

Structural Performance Analysis of HDPE and ABS Formwork Designs Using Finite Element Analysis

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KEYWORDS

Formwork
Finite Element Method
HDPE
ABS
Honeycomb

ABSTRACT – This study evaluates the structural performance of polymer-based formwork systems using HDPE and ABS materials through numerical simulation based on the Finite Element Method (FEM). Rib design variations, including square, round, and honeycomb, were analyzed by considering key parameters such as deformation, elastic strain, equivalent stress, and safety factor. The applied loading conditions consisted of hydrostatic pressure from fresh concrete and additional loads due to the accumulation of upper structural segments. The results show that ABS exhibits higher stiffness, leading to lower deformation and elastic strain values compared to HDPE. Nevertheless, HDPE demonstrates competitive performance, offering advantages in ductility, environmental resistance, and lower weight. Among the design configurations, the honeycomb structure provides the most efficient load distribution and minimizes stress concentration more effectively than square and round designs. All models, for both HDPE and ABS materials, satisfy structural safety requirements with safety factor values greater than one. Therefore, the combination of ABS material and honeycomb rib design is recommended as an optimal solution for polymer-based formwork applications, while HDPE remains a viable alternative for applications requiring enhanced flexibility and environmental durability.

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INTRODUCTION

In the modern construction industry, the use of formwork plays a crucial role in determining the quality, geometry, and strength of the resulting concrete structure. Formwork functions as a temporary or permanent mold that supports fresh concrete loads until sufficient strength is achieved. With the advancement of construction technology, the demand for more efficient, economical, and environmentally friendly formwork systems continues to increase. This has driven innovation in formwork materials, shifting from conventional materials such as timber and steel toward alternative materials, including polymers [1][2].

The use of polymer-based formwork, particularly High-Density Polyethylene (HDPE) and Acrylonitrile Butadiene Styrene (ABS), has gained increasing attention due to advantages such as lightweight properties, corrosion resistance, and reusability. In addition, polymer materials can improve the surface quality of concrete and enhance the durability of structures exposed to aggressive environments. Previous studies have shown that permanent formwork systems can increase structural capacity and delay the occurrence of flexural cracking in concrete elements [3][4][5].

Several previous studies have further examined the role of polymer materials in formwork systems. Kim et al. [6] reported that polymer formwork not only improves concrete surface quality but also reduces life-cycle costs compared to conventional formwork, demonstrating both technical and economic benefits. This finding is consistent with Nilimaa et al. [7], who emphasized that formwork systems significantly influence structural performance, surface quality, and overall construction efficiency. Furthermore, the use of alternative materials, including polymers, contributes to improved sustainability in construction, reinforcing the potential of polymer-based formwork as an efficient and environmentally friendly solution.

Other studies have highlighted the potential of polymer materials such as HDPE in construction applications due to their mechanical properties and environmental resistance. Ferreira et al. [8] reported that HDPE exhibits good chemical resistance and material characteristics suitable for various engineering applications, including as a sustainable alternative material. Meanwhile, Jipa et al. [9] found that certain 3D-printed polymers, including ABS, demonstrate resistance to concrete environments, although their performance is influenced by stress conditions and chemical exposure, indicating their potential for use in construction applications involving complex geometries.

In terms of analysis, numerical simulation using the Finite Element Method (FEM) has become a widely adopted approach for evaluating structural behavior [10][11]. This method enables detailed and efficient prediction of stress distribution, deformation, and structural response under loading conditions. Singleton et al. [12] demonstrated that numerical simulation results show high accuracy when compared with experimental testing on polymer-based materials, with relatively small deviations.

Despite these advancements, there remains a lack of studies that directly compare the structural performance of HDPE and ABS materials in various formwork design configurations. In addition, comprehensive analyses that integrate the effects of both material selection and design variation on stress distribution and deformation through numerical simulation are still limited. Therefore, this study aims to evaluate the structural performance of HDPE- and ABS-based formwork using numerical simulation with the Finite Element Method, in order to identify the most optimal material and design for construction applications.

METHODS

Formwork Design

The formwork design in this study was developed as a square panel with dimensions of 682 mm × 605 mm and a thickness of 5 mm. The panel geometry was designed to represent actual conditions in construction applications, particularly in resisting the pressure of fresh concrete. In addition to the basic dimensions, the formwork system was arranged in a modular configuration consisting of six panel segments with a total length of 3630 mm, thereby representing field applications on a more realistic scale [13].

