EXPERIMENTAL STUDY ON THE PERFORMANCE OF DATE PALM SURFACE FIBER REINFORCED CONCRETE UNDER ACIDIC CONDITION

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Abstract- This study evaluates the performance of concrete reinforced with date palm fiber (DPF) as a sustainable and cost-effective alternative to conventional concrete. The experimental program investigates the effects of varying water-to-cement (W/C) ratios (0.60, 0.64, 0.68, and 0.72), DPF content levels (3%, 5%, 7%, and 9% by weight of cement), and cement types on the mechanical strength and acid resistance of concrete. A total of sixteen mix designs were developed and tested for compressive and split tensile strength under standard curing, as well as after 28 days of exposure to a 5% sulfuric acid solution. The results show that lower W/C ratios (0.60–0.64) lead to improved strength characteristics, possibly due to a denser microstructure and reduced void content. Incorporation of DPF at 3%–7% resulted in moderate strength enhancement, which may be attributed to improved internal reinforcement provided by the fibers. However, at 9% DPF content, fiber agglomeration and reduced workability likely contributed to a decline in strength. Acid exposure caused a noticeable reduction in strength across all mixes, with mixtures containing higher W/C ratios and higher fiber contents being more vulnerable. Mixes with W/C ratios of 0.60–0.64 and DPF contents of 5%–7% demonstrated comparatively better retention of mechanical properties under acidic conditions. These findings highlight the potential of optimized DPF-reinforced concrete as a sustainable material for use in aggressive environments such as sewage systems and industrial floors, provided that fiber dosage and mix proportions are carefully selected.

Keywords- Date Palm Fiber, Acid Resistance, Water-Cement Ratio, Durability, Sulfate Attack

1 Introduction

Researchers have started looking to promote the usage of alternative and eco-friendly building materials that are less expensive due to industry's negative environmental effects and the steadily rising cost of construction supplies. Although concrete has a high compressive strength, it is brittle and weak under tension. [1]. Steel reinforcement has long been employed to withstand tensile loads. However, because of the high permeability of reinforced concrete, steel is expensive and extremely susceptible to corrosion. The possibility of using plant wastes in concrete as fiber reinforcements, aggregate substitutes, or cement substitutes has been the subject of numerous investigations [2]. Numerous natural fibers have been studied in the past, including bamboo, kenaf, flax (linseed), sugarcane bagasse, coconut coir, hemp, oil palm fiber, banana fiber, ramie, abaca (Manila hemp), sisal, henequen, wheat straw, cotton, jute, eucalyptus fiber, rice straw, corn stalk, and pineapple leaf fiber (PALF)[3]. When low-cost building is required in underdeveloped nations, natural fibers are particularly well-suited for utilization. Natural fibers in concrete have generally been found to improve post-cracking performance, toughness, and fracture resistance. [4]. Utilization of date palm fiber in concrete has also been the subject of numerous investigations. Which are widely distributed in hot, arid regions of the world, particularly date palm is widely cultivated in regions such as the Middle East, North Africa, the Canary Islands, India, Pakistan, and the southern parts of the United States. [5].

With tensile strengths ranging from 170 to 300 MPa, the male date palm surface fiber (MDPSF) exhibits the highest tensile strength [6]. MDPSF improves concrete's compressive, flexural, ductile, and crack resistance. Fiber length does not affect modulus of elasticity, however excessive fiber quantity reduces compressive and flexural strengths. Increased fiber content and length lower concrete density and heat conductivity [7]. Previous studies suggest that MDPSF in concrete should have a fiber length of 2-5 cm and a mass percentage of 0.5%, however mechanical performance varies. Faesal Alatshan et al. [8] examined how MDPSF affects concrete mechanical characteristics. They found that fiber diameter affected surface void distribution and that MDPSF increased flexural strength. Compressive strength was highest with 50 mm fibers at 0.5%. Fiber length and mass percentage greatly affect ultrasonic speed, compressive strength, and flexural strength, hence the authors recommended more MDPSF concrete curing studies in hot-dry regions. Future research on fiber diameter dispersion and concrete behavior was also suggested.

