M. Giorgetti et al. (Eds.)

doi:10.3233/ATDE240614

Development of a Hydraulic Press for Composite Material Fabrication

Wai Heng CHOONG [a,1], Muhammad Fadzlih BAHARUDIN [a], Hou Pin YOONG [a], Bih Lii CHUA [a] and Mohd Kamal MOHD SHAH [a]
[a] *Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia*

Abstract. This paper presents the development of a hydraulic press machine for composite material fabrication, specifically aimed at educational purposes. Although various hydraulic press machines are available, this development addresses specific needs and financial limitations. The project adhered to defined design requirements, evaluated through finite element analysis (FEA) and further refined into a physical prototype. An on-scale 3-dimensional virtual model modeled for FEA purposes. The analysis revealed that the machine structure deforms by 0.57 mm along the vertical axis under a maximum compression load of a 2-ton hydraulic jack, which is insignificant influenced the fabricated composite panel thickness uniformity. A physical prototype was constructed based on the blueprint drawing, and a series of trial composite material panel fabrications were conducted for improvement purposes. Through a series of fine-tuning adjustments, the resulting panels achieved overall maximum thickness deviation of 3.81%, meeting the ASTM D7136 tolerance for drop-weight impact resistance testing.

Keywords. Hydraulic press machine, composite material fabrication, finite element analysis, thickness deviation

1. Introduction

Research and development in composite materials are continually advancing across various material classes. Natural fiber composite materials are in high demand due to their advantages, such as low cost, biodegradability, superior specific properties, and abundance as a natural resource [1].

The manufacturing process of composite materials is directly influenced by factors such as stacking sequence, fiber volume fraction, and the curing process [2]. There are various methods for manufacturing composite materials, with hand lay-up being one of the most common. However, this approach is far from ideal due to its low production rates and the need for additional compression tools for effective compression, as opposed to relying on dead weight compression. Dead weight compression can lead to inconsistent thickness, poor bonding properties, and low-density material. Hand lay-up techniques offer advantages such as design flexibility, low tooling costs, and the ability to produce large and complex items with the use of semi-skilled workers. Despite these benefits, there are several disadvantages, including the production of only one good

[1] Wai Heng CHOONG, Corresponding Author, Mechanical Programme, Faculty of Engineering, Universiti Malaysia Sabah, Jln UMS, 88450 Kota Kinabalu, Sabah, Malaysia; E-mail: whchoong@ums.edu.my.

(molded) surface, low production volumes, and difficulty in maintaining product uniformity within a single part or across multiple parts [3].

The design and development of a hydraulic press machine offer a solution to the challenges associated with manual fabrication techniques of composite materials and development budget. Utilizing a hydraulic jack to deliver evenly distributed pressure allows for precise control of specimen thickness and enhances material quality. The ability to control compression pressure helps reduce void formation by forcing out air bubbles before the mixture's gel time.

Many commercial hydraulic press machines for composite material fabrication come with or without heating features, and their costs range from high to low. In academic development, Hafids and Yernisa (2021) developed a machine specifically for producing natural composite materials using a screw compression mechanism and an embedded heating system [4]. Similarly, the University of Technology Yola, Nigeria fabricated a 30-ton hydraulic press machine for in-house applications such as metal forming and material strength testing [5].

In response to current needs and advancements, this project presents the development of a hydraulic press machine specifically for composite material fabrication and consideration of limitation of development budget. This machine aims to improve efficiency and quality through controlled compression and pressure distribution.

2. Hydraulic Press Development Framework

The hydraulic press main structure design and development is conducted as follows:

2.1. Design Requirement

The preliminary design of the hydraulic press begins with conceptualization. This ideation phase often lacks the detailed information needed to complete the development stage. Therefore, design criteria and requirements are established to guide the configuration and realization of the entire machine. The main design requirements are such as:

a) Ability to transfer uniform pressure during the compression process,
b) Controllable compression pressure,
c) Ability to produce panels with uniform thickness, within a tolerance of ± 0.25 mm, by the standards for drop-weight impact testing of polymer-based composite materials, ASTM D7136 [6].

