

ANALYTICAL MODEL FOR THE PREDICTION OF MECHANICAL PROPERTIES OF PINEAPPLE LEAF FIBRE REINFORCED CONCRETE BEAM

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ABSTRACT

In recent years, the field of concrete technology has undergone several changes. One of them is the addition of natural fibres to the concrete. In recent years, there has been a growing interest in utilizing natural fibres for low-cost construction materials. Natural fibers are far more suggested than synthetic ones for reasons of environmental protection. Also, in the construction industry, various additives are being used to form various mixtures to enhance various mechanical properties better than those of conventional concrete. Pineapple leaf fibre is a more compatible natural fibre resource and has a good chemical composition and the highest tensile strength. It is used as a reinforcing material in place of steel in concrete to achieve better results when compared to other natural fibres also used as a reinforcing material in place of steel in concrete. In this study, physical properties such as specific gravity, sieve analysis, water absorption test, and fineness of materials for cement, fine aggregate, and coarse aggregate were studied. The experimental and analytical studies are done. The ultimate load-carrying capacity of the beam was compared with the nominal reinforced cement concrete. The rule of mixture equations was used for analysis to predict the compressive and flexural strengths of the pineapple leaf fibre concrete.

Keywords: - Natural Leaf fibre, compressive strength, tensile strength, flexural strength.

1 INTRODUCTION

Concrete is one of the most important materials that use up lots of natural resources. Concrete utilization has been the mainstay of the country's construction industry in the contemporary era. One of the commonly used building materials for infrastructure development is concrete. It perfectly matches several requirements like strength, durability, impermeability, fire resistance, and abrasion resistance based on [1]. Cement and fine aggregate are the main ingredients used to make concrete, which are obtained from natural resources. The development of the local construction industry demands a higher concrete volume, which indirectly increases the need for a larger natural resource supply to produce concrete, as per review [2]. To increase the strength and durability of concrete, natural leaf fibres are used as



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secondary reinforcement. Strength and ductility are increased when concrete cracks because the randomly oriented fibers begin to work when the cracks begin to develop and spread, according to [3]. Pineapple leaf fibre is a more compatible natural fibre resource, has a good chemical composition, and has better mechanical strength.

Natural fibres provide sustainable supply because they have low cost, low density, the least processing expenditure, no health hazards, and better mechanical and physical properties based on [4]. Researchers have used plant fibre as an alternative source of artificial fibres for a higher specific strength, rigidity, flexural, and torsional rigidity than other fibres according to [5]. Pineapple leaf fibre reinforced concrete beam is a structural model designed to address three major problems: waste management, pollution control, and climatic change based on [6].

Bio composite-reinforced materials are now often used in high-strength and several lightweight applications in place of conventional materials. Also, [7] showed that such composite materials exhibit good strength by weight ratio, high tensile and flexural strength, high creep resistance, and high compactness. Natural fibres reinforced into bioplastics are a good example of green composites, which are easily degradable by bacteria and enzymes, according to [8]. The primary issue with using natural fibers as reinforced materials is that the adhering surface and polymer matrix do not make good contact, which results in a poor interaction load transformation from the matrix to the fiber based on [9]. Thus, surface modification with the right chemicals is required to improve the adhesion characteristic of fibers. These modification methods can be alkaline treatment grafting with malic anhydride copolymer and using a saline coupling agent.

A novel source of materials that can be affordable, environmentally benign, and recyclable is the use of pineapple leaf fiber in composite materials. The primary problem with PALF is that it is hygroscopic, which presents a significant obstacle to the use of fiber as a reinforced material, according to [10]. Surface modification of PALF is required to improve good interfacial adhesion of PALF with the matrix concrete for getting effective results. A study by [11] investigated the tensile and flexural behaviors of these composites as a function of volume fraction. The use of pineapple leaf fibre in composite materials and highlighted the importance of these fibres in enhancing mechanical properties by [12].

Focused on studying the workability characteristics of high-strength concrete containing PALF, showing an increase in concrete strength with the addition of PALF composition [13]. [14] specifically focused on the workability of self-compacting concrete (SCC) with PALF, demonstrating satisfactory results in terms of flow ability, filling ability, and resistance to segregation. The incorporation of PALF as a reinforcement fiber in concrete can enhance the bridging force in interfacial transition zones within the concrete matrix [13]. According to the literature, PALF is a promising reinforcement material for a range of applications since it may improve the mechanical qualities of concrete and composites. It is necessary to conduct more study on PALF-based composites' performance in various settings and optimization.

2 MATERIALS AND ITS PROPERTIES

The various materials used in the concrete mix of fiber-reinforced concrete and its properties are discussed below. The various materials used are 1.Cement, 2.Fine aggregate, 3.Coarse aggregate, 4.Pineapple leaf fiber and 5. Water

2.1 Cement

The ordinary Portland cement of 53 grades complying with Indian standard IS 12269-2013, particle size 1-100 μ , normal consistency of 28% with a specific gravity of 3:16, fineness of cement of 2%, initial and final setting times of 30 minutes and 60 minutes are used.