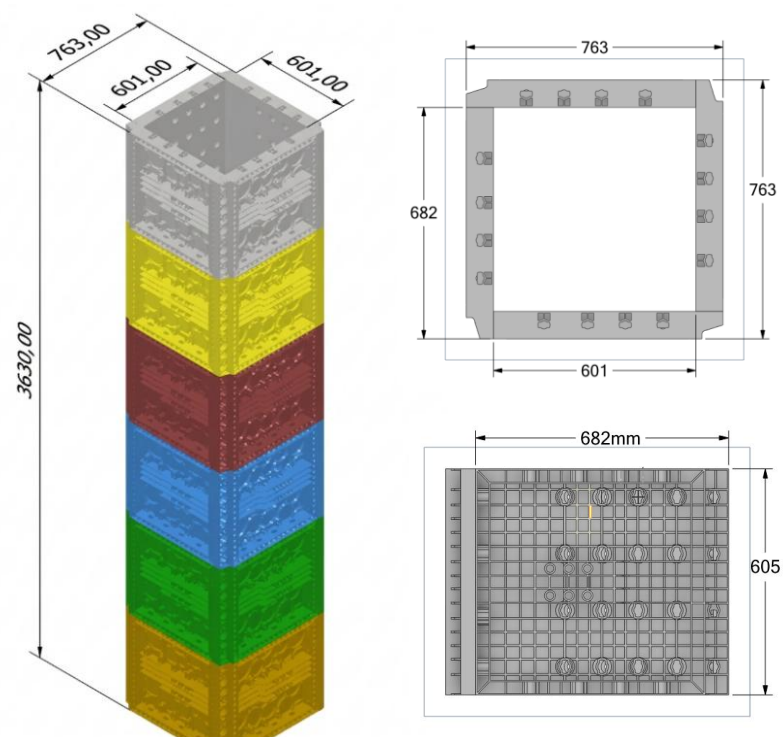


Figure 1. Formwork dimensions

Each formwork model was equipped with stiffening ribs that function to enhance structural stiffness and reduce deformation under loading. The addition of ribs in thin plate structures is known to significantly improve stiffness and load-carrying capacity without substantially increasing mass, making it widely applied in modern structural engineering. Furthermore, the configuration and orientation of ribs greatly influence stress distribution and structural stability; therefore, their design must be carried out systematically to achieve optimal efficiency [14].

The rib variations used in this study consist of three types, namely square, round, and honeycomb. The honeycomb structure is known for its high strength-to-weight ratio and excellent load distribution capability due to its hexagonal cell geometry, making it widely applied in lightweight engineering structures [15]. The combination of rib design and internal structural configuration has also been shown to improve structural stability and energy absorption capacity [16].

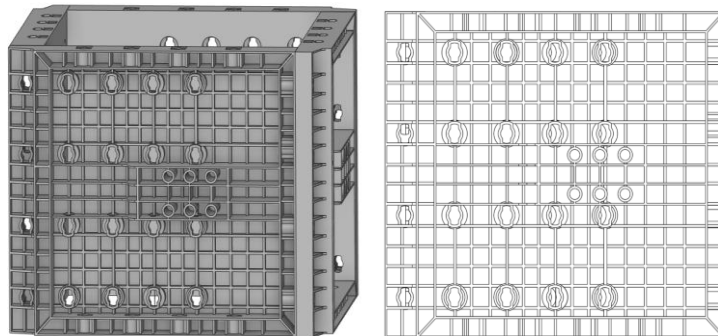


Figure 2. Square formwork design

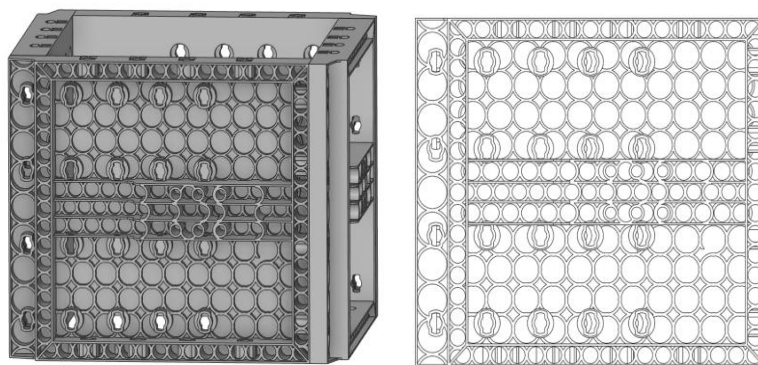


Figure 3. Round formwork design

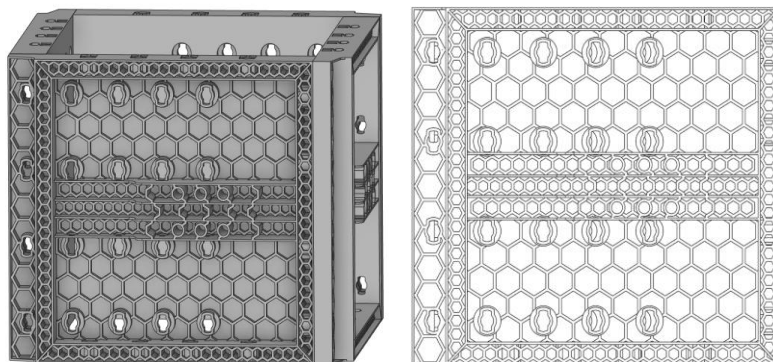


Figure 4. Honeycomb formwork design

The overall dimensions of the formwork and the panel arrangement are presented in Figure 1, while the variations of rib designs for each model are shown in Figures 2 to 4. The use of these design variations is expected to provide insight into the most optimal structural configuration for enhancing formwork performance, particularly when combined with polymer materials through a numerical simulation approach based on the Finite Element Method.

Numerical Simulation

The numerical analysis in this study was conducted using the Finite Element Method (FEM) with a static structural analysis approach [17]. Simulations were performed using ANSYS Workbench to evaluate the structural response of the formwork under pressure loading. The analysis was carried out under linear static assumptions, where the material behavior is considered linearly elastic and the loading is applied gradually (quasi-static), allowing inertia effects to be neglected.

The geometric model used in the simulation refers to the previously described formwork design, including variations in rib geometry and the configuration of six panel segments. The analysis procedure consists of pre-processing, solution, and post-processing stages. During the pre-processing stage, the geometry was created and meshing was performed using three-dimensional elements.