2.2. Hydraulic Press Design

The machine's design requirements can be met with a solid flat steel plate of appropriate thickness to prevent bending. This plate is designed to move linearly in a flat position during compression, ensuring uniform compression. To maintain consistent pressure for subsequent fabrications, the ratio of the composite material mixture must remain constant compared to previous batches, using the same reference panel. This ensures uniform panel thickness and consistent application of pressure. The structural design follows a four-column hydraulic press concept, as shown in figure 1. The key components include the steel plate, shaft rod, linear bearing, hydraulic bottle jack, and pressure gauge. The machine operates by pumping the hydraulic jack, which pushes the middle plate upwards to compress the composite material placed inside the mold. Smooth movement of the middle plate is guided by steel rods and linear bearings. The upper plate and hollow rod are key components that can significantly influence the structural rigidity and performance of the machine.

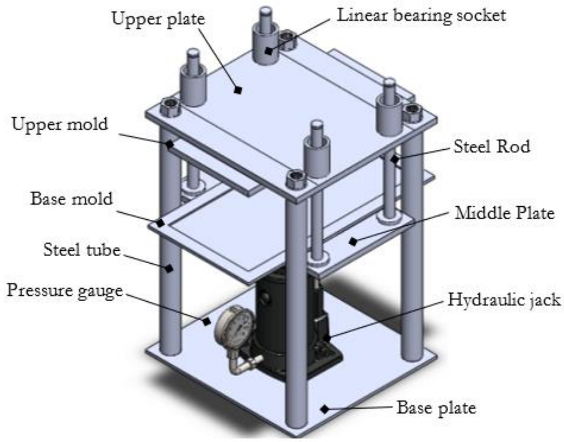
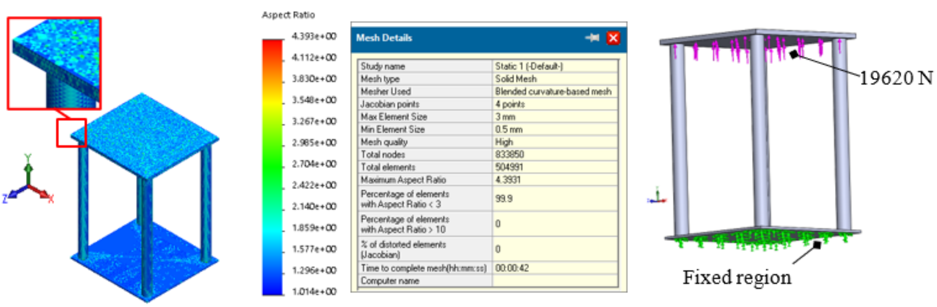


Figure 1. Virtual model of the hydraulic press machine.

2.3. FEA Structural Analysis

Finite element analysis (FEA) using SolidWorks was conducted to evaluate the structural performance of press machine main structure. The study focused on stress and deformation along the Y-axis under a 2-ton (19620 N) hydraulic jack load. The model was fixed at the base plate's bottom surface. Figure 2 shows the boundary conditions and mesh detail. The mesh was optimized with a local element size of 1 mm in critical areas, ensuring high mesh quality with maximum aspect ratio of 4.39 [7]. Figure 3 displays the deformation and stress plots. Results indicated a Y-axis deformation of 0.57 mm, with maximum deflection at the center of the upper plate. The deformation behavior will not have a significant impact on the uniformity of the composite panel's thickness. The maximum stress (σ_{max} = 187 MPa) was concentrated at the steel tube's top end point, connecting to the upper plate.



(a) Mesh plot and details. (b) Simulation boundary conditions.

Figure 2. FEA boundary conditions and mesh detail.