2.2 Fine aggregate

The fine aggregate is made of manufactured sand, often known as M-sand. M-sand is artificial sand produced from crushing hard stones into small sand-sized angular-shaped particles, washed, and finely graded to be used for construction aggregate. It is a better substitute for river sand in buildings. The specific gravity of M-sand is 2.63, and fineness modulus=3.1(zone III of classification IS382-1970) is used.

2.3 Coarse aggregate

Coarse aggregates are particles that are greater than 9.5 mm. Diameters between 9.5 and 37.5 mm are the usual ranges used. In the building industry, 20 mm aggregate is typically used most frequently. The material that remains after being sieved through a 4.75 mm sieve is referred to as coarse aggregate. The specific gravity of coarse aggregate is 2.72, water absorption is 1.2%, impact strength is 23.81%, and the fineness of coarse aggregate is 7.3.

2.4 Pineapple leaf fiber

The pineapple plant leaves are detached from the trunk once the fruit is harvested. After that, the fibers are physically separated from the leaves using a scraping technique called decortication. PALF is a multicellular vegetable fiber with an average diameter of 10 μ m, a mean length of 4.5 μ m, and an elementary fiber diameter of 25-34 μ m. Figure 1 shows the extracted fibre from pineapple leaf.



Figure 1 *Pineapple leaf fibre*

Pineapple leaf fibre is used within the concrete to increase its tensile strength. This composite has the suitable property to reduce the cracking of the surface. In this work, approximately 0.35 mm- diameter pineapple leaf fibres are used. The average length of pineapple leaf fibre used in this work is 5 cm. Table 1 shows the physical characteristics of pineapple leaf fibre.

Table 1: Physical characteristics of pineapple leaf fiber

Size/length	5cm
Colour	Natural
Usage	Art and crafts
Fibre strength	880N
Diameter	0.35mm
Density	54wt% and value is 1.2g/cc

2.5 Water

Water is one of the most important elements in construction and is required for the penetration of mortar, mixing of cement concrete, and curing work. In building, the strength of the cement and mortar is directly impacted by the amount of water utilized.

3 CONCRETE MIX DESIGN

The process of choosing appropriate concrete ingredients and figuring out how much of each is needed to produce concrete that has the necessary strength, durability, and workability in the most cost-effective way possible is termed the concrete mix design. The requirements that form the basis of the selection and proportioning of mixed ingredients are (1) the minimum compressive strength required from structural consideration. (2) The sufficient workability required to fully compact using the existing compacting machinery. (3) Max water-cement ratio and/or maximum water cement content to give adequate durability for the particular site condition.

The step in the procedure adopted for the selection of mix proportion for M30 grade of concrete as per Indian standard 10262:2009 with the following: Mix Designation M30, Cement used OPC 53 grade, maximum cement content 450 kg/m³, minimum cement content 320 kg/m³, maximum nominal size of aggregate 20 mm, minimum water cement ratio 0.45 from this result obtained for mix proportion as 1:1.8:2.27:0.45 (C: FA: CA: W).

4 RESULTS AND DISCUSSIONS

Comparing the effects of conventional concrete with PALF-reinforced concrete in terms of flexural behavior, split tensile strength, and compressive strength is given below.

4.1 Compressive Strength Test

The compressive strength test was carried out to find the compressive strength of concrete by adding pineapple leaf fiber by 0%, 0.25%, 0.5%, 0.75%, and 1% for the volume of concrete. It is observed that the addition of 0.75% of pineapple leaf fiber to concrete provides maximum compressive strength at 7 and 28 days. When pineapple fiber is treated with sodium hydroxide (NaOH), the result shows a decrease in compressive strength [16]. The highest value of compressive strength obtained for 0.1% PALF addition was found to be 27.31 MPa after 7 days of curing and 40.53 MPa after 28 days of curing for preparation of specimens for testing at

high temperatures [17]. The compressive strength attained for the concrete containing 0.75% pineapple leaf fibre was measured to be 13% higher than the reference concrete [18].

4.2 Split Tensile Test

The split tensile test was carried out to find the tensile strength of concrete by adding pineapple leaf fiber by 0%, 0.25%, 0.5%, 0.75%, and 1% for the volume of concrete. It is observed that adding 0.75% pineapple leaf fiber to concrete provides maximum split tensile strength at 7 and 28 days. When pineapple fiber is treated with sodium hydroxide (NaOH), the result shows a decrease in split tensile strength [16]. 0.1% of PALF at room temperature split tensile strength is increases [17]. The split tensile strength concrete cylinder increases with the increases of pineapple leaf fibre in concrete up to 0.75% [18].

4.3 Flexural Strength

The modulus of rupture, or F_b , is the flexural strength of the specimen and can be computed as equation 1:

$$F_b = \frac{Pl}{bd^2} \quad \text{-----Eq.1}$$

Where b = measured width in mm, d = measured depth in mm of the specimen at the failure point, and l = length in mm of the span on which the specimen was supported P = maximum load in N applied to the specimen. The flexural strength test is shown in Figure 2.



