Performance Evaluation of Recycled Mask as Permanent Formwork in Reinforced Beams

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Abstract

The construction industry heavily relies on traditional formwork materials such as timber, steel, plywood, and aluminum, which contribute to environmental degradation, resource depletion, and high costs, necessitating the exploration of sustainable alternatives. This study explores the innovative use of single-use masks as a sustainable and environmentally friendly alternative to these traditional formwork materials. This research evaluates the feasibility of formwork as a permanent member of a structure through Finite element analysis. The analysis was performed using Fusion 360, where stress-strain and stress-displacement behavior were inspected under different loads. The Finite element shows negligible displacement and strain, substantiating structural integrity in the suggested formwork. In addition, the simulations verified that the reinforced beam maintained its performance inside bearable limits. The strain values obtained were 0.00001-0.00009 as the load increased, which lies in the elastic strain limit. The effect of pressure of concrete exerted on the walls of formwork examines stress-strain behavior to assess structural performance. The study also discusses the physical and mechanical properties of the proposed formwork system and compares it with conventional alternatives across various construction applications. This study evaluates the different formworks of various construction processes, enhancing construction practices to be more cost-coherent, sustainable, and environmentally strategic.

Keywords: Sustainable construction, Polypropylene (PP), environmentally friendly Materials, Construction Innovation, Finite element analysis (FEA), Daily Face Mask (DFM), Daily Facemask Wearing (DFMW).

1. Introduction

The construction industry laboriously depends on formwork for structural form up until they get adequate solidity. Conventional mediums like timber and steel influence retail yet constitute challenges, encompassing environmental degradation and huge costs. The study offers polypropylene (PP) obtained from a one-time-use mask as a sustainable, flimsy alternative targeting to enhance outcomes and decrease environmental effects [1].

Using formwork made of recycled polypropylene (PP) from one time used mask is a promising reassuring solution. While acting as a part of the structure, it will serve as a non-removable mold that supports concrete. Like traditional formworks that are removed after the concrete hardens, permanent formwork will remain in place, offering more durability, less labor cost, and increased finishes. The high tensile strength, low density, and resistance to environmental degradation of material make it attractive to be used as formwork. This research centered on the performance evaluation of

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formwork made of recycled polypropylene employing software-based analysis in Fusion 360; different strain behaviors of material under different loads were assessed. How much deformation a material will undergo is subjected to external forces causing strain, an important parameter in structural analysis. Under normal working conditions, polypropylene shows minimal strain.

The use of recycled materials like polypropylene in construction positions with global efforts to encourage eco-friendly building materials. Reusing medical waste and bringing down the dependence on traditional formwork also enhances the economic feasibility of construction projects. Additionally, the adaptation of lightweight and durable material improves construction efficiency, transportation costs, more importantly, structural lifespan. The study aims to extend across sustainability structural performance provided that analysis of formwork. The research offers important observations into the mechanical properties, practical applicability, and durability of these construction practices.

The current Covid-19 pandemic proved to be fruitful for the surgical mask industry. Leading to the huge number of masks to be disposed of. According to a study, mask consumption in China alone reached 20.3 billion in 2023 wang et al. [1]. From which 1.4 billion disposable masks junked into the environment turn out to be part of rivers, oceans, and natural surroundings. Considering the widespread use of disposable masks and their presumed adaptability, it is estimated that between December 2019 and May 2021, over 1.24 trillion disposable masks were introduced into the natural environment [1].

2. Materials and Methods

The quantity of daily face mask is estimated using an equation adapted from Nzediegwu and Chang [2] as follows:

$$DFM = P \times U_p \times F_{MAR} \times (F_{MGP}/10{,}000) \quad (1)$$

Where,

DFM = Daily face mask use (pieces).

P = Population (persons).

UP = Urban population (percentage).

FMAR = Acceptance rate of face mask – 80% [2].

FMGP = Assumption that each person in the general population uses one face mask each day.