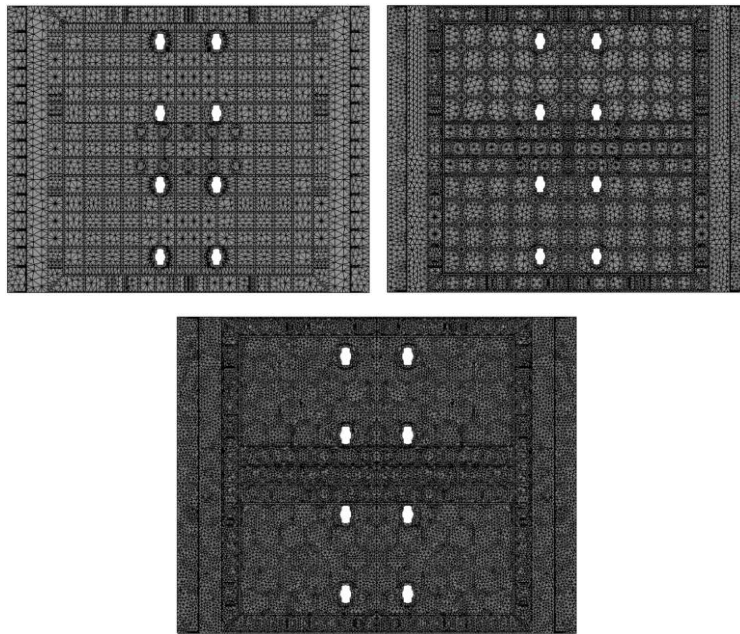


Figure 5. Meshing

The meshing process employed tetrahedral elements with a global element size of 6 mm. This element size was selected based on a mesh convergence study conducted to evaluate the influence of element size on stress results. The mesh visualization for each model is presented in Figure 5, while the detailed mesh parameters used in the simulation are summarized in Table 1.

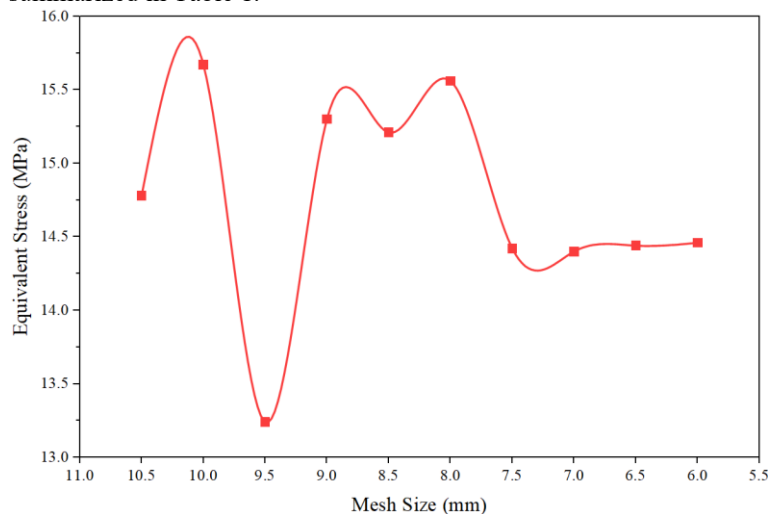


Figure 6. Mesh convergence

Table 1. Mesh details

Mesh details	Descriptions
Mesh size	8 mm
Mesh quality skewness	0.6
Mesh quality orthogonal quality	0.7
Element type	Tetrahedral

The results of the mesh convergence study indicate that the variation in stress values becomes insignificant at a mesh size of 6 mm, confirming that the mesh has reached a converged condition. The convergence curve illustrating the relationship between element size and stress values is presented in Figure 6.

The mesh quality was evaluated using skewness and orthogonal quality parameters. An average skewness value of 0.6 indicates that the mesh elements fall within an acceptable range, while an orthogonal quality value of 0.7 reflects good mesh quality suitable for numerical analysis. The combination of these parameters ensures that the simulation results achieve adequate accuracy without significantly increasing computational cost.

Material Model

The material model used in this study consists of two types of polymers, namely High-Density Polyethylene (HDPE) and Acrylonitrile Butadiene Styrene (ABS). Both materials were modeled as homogeneous isotropic materials with linear elastic behavior under static structural analysis. This approach was adopted to represent the initial material response under loading, particularly in evaluating stress distribution and deformation in the formwork structure.

The mechanical properties used in the simulation include density, Young's modulus, Poisson's ratio, yield strength, and coefficient of thermal expansion. These parameters were defined in the engineering data of ANSYS Workbench as the basis for numerical calculations. The material properties were obtained from previous studies and relevant literature [18][19], as presented in Table 2.

The coefficient of thermal expansion was included in the material model to account for the potential influence of temperature from fresh concrete during the hydration process. The cement hydration reaction is exothermic and can increase the temperature of fresh concrete, which may affect the behavior of the formwork material. By incorporating this parameter, the material model becomes more representative in capturing potential thermal effects, although no direct thermal coupling analysis was performed in this study.

Table 2. Material properties

Material properties	HDPE	ABS
Density (kg/m ³)	950	1024
Young's modulus (MPa)	700	1826
Poisson's ratio	0.4	0.38
Yield Strength (MPa)	25	38.273

Loading and Boundary Conditions

The boundary conditions and loading in this study were defined to represent the actual condition of formwork during the concrete casting process. The analyzed model corresponds to the bottom segment of the formwork assembly, as this segment experiences the highest pressure and forces due to the accumulation of loads from the five segments above it. The primary loading originates from the pressure of fresh concrete, which is modeled as hydrostatic pressure. This pressure is calculated based on the density of fresh concrete of 2400 kg/m³, considering the total height of the formwork assembly of 3.63 m. According to the principle of hydrostatic pressure, the pressure increases linearly with depth, resulting in the maximum pressure occurring at the bottom of the structure.