Ordinary Portland Cement (OPC) is highly alkaline with a pH above 12. When it contacts acids, its compounds break down, causing an acid attack. This can lead to cracks and surface damage, especially under water pressure. Concrete durability against acids depends on materials, curing, and workmanship. Acid attacks occur in environments like acid rain, sewers, factories, or chemical spills. In reality, concrete is usually exposed to diluted or mixed acids over varying periods, from seconds to years [9]. There is no prior research on acid attack resistance of concrete reinforced with date palm fibers, especially against H_2SO_4 and HCl. The results of this study can help improve the durability and service life of structures exposed to acidic environments.

SEM investigation of four acid-exposed concrete mixes by Emmanuel K. et al. [10] showed that volume growth and density decrease were greater at lower pH. Beulah and Prahallada [11] examined the effects of substituting 20% cement with metakaolin in hydrochloric acid-exposed high-performance concrete. Increased acid content lowered strength, and Jennite chemicals may have led to degeneration. V. Arivudamai and R. Velkennedy [12] tested artificial sand, silica fume, and coconut shell fiber-reinforced concrete under acid assault. Adding up to 3% fibers (steel, coir, sisal) increased acid and cracking resistance. Blessen Skariah Thomas et al. [13] tested acid-exposed rubberized concrete. More crumb rubber increased water absorption, but rubberized concrete lost less weight following acid exposure than traditional mixtures, indicating higher acid resistance. These investigations show that material alteration improves concrete's acidic performance. Despite extensive research, DPSF-reinforced concrete has not been studied against acid assault, particularly against H_2SO_4 and HCl. This is a critical research gap because DPSF might be employed in eco-friendly, low-cost building, especially in hot areas. DPSF in construction could promote sustainable development while improving building durability and energy efficiency. Concrete is alkaline, making it susceptible to acid assault in chemical plants, sewers, and acid rain. Acid attack causes significant cracking, mass loss, and disintegration, especially when the structure is under persistent water pressure. The purpose is to determine how acids, concentrations, and exposure times affect DPSF concrete compressive strength.

This research is focused on understanding how acid exposure affects fiber-reinforced concrete, particularly concrete that incorporates natural fibers such as date palm surface fibers (DPSF). The study will investigate how acid attack influences the compressive strength of DPSF-reinforced concrete. To strengthen the findings, the study will also examine the role of three key mix design variables: water-cement ratio, cement content, and fiber dosage. The ultimate goal is to enhance the service life of concrete structures in corrosive environments by investigating the use of natural, sustainable reinforcing.

2 Research Methodology

2.1 Mix Design and Material Proportions:

A total of sixteen concrete mix designs were developed using a consistent volumetric ratio of 1:1.54:2.85 for cement, fine aggregate, and coarse aggregate, respectively. The experimental program incorporated four types of cement, four levels of date palm fiber content, and four different water-cement (w/c) ratios achieved through 3" fresh concrete slump test (ASTM C143) at four different fiber content [14]. These variables were systematically rotated and combined to assess their interactive effects on concrete performance. The w/c ratios were established through preliminary testing to ensure uniform workability, targeting a slump of approximately 3 inches for each fiber level. Once determined, these ratios were strategically distributed among the various mix designs. Each mix was assigned a unique code for identification and subsequently tested for key mechanical properties. The resulting data were analyzed to identify performance patterns and determine the most effective material combinations.

Table 1 Four level mix design: Cement: Fiber Addition DPSF content

Factors	Level 01	Level 02	Level 03	Level 04
A. Cement (Kg/m³)	399.08	390.86	382.62	374.40
B. Fiber Addition (%)	3	5	7	9
C. W/C	0.60	0.64	0.68	0.72

The experimental program was carefully structured to ensure a systematic investigation to assess key mechanical properties such as compressive strength and tensile strength, along with durability characteristics. Specimens were tested both in a controlled laboratory environment and after being subjected to an aggressive chemical environment (ASTM C267) using a 5% sulfuric acid solution, by practices commonly adopted in previous studies [15] [16]. The goal was to evaluate the potential of DPF-reinforced concrete for improved sustainability and durability in corrosive conditions.