Table 1: Global mask consumption and production statistics categorized by countries Source: Wang et al. [3].

Mask & usage demand	Continent	Country	Number of masks
Consumption	Asia	China	~455 million/month
	Europe	France	~40 million/month
	South America	Brazil	~255 million/month
Production	Asia	China	~200 million/day

	Europe	Italy	~90 million/day
	America	USA	~1.56 million/day

The table highlights the insights on the analysis of mask usage and production levels in continents. It shows that China is a significant consumer of masks, with 455 million masks monthly and a mask production capacity of 200 million marks per day, taking a leading role in mask production. America and Italy also show significant production potential of 90 million marks per day [2]. The mask consumption in countries like China, Brazil, France, Bangladesh, Pakistan, India, and Italy. Brazil and Italy follow with 255 million and 1200 million per month. As of July 2020, 61,762,860 pieces of masks were used in Pakistan (Statista, 2024). As we know, per mass contains 11g of polypropylene, so the amount we can obtain from such a huge number is 679391.40 kg (679 tons) of polypropylene.

The total daily number of discarded facemasks was calculated using the following equation [5] :

$$\text{Total daily discarded DMFMs} = 1\times10^{-4} \times (PTotal \times PUrban \times A \times B) \quad (2)$$

Where PTotal, PUrban, A, and B represent the total population of each region/sub-region, the urban population of each region/sub-region, the facemask-wearing acceptance rate, and daily per-person usage of facemasks, respectively [5].

All through their life period, the production of CO2 50-52 (Clemens et al. Report) on energy depletion suggests that the global warming dormant of 52 billion disposable masks fabricated in 2020 was evaluated to ~2.6 million tons of CO2 comparable to 22 tera joules (Turkmen 2022). Hence, another product can become the agent of carbon production [4].

As a facemask, it can also contribute to microplastic and microplastic pollution in the environment. The polymeric material from plastic waste and food containers also contributes to aquatic pollution and contributes to carbon footprints [6].

2.1 Mechanical Properties

The density of polypropylene is from 0.0325 to 0.0408 lb/in3, showing a lightweight material. The oxygen transmission rate of 244 cc/mil (cubic centimeters-one-thousandths of an inch) /100in2-24 hr-atm (hours-atmosphere) indicates moderate permeability relevant for structural durability. The melt flow surface tension of 0.450-8g/10 minutes and melt temperature of 193℃-260 ℃, which shows its thermal stability. The ultimate tensile strength is 0.95-1.30 N/mm2, indicating structural integrity and modulus elasticity ranges from 0.280-2.05 GPa (Giga Pascal), shows a balanced, which makes it a viable choice to traditional formwork material matweb.com.

2.2 Physical Properties

Polypropylene, with its noteworthy properties, falls under the category of a thermoplastic polymer and, for this reason, is gaining importance in the construction sector, especially in the formwork industry. Formwork has typically been a temporary construction that allows partially cured concrete to keep its shape as it hardens. Notably, the provision of polypropylene sheets as part of the building system allows for insulation as well as for the use of polypropylene as formwork, allowing for completing drywall systems. The versatility of the material combined with its properties, including but not limited to high strength-to-weight ratio, high material durability, high weather, and chemical resistance, and the fact that it is recyclable, allows for such propositions. Most importantly, the material demonstrates far greater performance characteristics than those incurred from traditional materials such as timber, steel, or aluminum concerning cost, environmental concerns, and functional properties [8-10].

Formwork has become one of the most important factors in form and geometry. Formwork is now constructed using polypropylene sheets, which are known for their strength and flexibility. The casting of concrete or a wooden polystyrene foam into a mold result in the mold becoming part of the structure. The use of finishing material enables such dual purposes, which cuts down on further finishing processes, saving on labor, material, and the cost incurred. Because it is chemically resistant and readily acceptably lightweight, steel poly panels minimize the potentially detrimental effects on finished and compliant long-term surfaces. This leads to the panels being affordable and effective even in regions where panels are to be exposed to chemicals, solvents, and water.