Figure 2 Flexural strength test

It was observed that in all beams, the formation of flexural cracks was in the pure bending region of the beam, and in some cases, with further increments of loading, very small diagonal shear cracks were formed. For conventional concrete, the initial crack load is 27 kN, and the ultimate strength is 46.5 kN; for the beam with PALF, the initial crack load is 36.5 kN, and the ultimate load is 56.5 kN. 0.75% PALF-adding beam exhibits the best resistance against cracking. PLF treated in sodium hydroxide has significantly increased the flexural strength of concrete which will eventually reduce the volume of concrete in structures [16]. At 0.1%

flexural strength is decreasing with increasing in temperature. Till 400oC the rate of decrease is low. At 600oC tensile strength showing a sudden drop dropped by 75% [17]. The flexural strength concrete prism increases with the increases of pineapple leaf fibre in concrete up to 0.75% [18].

The study examines the impact of adding pineapple leaf fiber (PALF) to concrete using experimental and analytical models. The optimal mix, containing **0.75% PALF**, significantly enhances mechanical properties. **Compressive strength** increases by **16.93% at 7 days** and **23.03% at 28 days**, while **split tensile strength** improves by **28.77% at 7 days** and **34.8% at 28 days**. **Flexural performance** improves, with reinforced concrete beams supporting **54.5 kN** and deflecting **5.12 mm**. PALF treated with **sodium hydroxide (NaOH)** reduces **compressive and split tensile strength** but enhances **flexural strength**, potentially lowering concrete volume in structures. For **high-temperature applications**, **0.1% PALF** achieves a compressive strength of **27.31 MPa at 7 days** and **40.53 MPa at 28 days**. Flexural strength declines with temperature increase, with a **sharp 75% tensile strength drop at 600°C**. Overall, **PALF up to 0.75% improves concrete strength and durability**, making it a **sustainable and eco-friendly reinforcement option**.

5 ANALYSIS

5.1 Rule of Mixture

The modulus and strength of fiber-reinforced composites are frequently predicted using the "rule of mixture" equations, which take into account the weighted contributions from the matrix and fiber filler. According to the micromechanics method from the rule of mixtures, the compressive strength of concrete composites was calculated as per equation 2.

$$\text{Rule of mixtures, } \sigma_c = \sigma_f v_f + \sigma_m v_m \text{ -----Eq. 2}$$

Where, σ_m = Compressive Strength of Matrix, v_m = Volume fraction of Matrix, σ_c = Compressive Strength of Composite, σ_f = Tensile Strength of Fiber, and v_f = Volume percentage of Fiber

5.2 Micromechanics Equation for Flexural Strength

According to the micromechanics method from the rule of mixtures, the flexural strength of concrete composites was calculated as per equation 3.

Rule of mixtures,

$$\sigma_c = \sigma_f v_f + \sigma_m v_m \text{ -----Eq. 3}$$

Where, σ_c = Flexural strength of composite σ_f =Tensile Strength of fiber, v_f =Volume fraction of reinforcement, σ_m =Tensile Strength of matrix, v_m =Volume fraction of matrix

From the analysis, the compressive strength test was carried out to find out the conventional concrete and 0.75% of adding PALF concrete for both experimental and analytical methods. 0.75% of adding PALF gave better results of 37.8 N/mm² and 40.71 N/mm².

From the analysis, the flexural strength test was carried out to find out the conventional concrete and 0.75% of adding PALF concrete for both experimental and analytical methods. 0.75% of adding PALF gave better results of 16.89 N/mm² and 10.4 N/mm².

6 CONCLUSION

The investigation into the effect of adding pineapple leaf fiber (PALF) to concrete has been conducted through both experimental and analytical models to predict compressive and flexural strength. The results indicate that the mix containing 0.75% PALF exhibits superior performance compared to the nominal mix. Specifically, the compressive strength of this mix is 16.93% higher at 7 days and 23.03% higher at 28 days. Additionally, the split tensile strength shows significant improvement, with increases of 28.77% at 7 days and 34.8% at 28 days. The flexural behavior of the mix with 0.75% PALF is also enhanced, as evidenced by the maximum load-carrying capacity of reinforced concrete beams reaching 54.5 kN and a maximum deflection of 5.12 mm. Analytical studies further support these findings, showing that the compressive strength of the 0.75% PALF mix is 18.44% higher than the nominal mix after 28 days. Moreover, the analytical study reveals that the flexural strength of this mix is 10.4 N/mm² at the 28-day. The study demonstrates that pineapple leaf fiber (PALF) enhances concrete's mechanical properties, with 0.75% PALF identified as the optimal mix for improving compressive, split tensile, and flexural strength. This makes PALF a promising natural and sustainable reinforcement for concrete structures. Practical applications include its use in eco-friendly construction, cost-effective material alternatives, and enhanced durability. However, limitations such as fiber property variability, durability concerns, and workability challenges must be addressed. Future research should explore long-term performance, fiber treatment methods, structural applications, and economic feasibility to ensure widespread adoption. Overall, PALF has strong potential as a green, high-performance reinforcement for concrete.

Conflicts of Interest: The authors have no conflicts of interest to declare.

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