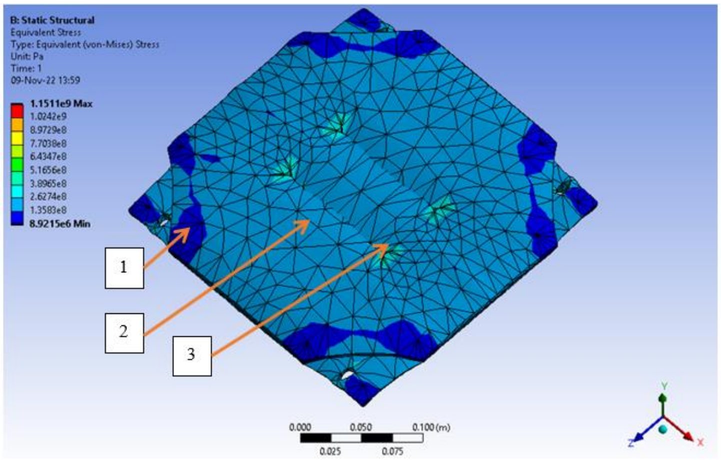

Fig. 10. The result of stress distribution of cavity using Ansys R19.2

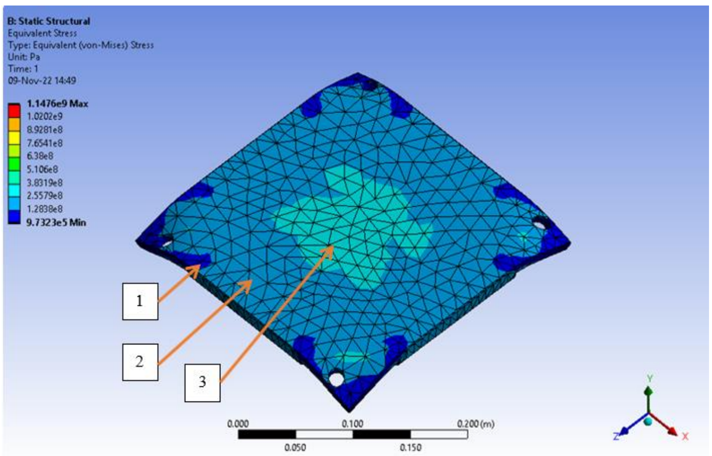

Fig. 11. The result of stress distribution of Core using Ansys R19.2

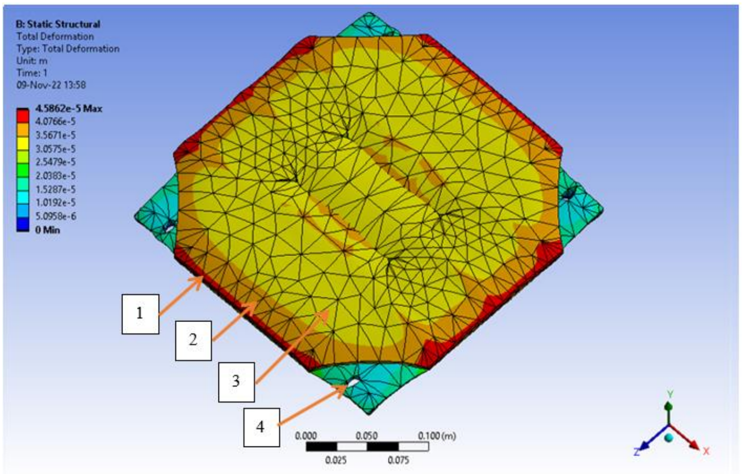

Fig. 12. The result of deflection of Cavity using Ansys R19.2

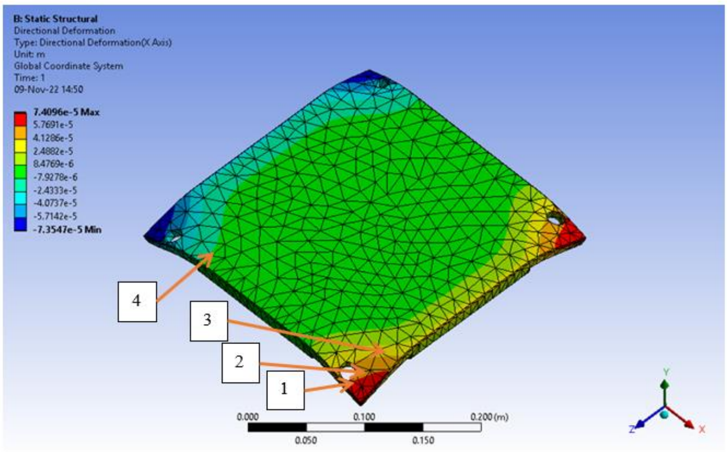

Fig. 13. The result of deflection of Core using Ansys R19.2

Table 3. Max deplection of cavity and core

	Max Deflection			Standard	Conclusion
	Experimental Computation	Ansys Simulation	Error		
Cavity	4.40 x 10^{-4} mm	$4.56x10^{-5}\ mm$	$6.87\ x10^{-5}\ \ mm$	< 0.025 mm	safe
Core	1.53 x 10^{-4} mm	$7.41x10^{-5}\ mm$	$-3.32x10^{-5}mm$	< 0.025 mm	safe
	Max Stress				
	Experimental Computation	Ansys Simulation	Error		
Cavity	37.94 MPa	$2.62x10^{8}$ Pa (262 MPa)	-	< 1034 MPa	safe
Core	37.94 MPa	$2.56x10^{8}$ Pa (256 MPa)	-	< 1034 MPa	safe

Based on the result, experimental analysis shows that the maximum deflection of the cavity and the core is 4.40 x10-4 mm and 1.53 x 10−4 mm, respectively. While simulation analysis shows the maximum deflection of the cavity and core is 4.56 x 10−4 mm and 7.41 x 10-5 mm, respectively. The error between experimental analysis and simulation is 6.87 x 10-5 mm and 3.32 x 10-5 mm for the cavity and the core, respectively. Experimental computation for stress analysis is 37.94 MPa for the cavity and core. Simulation analysis shows 262 MPa and 256 MPa for the cavity and core, respectively. Both experimental analysis and simulation show that the result is appropriate to the deflection standard, less than 0,025 mm for deflection, and stress is less than 1034 MPa for maximum stress.