2.3 Comparison with other formworks

Polypropylene, in comparison with the usual materials, has some benefits. Timber, which is one of the most used formwork materials, deforms due to moisture strain and roots and largely gets damaged over the period. Thus, its cohesiveness is weak. Labor used in timber formwork is extensive, this timber formwork is sometimes used once and thrown away, which increases the cost of material procurement and disposal. Steel, on the other hand, is durable and can be reused but is bulky, costly, and gets corroded quickly in damp or chemical conditions, which also accumulates in maintenance costs. Aluminum is not only lighter than steel but also more costly and consumes huge energy for production processes, making it unfriendly compared to polypropylene due to the highly energy-intensive production of steel and aluminum formwork, resulting in increased carbon emissions. With properties such as being lightweight and having a longer lifespan while being cost-effective, polypropylene fits the bill well.

Construction sustainability proponents will appreciate polypropylene sheets formwork as they are environmentally friendly. Being a recyclable material is in line with the current trend of advocating for environmentally friendly means of construction. The formwork use will either call for the recycled sheet or a new one, thus supplementing any wastage with lower volumes use. When the polypropylene sheets are embedded in the structure, there will be no need for extra finishing by using plaster or painting. This will have a positive effect on the environment as it will lessen the volume of materials to be used and the energy needed during the construction phase.

3. Methodology

The methodology follows structure design, material selection, design of formwork, selection of formwork material, simulation setup, data extraction from the file for Finite element analysis, and result evaluation. The material under investigation was recycled polypropylene obtained from a one-time-use surgical mask. The properties such as density, Young's modulus, Poisson's ratio, and tensile strength were collected from a literature review as discussed previously in mechanical properties. These properties are important for ensuring accurate simulation of formwork in structural analysis.

The formwork was designed as a thin wall of different thicknesses encasing reinforced beams. The main objective of the formwork is to ensure that it withstands the concrete pouring process without any deformation while also helping accurate bonding between concrete and reinforcement. The formwork was designed to be adaptable to different structures. For the finite element analysis (FEA), the structure is meshed with a fine grid to analyze stress concentration correctly. The material properties were assigned to formwork, and concrete properties were also assigned encased by the polypropylene for formwork. UDL loading condition is applied to evaluate stress concentration. Static structural simulation was carried out to determine stress, strain, and deformation under loading conditions. The result was inspected to measure maximum defections, stress, and strain values.

In the end, using the available literature review, a comparison discussion with other formworks was performed. The results show the feasibility of polypropylene formwork in construction, highlighting the sustainability and structural efficiency of this innovative approach.

3.1 Comparison with other formworks

Polypropylene, in comparison with the usual materials, has some benefits. Timber, which is one of the most used formwork materials, deforms due to moisture strain and roots and largely gets damaged over the period. Thus, its cohesiveness is weak. Labor used in timber formwork is extensive, this timber formwork is sometimes used once and thrown away, which increases the cost of material procurement and disposal. Steel, on the other hand, is durable and can be reused but is bulky, costly, and gets corroded quickly in damp or chemical conditions, which also accumulates in maintenance costs. Aluminum is not only lighter than steel but also more costly and consumes huge energy for production processes, making it unfriendly compared to polypropylene due to the highly energy-intensive production of steel and aluminum formwork, resulting in increased carbon emission. With properties such as being lightweight and having a longer lifespan while being cost-effective, polypropylene fits the bill well.

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3.2 Polypropylene as permanent formwork

Permanent architectural design using polypropylene has more advantages. Due to the great variety of colors and textures, aesthetics can be maintained or achieved without great expense for finishing works such as plastering, painting, or cladding. Since polypropylene repels moisture, chemical attack, and ultraviolet light, it protects the building from harsh environments and reduces the overall amount of maintenance. This factor is useful in buildings that are in extreme environments like coastal areas or industrial zones. At the same time, the cost of the project and the cost of ownership in the long term are diminished due to the absence of additional finishing materials and less maintenance.