2.2 Experimental Design

The experimental program consisted of sixteen concrete mix designs, developed through a systematic combination of three key input parameters: four types of cement, four levels of date palm fiber (DPF) content (3%, 5%, 7%, and 9% by weight of cement), and four water-cement (w/c) ratios. Each sample in this study is identified using a code in the format S-XYZ, like S-111 etc., where each letter represents a specific experimental factor. In this format, X indicates the cement weight or level, Y refers to the content level of date palm fiber (DPF), and Z corresponds to the water-to-cement (W/C) ratio level. Each of these factors has four levels, labeled from 1 to 4. For example, a sample labeled S-212 would represent cement 390.86 Kg/m³, DPF content level 1 (3%), and a W/C ratio level 2 (0.64). Detailed descriptions of these levels for each factor are provided in Table 1 for further clarity. The mix proportions were carefully adjusted to maintain consistent workability, targeting a slump of approximately 75 mm. Each mix was assigned a distinct code to ensure proper identification during the preparation, curing, and testing phases.

Table 2 Mix design matrix showing combination of cement type, fiber content and w/c ratio

Sr No	Mix ID	Cement Type((Kg/m³)	Fiber Content (%)	W/C Ratio
1	S-111	399.08	3	0.60
2	S-212	390.86	3	0.64
3	S-313	382.62	3	0.68
4	S-414	374.40	3	0.72
5	S-122	399.08	5	0.64
6	S-223	390.86	5	0.68
7	S-324	382.62	5	0.72
8	S-421	374.40	5	0.60
9	S-133	399.08	7	0.68
10	S-234	390.86	7	0.72
11	S-331	382.62	7	0.60
12	S-432	374.40	7	0.64
13	S-144	399.08	9	0.72
14	S-241	390.86	9	0.60
15	S-342	382.62	9	0.64
16	S-443	374.40	9	0.68

2.3 Concrete Preparation, Mixing, Casting, and Curing Method

2.3.1 Material Preparation

All constituent materials cement, fine aggregate (natural river sand), coarse aggregate (crushed stone aggregate), potable water, and date palm fibers (DPF) were prepared and inspected prior to mixing. Fine and coarse aggregates were cleaned to remove dust, clay, and organic impurities to prevent adverse effects on concrete bonding and strength development. Date palm fibers were manually cleaned and cut to uniform lengths ranging from 25 mm to 37 mm, based on optimum dispersion criteria [17]. The processed fibers were air-dried and stored in moisture-free conditions prior to batching.

2.3.2 Mixing Procedure

Mixture for all concrete batches were prepared using a pan-type concrete mixer located in material lab. Cement, sand, and coarse aggregate were first placed into the mixer and mixed in dry condition for 2 to 3 minutes to ensure a homogeneous distribution of dry materials. Date palm fiber were gradually added into the dry mix to prevent clumping and ensure uniform dispersion. The required quantity of water was added gradually while continuously mixing the concrete. An additional 3 to 5 minutes of mixing followed after water addition to ensure uniform consistency and fiber distribution throughout the matrix.

2.3.3 Casting Procedure

Fresh concrete was poured into standardized metallic molds in three uniform layers following ASTM C192. Each layer was properly compacted manually using a tamping rod (25 tamping rod strokes per layer) to remove air voids. Upon placing the final layer, the top surface was levelled and finished with a trowel to ensure a smooth, flush finish. [18]

2.4 Sample Preparation and testing

2.4.1 Cube Specimens

A total of 96 cube samples, each having dimensions of (100 × 100 × 100) mm, were cast to evaluate the compressive strength and were cured at 23 ± 2°C for 28 days [19]. Three specimens of each code were tested for compressive strength [20] using compressive testing Machine. Another set of three cubes per mix design was subjected to chemical degradation assessment. These specimens were also cured in water for 28 days, followed by 28 days of immersion in a 5% sulfuric acid (H_2SO_4) solution. After acid exposure, the same testing protocol was applied. Notably, acid was added to water slowly, never the reverse, to prevent violent exothermic reactions and splashing hazards.