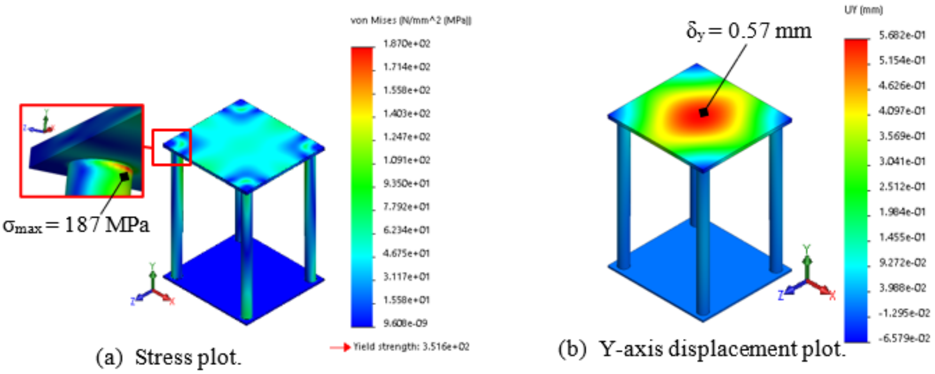


Figure 3. FEA stress and deformation plots.

2.4. Physical Prototype

Based on a series of design and verification steps, including theoretical modeling and FEA assessment, a physical prototype of the hydraulic press machine was developed, as shown in figure 4. Each component was fabricated according to the Computer-Aided Design (CAD) blueprints. The overall dimensions of the machine are 370 mm in height, 300 mm in width, and 280 mm in length. To achieve uniform compression, it is essential to ensure that the middle plate moves in a flat condition. This requirement can be assessed by examining the thickness uniformity of the composite material fabricated by the machine. If the thickness deviation of the manufactured composite panels indicates non-uniform compression, it suggests that the center plate or mold needs modification to ensure flat and even movement during compression.

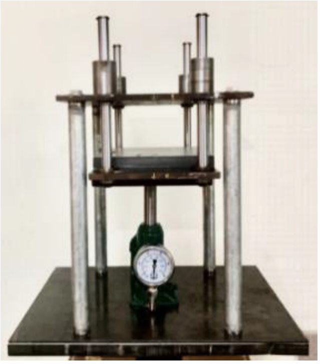


Figure 4. Fabricated physical prototype.

3. Result and Discussion

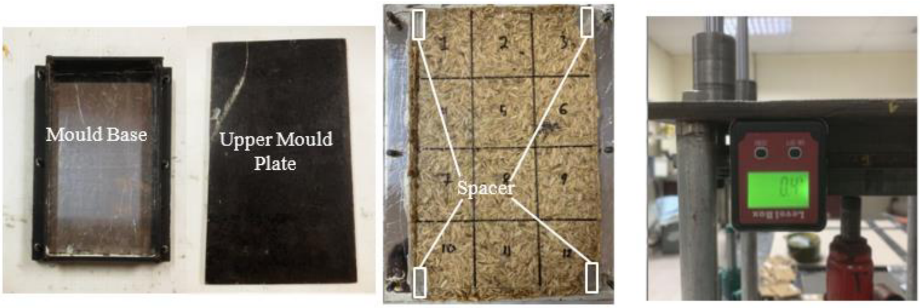
This section discusses the system functionality and performance to validate the design and ensure it meets its intended purposes.

3.1. Structural Performance

The hydraulic press machine structures are well-designed. Based on FEA results, the maximum vertical displacement is 0.57 mm at a maximum load of a 2-ton hydraulic jack. This displacement is considered insignificant regarding its influence on the structural integrity and uniformity of the product panel thickness. The vertical movement of the middle plate is guided by a linear bearing mechanism, which ensures smooth and accurate movement during the compression process. This mechanism also contributes to achieving uniform thickness in the produced panels.

3.2. Product Panel Uniform Thickness

In testing the prototyped hydraulic press machine, several rice husk-reinforced polymer composite panels were fabricated. The composite panels and fabrication tools are shown in figure 5. Three panels were fabricated and assessed for thickness uniformity. The results from each assessment were used to improve subsequent fabrications.



(a) Two-part open mold. (b) Fabricated panel. (c) Leveling with digital level gauge.

Figure 5. Rice husk reinforced polymer composite material panels and tools.

Each panel was divided into 12 sections to evaluate thickness deviation, as illustrated in figure 5(b). The evaluation allowed for precise identification of areas needing adjustment to achieve consistent panel thickness. The thickness deviation yield,

$$\Delta t = \left((t_r - t_m)\right) \times 100\% \tag{1}$$

where the reference thickness, t_r is set at 4.2 mm, and the measured thickness, t_m is the thickness of each section. Three panels were involved and the thickness deviation for each panel plotted in figure 6.