The construction of formwork out of polypropylene plate represents a new trend in the sphere of construction and assembly because it is durable, ecological, and economical. It combines both elements of formwork and finishing in one material, which allows for simplifying construction sites and their elements while improving the strength and beauty of the structures. Polypropylene has an edge over wood, polyethylene, and aluminum as they are widely used construction materials, so it's an added benefit for construction techniques.

3.3 Final Thoughts

Formwork made from polypropylene is an improvement in using timber and aluminum as well as steel. The cost and performance aspects it offers are quite impressive due to its characteristics of performing as a work form as well as a final finish. It is lightweight, and polypropylene is moisture, chemicals, and environmentally direct weather conditions resistant, which makes it usable for the construction industry with strength, green, and economic targets. With the highest construction activity expectations, using polypropylene formwork as a useful finishing touch to the walls is expected to reduce building problems by submitting greener conditions of building in the future. So, we can use disposable face masks in the formwork of polypropylene as it is around 20-30% of the overall construction expenditure.

4. Results and Discussion

Finite element analysis (FEA) is performed to evaluate the structural performance and stress distribution on formwork made of polypropylene under a lateral load of 100lb/ft and gravity load of 130lb/ft2. The analysis shows material formwork's ability to resist forces without significant deformation. Analysis of reaction forces analysis shows a uniform distribution of loads, hence securing structural stability. This approach simulation-based method ensures the polypropylene sheets in construction [7, 11].

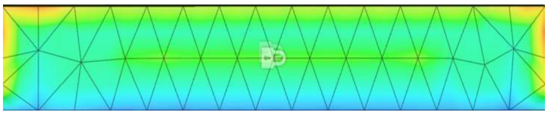

Fig 1-a. Shows FEA of formwork stresses on the left wall.

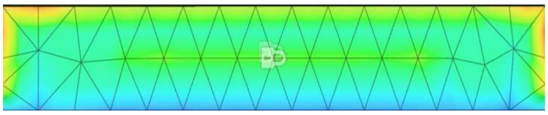

Fig 1-b. Shows FEA of formwork stresses on the right wall.

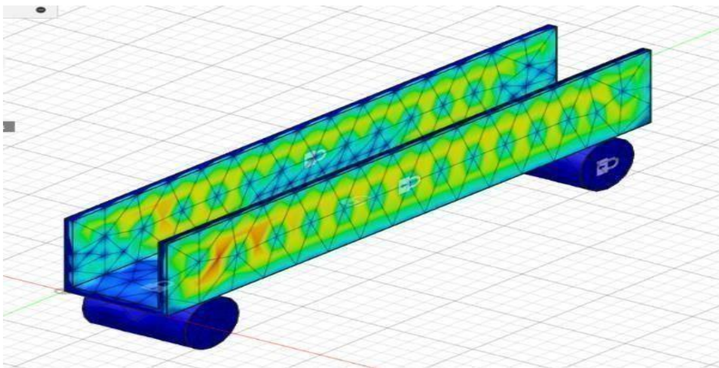

Fig 1-c. Shows FEA of formwork of 12mm thickness.

Fig 1-a, 1-b and 1-c shows that the green regions are not under the influence of high stress nor the minimum stress level and signifies the structure is within operating limits, and the yellow region shows stress high levels of stress but below failure thresholds.

A finite element analysis was conducted to assess the performance behavior and the stress distribution of the polypropylene formwork subjected to a lateral load of 100 lb/ft and a gravity load of 130 lb/ft^2. It is proven from the analysis that the formworks made of polypropylene material have large stresses while allowing small deformations.

Analysis of reaction force analysis shows that the loads are evenly dispersed throughout the structure, thus providing it with stability. This simulation-based method of approach guarantees that polypropylene sheets in building construction are employed.