In addition to hydrostatic pressure, an additional force is applied to represent the load from the five upper formwork segments. This force acts as a compressive load that contributes to increased stress and deformation in the bottom segment. In this simulation, the fresh concrete temperature is assumed to be 32°C, which falls within the typical temperature range of fresh concrete in tropical field conditions [20].

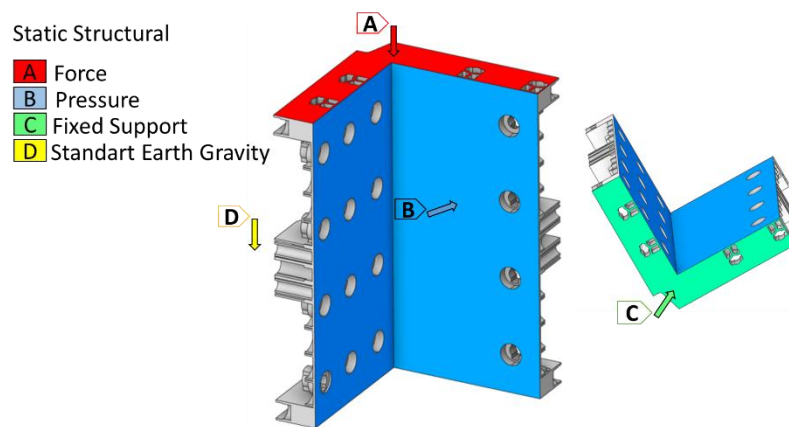


Figure 7. Boundary conditions applied to the formwork model

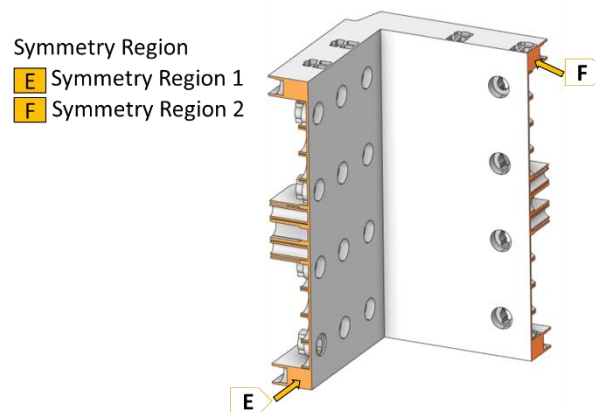


Figure 8. Symmetry boundary condition

The illustration of the actual condition and formwork arrangement during casting is presented in Figure 1, while the implementation of boundary conditions and loading in the simulation model is shown in Figure 7.

To improve computational efficiency, the model was simplified using a symmetry boundary approach by modeling only one-quarter (1/4) of the structure. The application of the symmetry condition is shown in Figure 8. Consequently, the applied loads, including hydrostatic pressure and forces from the upper segments, were also reduced to one-quarter of their actual values. Symmetry boundary conditions were applied on the cut planes to ensure that the model behavior accurately represents the full structure. The bottom part of the structure was assigned a fixed support to reflect actual formwork installation conditions. All boundary condition and loading parameters used in the simulation are summarized in Table 3.

Table 3. Boundary conditions parameters

Model	Massa (kg)		Pressure (MPa)		Force (N)			
					HDPE		ABS	
	HDPE	ABS	Full Model	¼ Model	Full Model	¼ Model	Full Model	¼ Model
Round	26.9	29	0.085	0.021	1319.44	329.9	1422.45	355.6
Square	23	24.8	0.085	0.021	1128.15	282	1216.44	304.1
Honeycomb	28.1	30.3	0.085	0.021	1378.3	344.6	1486.21	371.6

RESULTS AND DISCUSSION

The numerical simulation results demonstrate the structural response of HDPE and ABS formwork under variations of rib designs, namely square, round, and honeycomb, based on parameters including deformation, elastic strain, equivalent stress, and safety factor, as summarized in Table 4. The analysis was conducted to identify the influence of material and geometric combinations on load distribution, stress concentration, and structural safety levels.

Table 4. Numerical simulation results

Model	Material	Deformation (mm)	Elastic strain (mm)	Equivalent stress (MPa)	Safety factor
Square	HDPE	7.25	0.021	14.42	1.73
	ABS	2.78	0.008	14.49	2.64
Round	HDPE	8.18	0.027	18.54	1.35
	ABS	3.14	0.01	18.33	2.09
Honeycomb	HDPE	6.2	0.016	11.02	2.26
	ABS	2.42	0.006	11.18	3.42