Panel 1 exhibits a thickness distribution where thickness increases gradually from upper to lower sections. Maximum deviation reaches 46.43%. Negative values indicate thicker sections and vice versa. Deviation is attributed to insufficient mixture coverage in the mold, leading to uneven pressure distribution.

Based on Panel 1 results, an improvement strategy was executed. Mold surface levelness was adjusted for uniform pressure distribution in the composite mixture. Using a digital levelness gauge (figure 5(c)), corners were aligned to the same angle. Additionally, 4.2 mm thick polyester resin plates were placed at each corner inside the mold to ensure the panel's minimum thickness. Panel 2 demonstrated significant thickness deviation reduction, with a maximum decrease to 21.43%. All sections showed slight overfilling, ensuring compliance with the 4.2 mm reference thickness.

Panel 3 followed the same procedure as Panel 2, but material quantity adjusted to achieve a 4.2 mm thickness. Assessment showed a thickness range of 4.04 mm to 4.30 mm, with deviation between -2.38% and 3.81%. ASTM D7136 specifies a ±0.25 mm tolerance for polymer composite materials, translating to 3.95 mm to 4.45 mm for a 4.2 mm thickness [6]. The hydraulic press effectively produced panels meeting this industrial standard, with deviation under 5%.

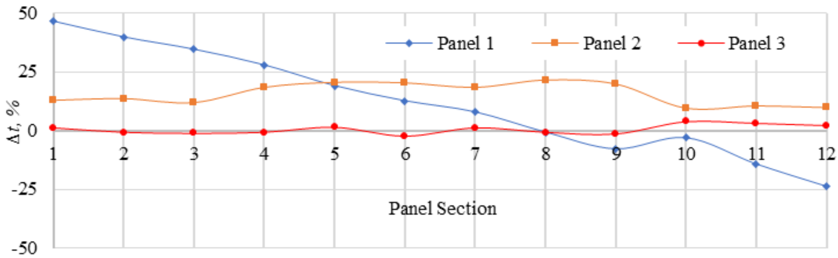


Figure 6. Panel section thickness differences result plot.

4. Conclusion

In conclusion, the hydraulic press machine was developed for fabricating composite materials, emphasizing uniform compression of uncured constituents to ensure consistent panel thickness. Structural analysis revealed minimal deformation (0.57 mm) under a 2-ton load, negligible to panel uniformity. Iterative improvements reduced maximum thickness deviation to 0.16 mm for 4.2 mm panels, meeting ASTM D7136 specifications. Future upgrades include integrating a heating element for precise curing control and cooling enhancement.

References

[1] Avila AF, Morais DTS. A multiscale investigation based on variance analysis for hand lay-up composite manufacturing. Composites Science and Technology. 2005;65(6).

[2] Elkington M, Bloom D, Ward C, Chatzimichali A, Potter K. Hand layup: understanding the manual process. Advanced Manufacturing: Polymer and Composites Science. 2015;1(3):138-151.

[3] Muniyasamy K, Moorthy C. Advantages of composite materials in aircraft structures. International Journal of Mechanical, Aerospace, Industrial, Mechantronic and Manufacturing Engineering. 2012;6.

[4] Hafids S, Yernisa Y. The performance comparison of two kinds of mold-hot-press machine. Proceedings of the 3rd Green Development International Conference (GDIC 2020); 2020 Oct 2-3; Jambi, Indonesia: Atlantis Press; 2021. p. 136-138.

[5] Sumaila M, Ibhadode AOA. Design and manufacture of a 30-ton hydraulic press. Assumption University Journal of Technology. 2011;14:196-200.

[6] ASTM D7136. American Standard Test Method for Measuring the Damage Resistance of a Fiber Reinforced Polymer Matrix Composite to a Drop Weight Impact.2015.

[7] Gukop NS, Kamtu PM, Lengs BD, Babawuya A, Adegoke A. Effect of mesh density on finite element analysis simulation of a support bracket. Fuoye Journal of Eng. and Tech. 2021; 6(2).