The studies also address the issues of mask pollution by incorporating recycled mask-obtained polypropylene into construction projects. Polypropylene can withstand diverse environmental conditions like freeze-thaw and exposure to caustic substances. Dissimilar to timber and steel, which are more prone to warping and corrosion. Polypropylene sheets are structurally tough and extend the structural integrity and life cycle of formwork. This innovative exercise illustrates how formwork can be effectually reused by addressing both environmental and industrial challenges simultaneously.

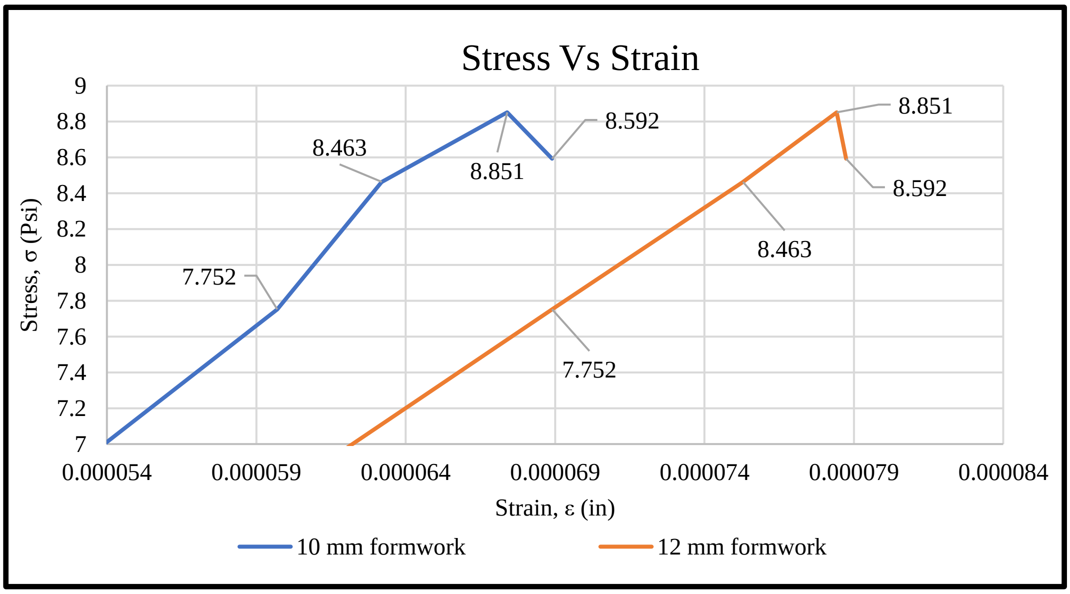

Fig 2. Stress-strain relationship for polypropylene formwork at different thicknesses of formwork.

The stress-strain graph of the polypropylene material formwork provides visual insights into its mechanical behavior under applied loads in Fig 2. Initially, the graph shows a linear relation, indicating the elastic region where the material deforms proportionally to the applied stress. Polypropylene formwork demonstrates excellent stiffness, as evidenced by the steep slope, representing a high modulus of elasticity. This behavior is critical for ensuring the structural integrity of formwork under construction loads. As the stress increases, the graph may show a deviation from linearity, marking the onset of plastic deformation. The transition point represents the yield stress, where the material begins to deform permanently. The ultimate stress is observed at the peak of the graph, representing the maximum stress the material can endure before rupture.

This behavior suggests that while polypropylene can sustain high stresses, its long-term application under extreme loads may require design considerations to prevent localized failures.

Overall, the stress-strain graph reaffirms polypropylene's potential as a durable and resilient material for formwork applications. Its combination of high strength, elasticity, and ductility ensures reliability in both static and dynamic loading conditions, making it a sustainable alternative to conventional materials.