Deformation and Elastic Strain Analysis

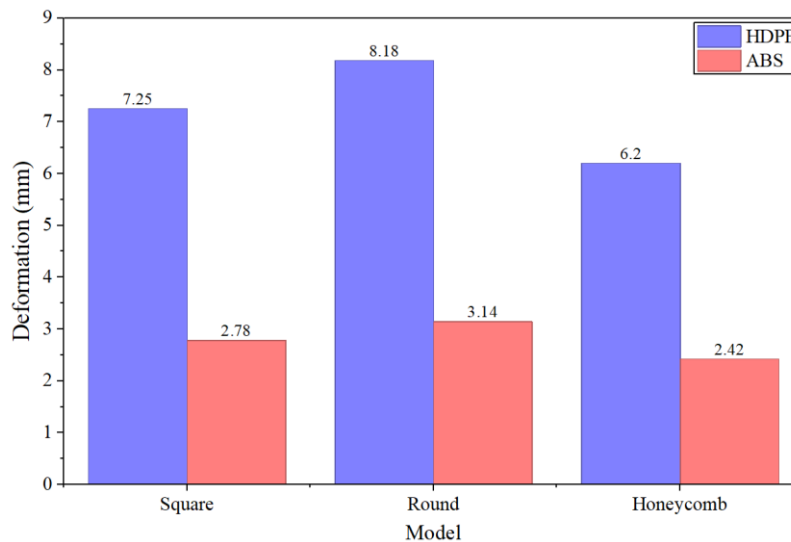


Figure 9. Deformation diagram

The numerical simulation results indicate that the deformation and elastic strain values of the formwork structure are significantly influenced by both the material type and the rib configuration. Based on the data presented in Table 4, ABS consistently exhibits lower deformation values compared to HDPE across all design variations. This is clearly illustrated in Figure 9, where the honeycomb model made of ABS shows the minimum deformation value of 2.42 mm, while the maximum value is observed in the round model made of HDPE at 8.18 mm. This phenomenon is attributed to the difference in Young's modulus, where ABS has higher stiffness than HDPE, allowing it to better resist deformation under the same loading conditions [19].

The distribution of elastic strain shown in Figure 10 follows a similar trend to the deformation results. The round model produces the highest elastic strain values, whereas the honeycomb model exhibits the lowest. This indicates that the structural geometry has a significant influence on the elastic deformation behavior of the material. The honeycomb structure is known for its more uniform load distribution due to its hexagonal cell configuration, which helps reduce local strain concentrations [15].

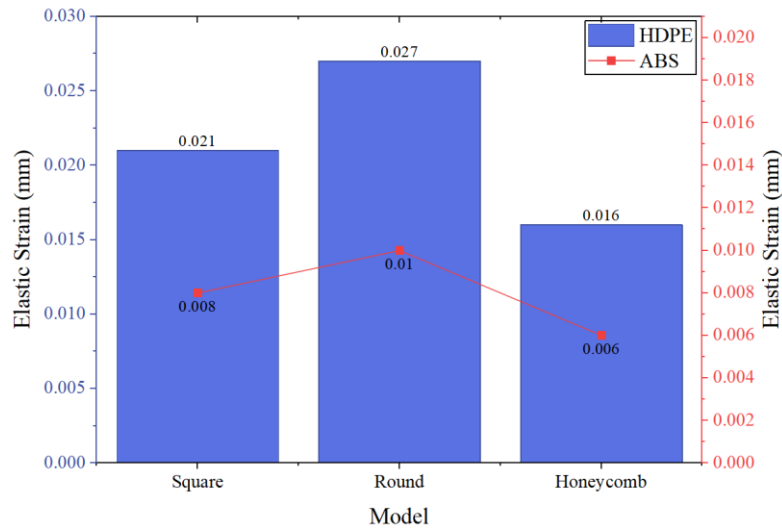


Figure 10. Elastic strain diagram

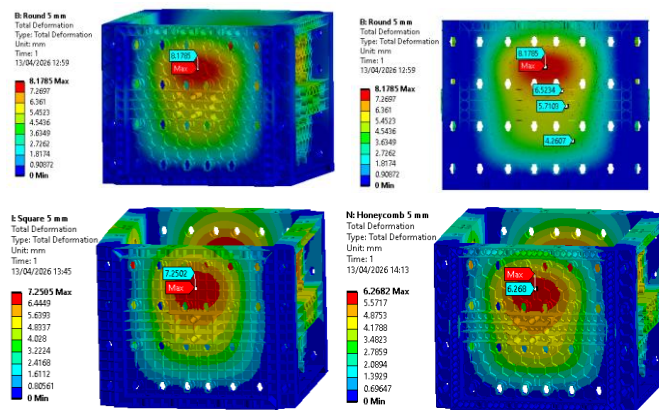


Figure 11. Deformation distribution pattern of HDPE material for different formwork configurations

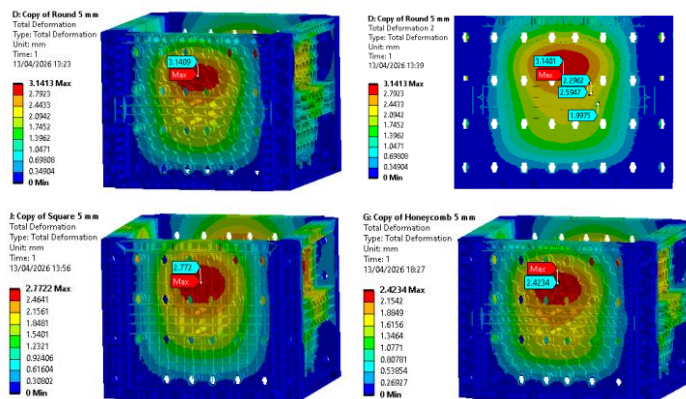


Figure 12. Deformation distribution pattern of ABS material for different formwork configurations

The deformation distribution pattern of HDPE, as shown in Figure 11, indicates that the maximum deformation occurs at the center of the panel, which is the region with the lowest stiffness. This pattern is commonly observed in thin plate structures subjected to uniformly distributed pressure, where maximum deflection occurs in free areas far from boundary constraints [13]. In contrast, the ABS material shown in Figure 12 exhibits a more uniform deformation distribution with lower values, indicating an overall increase in structural stiffness.