2.4.2 Cylinder Specimen

To evaluate the split tensile strength, a total of 96 cylindrical specimens (D100 mm and H200 mm) were cast. For each mix of sixteen mix design, three specimens were tested after 28 days of water curing under normal conditions, and three specimen**s** were tested after immersion in a 5% sulfuric acid solution for 28 days, following an initial water curing period. [21]

3 Results

3.1 Compressive Strength: Interpretation of Results

3.1.1 Influence of Water-to-Cement Ratio (W/C)

The water-to-cement (w/c) ratio plays a critical role in determining the density, porosity, and overall strength of concrete. Mixes with lower w/c ratios (e.g., 0.60–0.64) tend to exhibit a denser and more compact microstructure, which enhances compressive strength and long-term durability. As the w/c ratio increases (e.g., from 0.64 to 0.72), the excess water leaves behind capillary pores upon evaporation, resulting in a more porous matrix and weaker interfacial transition zones (ITZ). This reduction in matrix integrity becomes especially detrimental under aggressive environmental conditions, such as acid exposure, where porous concrete is more vulnerable to chemical attack and strength degradation.

3.1.2 Effect of Date Palm Fiber (DPF) Content

Incorporating date palm fiber (DPF) into the concrete matrix demonstrated a dual effect depending on the dosage level. At moderate fiber contents (3–7% by weight of cement), DPF contributes positively by enhancing internal bonding and acting as crack-bridging elements. These fibers help arrest microcrack propagation, leading to better load distribution and improved compressive strength.

However, when the fiber content increases to 9%, the benefits begin to reverse. Excessive fiber loading can cause dispersion issues, leading to clumping and uneven fiber distribution. This, combined with reduced workability, introduces voids and weak regions within the matrix. As a result, the overall compressive strength declines due to poor compaction and increased heterogeneity in the concrete structure.

3.1.3 Response to Acid Exposure

Exposure to sulfuric acid significantly affects the performance of concrete, particularly in mixes with higher porosity. Acidic environments attack the cementitious matrix by leaching calcium hydroxide ($Ca(OH)_2$) and other soluble compounds, weakening the matrix and promoting surface erosion. Mixes with higher w/c ratios are more susceptible due to their permeability, resulting in greater strength loss over time.

Conversely, fiber-reinforced mixes with lower w/c ratios displayed better resistance to acid attack. The denser matrix limits acid penetration, while the presence of DPF helps maintain structural cohesion even under chemically aggressive conditions. This combination of physical densification and fiber-induced toughness contributes to improved acid resistance and lower strength degradation compared to more porous, fiber-free counterparts.