4 Conclusions

This work is a design analysis of compression molding for composite process, mainly thermoset-matrix natural fiber composite, with 12-ton pressure and 100oC heat. The concerned analyses are stress and deflection of the core and cavity. The failure analysis uses von misses criteria. The mold cavity is a tensile test specimen shaped like dog bones, according to ASTM D638-4 standards. The mold cavity and core is SKD61 steel, and the other part is SS400 steel. Experimental examination results show that the maximum deflection of the cavity and the core is 4.40 x10-4 mm and 1.53 x 10−4 mm, respectively. While simulation shows the maximum deflection of the cavity and core is 4.56 x 10−4 mm and 7.41 x 10-5 mm, respectively. The study shows that the error between experimental analysis and simulation is 6.87 x 10-5 mm and 3.32 x 10-5 mm for the cavity and the core, respectively. Experimental computation for stress analysis is 37.94 MPa and 37.94 MPa for cavity and core, respectively. Simulation analysis shows 262 MPa and 256 MPa for the cavity and core, respectively. Both experimental analysis and simulation show that the result is appropriate to the deflection standard, less than 0,025 mm for deflection, and stress is less than 1034 MPa for maximum stress. Based on Von Mises' failure theory concludes that the stress that occurs in the cavity is still lower than the criteria for structural failure. The deflection is also minimal, so the cavity and core are safely used in compression molding for thermoset matrix composite.

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