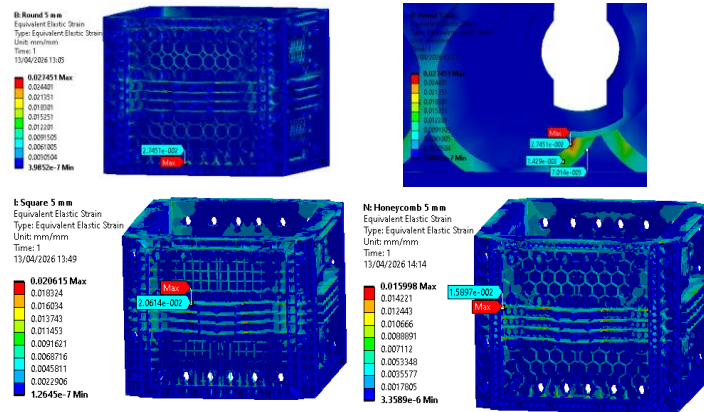


Figure 13. Elastic strain distribution pattern of HDPE material for different formwork configurations

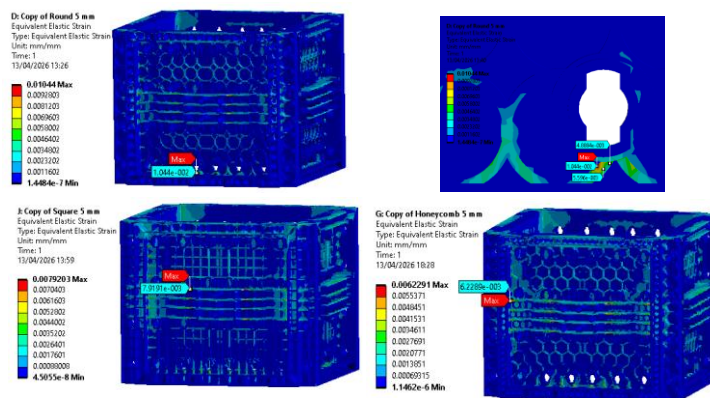


Figure 14. Elastic strain distribution pattern of ABS material for different formwork configurations

The elastic strain distribution for HDPE and ABS is presented in Figures 13 and 14, respectively. For both materials, the highest strain concentration occurs around the junctions between the panel and the ribs. This indicates that these regions act as critical points due to geometric discontinuities, which lead to stress concentration. This phenomenon is consistent with material mechanics principles, where geometric discontinuities can significantly increase stress and strain concentrations [12].

Overall, the analysis results indicate that the combination of ABS material and a honeycomb design represents the most optimal configuration in minimizing deformation and elastic strain. This finding is consistent with previous studies, which report that honeycomb structures possess a high strength-to-weight ratio and are capable of enhancing structural stability [16].

Equivalent Stress and Safety Factor Analysis

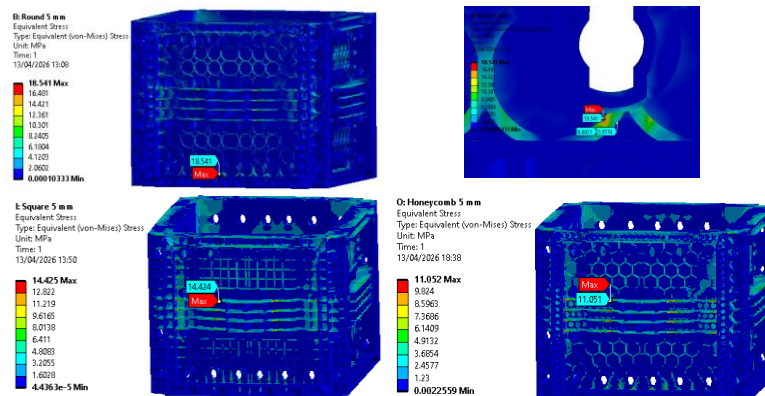


Figure 15. Equivalent stress distribution pattern of HDPE Material for different formwork configurations

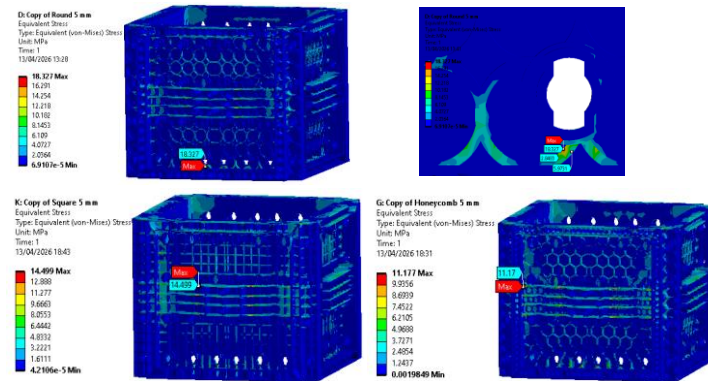


Figure 16. Equivalent Stress Distribution Pattern of ABS Material for different formwork configurations

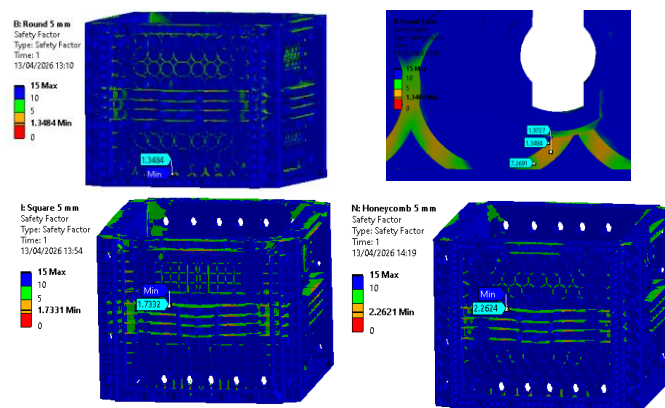


Figure 17. Safety Factor Distribution Pattern of HDPE Material for different formwork configurations