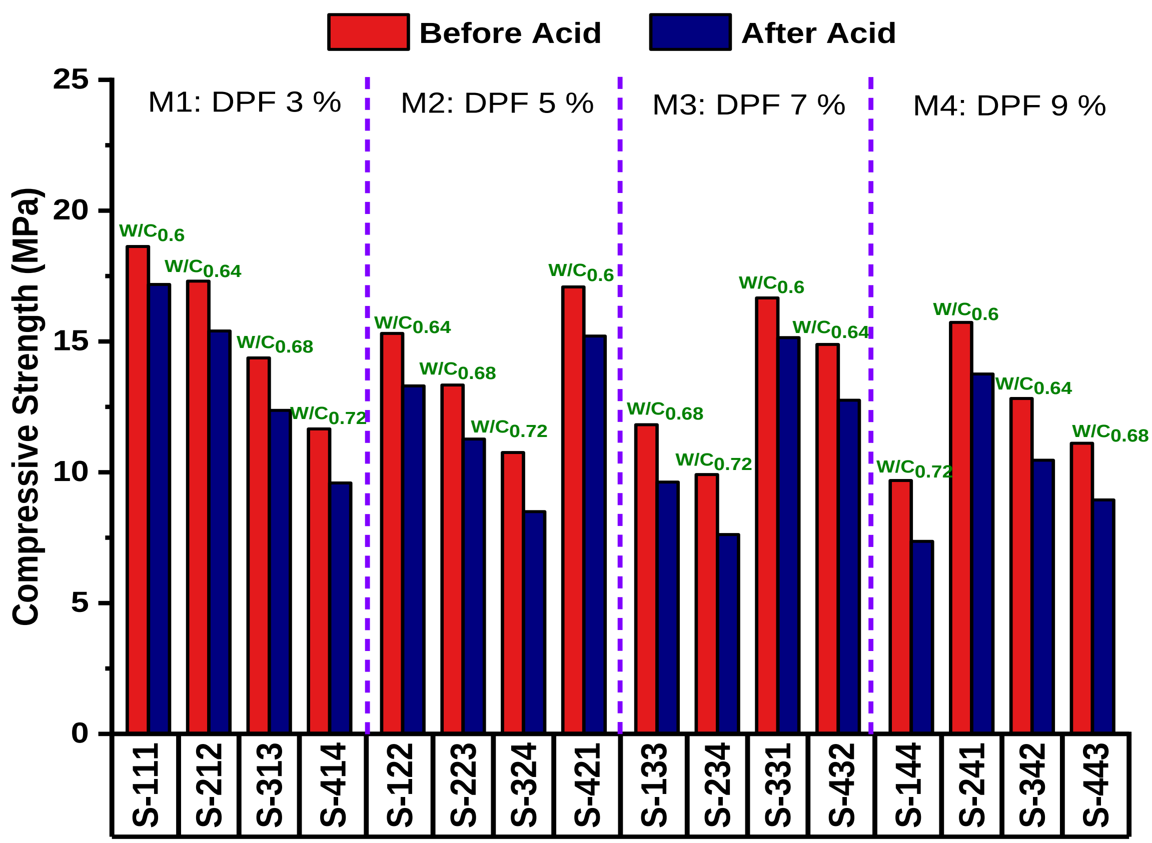

Figure 1: Compressive strength of DPF-reinforced concrete at varying DPF and W/C ratio

3.2 Tensile Strength: Interpretation of Results

3.2.1 Influence of Water-to-Cement Ratio (W/C)

The results indicate that tensile strength decreases consistently with the increase in water-cement (W/C) ratio from 0.60 to 0.72. A lower W/C ratio (0.60) produced higher tensile strength due to improved matrix density and reduced porosity, while higher W/C ratios resulted in weaker bonding and higher permeability, adversely affecting strength.

3.2.2 Effect of Date Palm Fiber (DPF) Content

Tensile strength improved with increasing DPF content up to 7%, attributed to effective crack bridging and fiber reinforcement. However, further increase to 9% led to a decline in strength due to fiber agglomeration, reduced workability, and the formation of voids within the matrix. This highlights 7% DPF as the optimum dosage for tensile performance.

3.2.3 Response to Acid Exposure

All mixes experienced a reduction in tensile strength after acid exposure. The strength loss was more significant in mixes with higher W/C ratios and higher DPF content, particularly at 9%, due to increased porosity facilitating acid ingress. Mixes incorporating a lower W/C ratio (0.60–0.64) and moderate DPF content (5–7%) demonstrated superior resistance against acid attack, retaining higher tensile strength post-exposure.