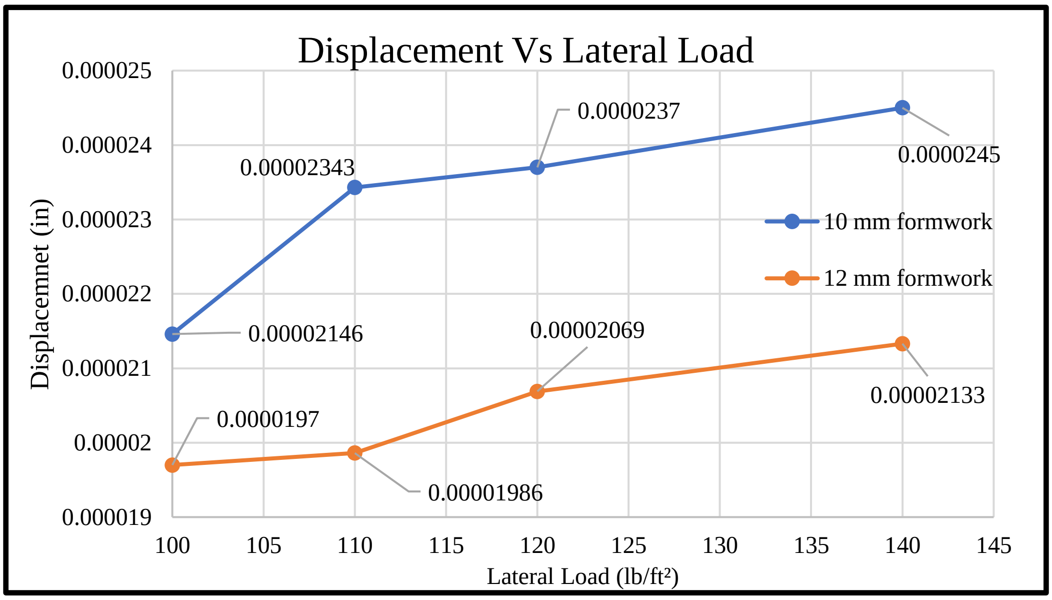

Fig 3. Displacement Variation under increasing loads for polypropylene formwork at different thicknesses.

The displacement vs lateral load illustrates the deformation behavior under increasing loads in Fig 3. The formwork thickness of 12mm in (blue line) shows less displacement than the 10mm in (red line) applied same lateral loads. The lateral displacement observed under lateral loads of 100lb/ft2, 110lb/ft2, 120lb/ft2, 140lb/ft2 are 2.146x10-5in, 2.343x10-5in, 2.37x10-5in, and 2.450x10- 5in respectively. The displacement values indicate a gradual and controlled deformation of the polypropylene as the lateral loads increase. These values validate that the material's capacity to withstand high stresses without failure highlights its suitability for formwork applications, outperforming traditional materials like timber, steel, and aluminum.

5. Conclusion

The Finite element analysis was run to assess the behavior of 10mm and 12mm thickness of formwork, the above graph shows the relation of stress and strain behavior of formwork. This behavior is critical for construction applications where formwork stability is essential to ensure the concrete's proper curing and final strength. The consistent performance under the different load scenarios highlights the potential of polypropylene sheets as a reliable and durable alternative to traditional formwork materials. No displacement was observed in flexural stresses. Polypropylene can withstand extreme environmental conditions, making it ideal for use as formwork. The temperature variation ensures that it maintains structural integrity during construction. Despite its sustainability benefits, there are still some challenges that must be reflected upon. The manufacturing cost can be high due to specialized processing and compatibility issues with some construction materials, like material that requires surface treatment for better performance and binding. Addressing these issues is important to achieve the potential of polypropylene formwork in sustainable construction.

Overall, these findings position propylene sheets as a promising solution for formwork in reinforced concrete solutions.

Polypropylene formwork represents a significant advancement in construction materials, joining lightweight properties with mechanical performance. As the industry moves towards sustainable solutions, polypropylene formwork stands out as a practical choice that balances performance with environmental considerations.

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