The comparison of equivalent stress presented in Figure 19 shows that the honeycomb model has the lowest stress values compared to the other models. This indicates that the load distribution in the honeycomb structure is more effective, thereby reducing stress concentration. This structure distributes forces through an interconnected network of cells, which helps minimize localized loads acting on a single point. Safety factor analysis was conducted to determine the structural safety level against failure. The distribution of safety factors for HDPE and ABS is shown in Figures 17 and 18, respectively. The results indicate that all models have safety factor values greater than 1, meaning that the structures are within safe conditions. However, significant differences are observed between HDPE and ABS materials. The highest safety factor is obtained in the honeycomb model made of ABS, with a value of 3.42, while the lowest value occurs in the round model made of HDPE, at 1.35. The comparison diagram in Figure 20 illustrates that ABS consistently exhibits higher safety levels than HDPE across all design variations. This is attributed to the higher yield strength of ABS, which enables it to withstand greater stress before failure occurs.

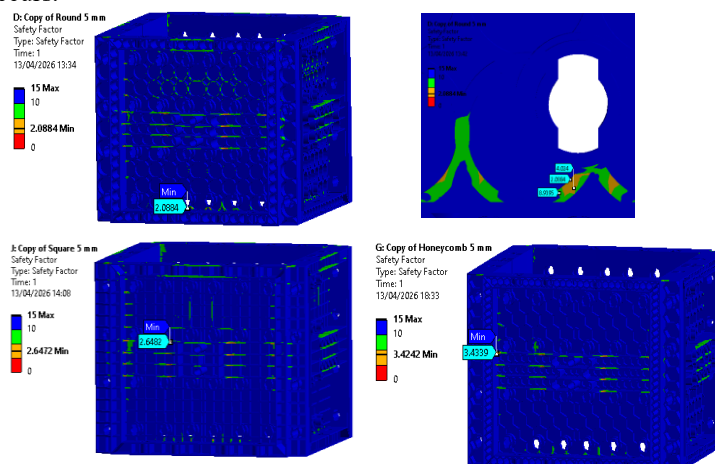


Figure 18. Safety factor distribution Pattern of ABS Material for different formwork configurations

The equivalent stress analysis was conducted to evaluate the von Mises stress distribution in the formwork structure under hydrostatic pressure and additional loading. The simulation results indicate that the highest stress values occur in the round model for both HDPE and ABS materials. The stress distribution pattern for HDPE is presented in Figure 15, while that for ABS is shown in Figure 16. Based on these results, the maximum stress concentration is located at the junction between the ribs and the main panel. This is caused by local stiffness variations that lead to stress concentration. This phenomenon is commonly observed in structures reinforced with stiffeners, where the connections become critical points under loading [14]. The highest equivalent stress value for HDPE reaches 18.54 MPa in the round model, while for ABS it is 18.33 MPa.