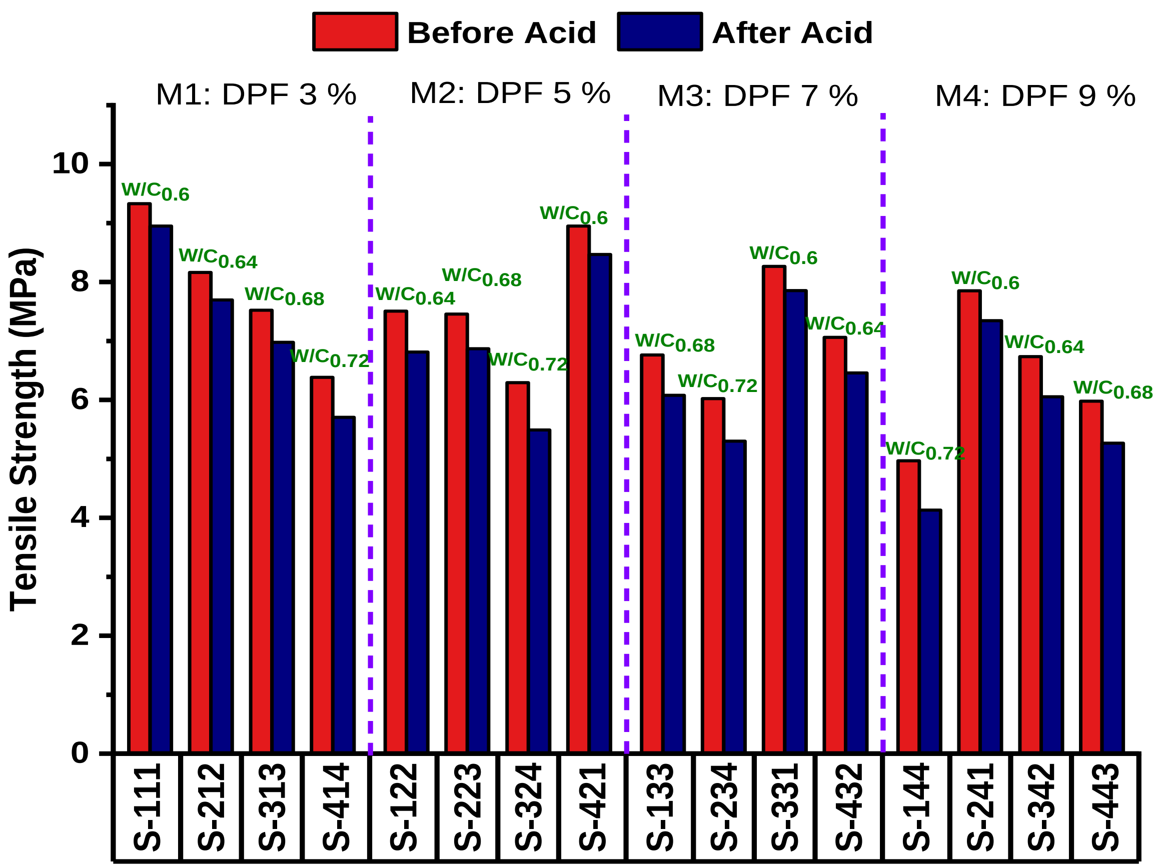

Figure 2: Tensile strength of DPF-reinforced concrete at varying of DPF-reinforced concrete at varying DPF and W/C ratio

4 Practical Implementation

The practical implementation of this study is that using a lower water-cement ratio (0.60–0.64) combined with 5–7% date palm fiber can produce concrete with higher strength, lower permeability, and better acid resistance. This is particularly beneficial for structures exposed to aggressive environments, such as industrial floors, sewage systems, and water treatment plants. However, using a higher fiber content (9%) or a higher W/C ratio can negatively impact strength and durability.

5 Conclusion

The following conclusions can be drawn from the conducted study:

1 Lower W/C ratios (0.60–0.64) significantly improved compressive and tensile strength due to reduced porosity and denser microstructure.

2 Moderate DPF content (3%–7%) enhanced strength and durability; 9% led to reduced performance due to fiber clumping and poor workability.

3 Mixes with low W/C and 3%–5% DPF showed superior resistance to acid attack and retained better mechanical properties.

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