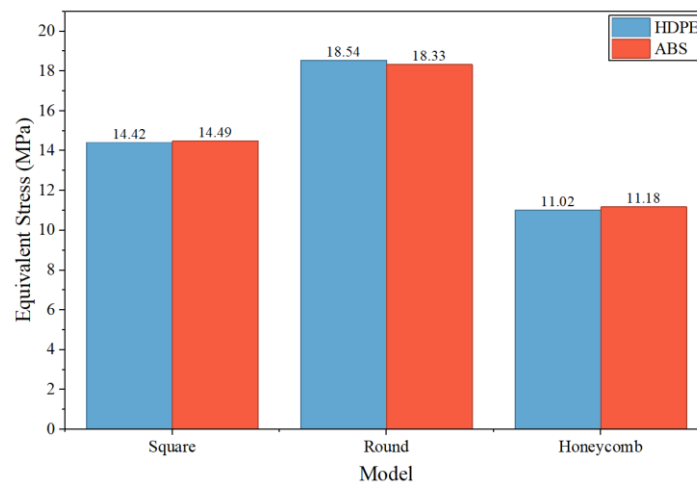


Figure 19. Equivalent stress diagram

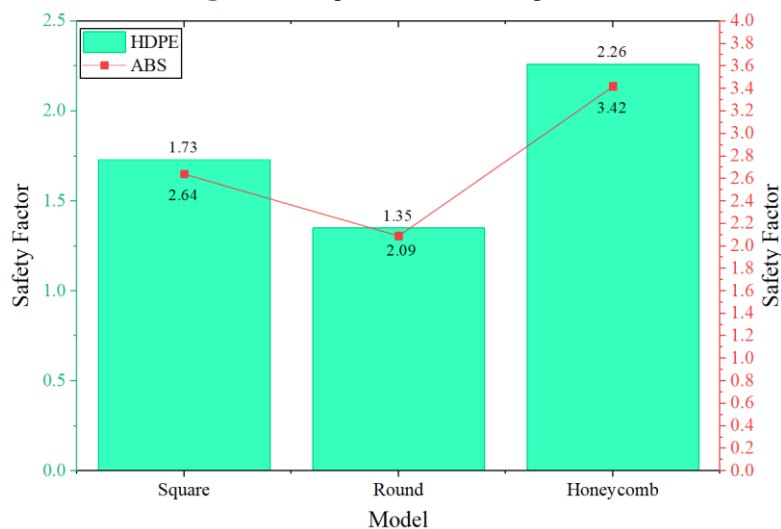


Figure 20. Safety factor diagram

The comparison of equivalent stress presented in Figure 19 shows that the honeycomb model has the lowest stress values compared to the other models. This indicates that the load distribution in the honeycomb structure is more effective, thereby reducing stress concentration. This structure distributes forces through an interconnected network of cells, which helps minimize localized loads acting on a single point. Safety factor analysis was conducted to determine the structural safety level against failure. The distribution of safety factors for HDPE and ABS is shown in Figures 17 and 18, respectively. The results indicate that all models have safety factor values greater than 1, meaning that the structures are within safe conditions. However, significant differences are observed between HDPE and ABS materials. The highest safety factor is obtained in the honeycomb model made of ABS, with a value of 3.42, while the lowest value occurs in the round model made of HDPE, at 1.35. The comparison diagram in Figure 20 illustrates that ABS consistently exhibits higher safety levels than HDPE across all design variations. This is attributed to the higher yield strength of ABS, which enables it to withstand greater stress before failure occurs.

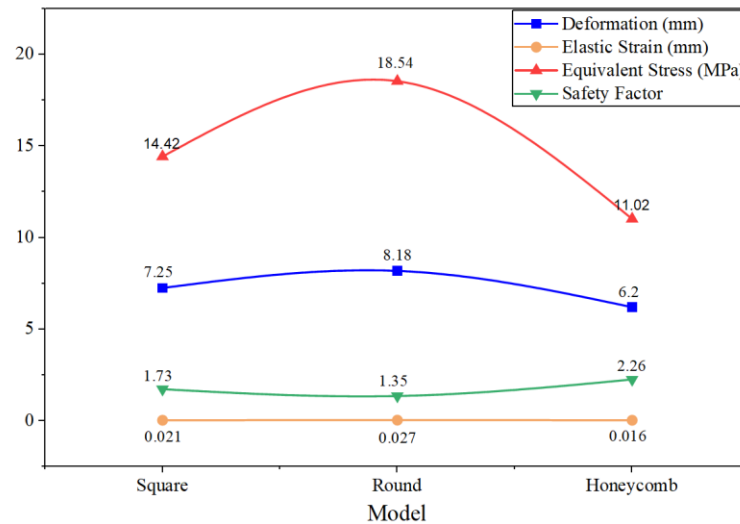


Figure 21. Simulation Results Graph of HDPE Material for different formwork configurations

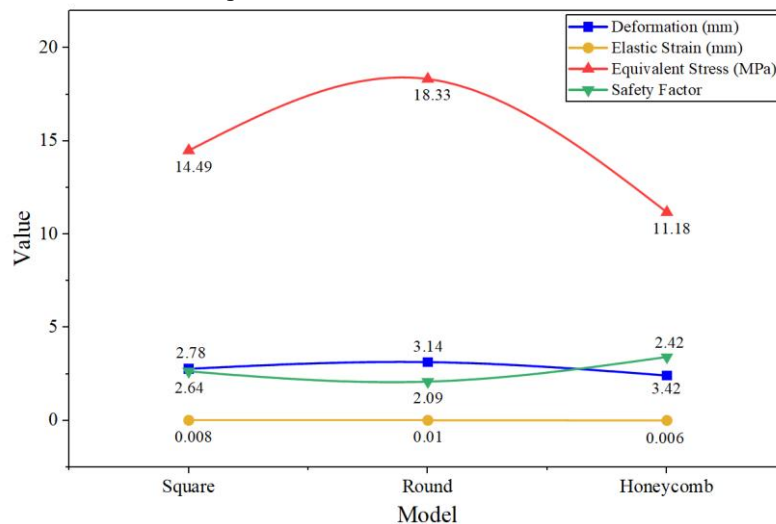


Figure 22. Simulation Results Graph of ABS Material for different formwork configurations

CONCLUSION

Based on the results of numerical simulations using the Finite Element Method, it can be concluded that the structural performance of formwork is significantly influenced by the combination of material and rib design. ABS material demonstrates better performance than HDPE in resisting deformation and producing higher safety factor values, indicating a higher level of structural safety under loading conditions. Nevertheless, HDPE also shows considerable potential for formwork applications. HDPE offers advantages such as resistance to corrosion and chemicals, high ductility, and the ability to absorb deformation energy without sudden failure. In addition, HDPE has a lower density, making it lighter and easier to handle and install, as well as providing good resistance to aggressive environmental conditions. The analysis results also indicate that all models, whether using ABS or HDPE materials, remain within a safe safety factor range (value > 1), meaning that all analyzed design configurations meet the structural strength criteria under the applied loading conditions. From a design perspective, the honeycomb configuration demonstrates the most optimal performance compared to square and round designs, as evaluated based on deformation, equivalent stress, and safety factor values. This is attributed to the ability of the honeycomb structure to distribute loads more evenly and reduce stress concentration. The overall performance comparison between HDPE and ABS is presented in Figures 21 and 22, showing that ABS produces a stiffer and more stable structural response, while HDPE exhibits more flexible and adaptive behavior under deformation. Therefore, the combination of ABS material and honeycomb design is recommended as an optimal solution, while HDPE remains a promising alternative, particularly for applications requiring flexibility, environmental resistance, and lightweight efficiency.

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