



A STUDY ON EFFECT OF WATER HYACINTH AS FIBRE ON PROPERTIES OF CONCRETE

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Abstract- The construction industry is increasingly focusing on sustainable and eco-friendly materials to reduce environmental impact and enhance resource efficiency. Natural fibres have gained significant attention as reinforcement materials in concrete due to their low cost, renewability, and biodegradability. This study investigates the effect of incorporating water hyacinth fibre as a natural reinforcement on the fresh and hardened properties of concrete. The fibres extracted from water hyacinth were subjected to alkali treatment using sodium hydroxide (NaOH) solution to improve fibre-matrix bonding. Concrete mixes were prepared with varying fibre contents and tested for workability, compressive strength, split tensile strength, and flexural strength. The results indicate that fibre inclusion enhances tensile and flexural properties due to crack-bridging mechanisms, while workability decreases with increased fibre content. The study demonstrates that water hyacinth fibre can be effectively utilized as a sustainable reinforcement material, contributing to waste utilization and improved performance of concrete.

Keywords: Water Hyacinth Fibre, Alkali Treatment, Compressive Strength, Split Tensile Strength, Flexural Strength.

1. INTRODUCTION

Soil Concrete is the most widely used construction material due to its strength, durability, and versatility. However, conventional concrete exhibits inherent limitations such as low tensile strength, brittleness, and poor crack resistance. These drawbacks reduce structural

performance and durability under tensile and flexural loading conditions.

To overcome these limitations, fibre-reinforced concrete (FRC) has been developed by incorporating discrete fibres into the concrete matrix. Fibres improve tensile strength, ductility, and crack resistance by acting as crack-bridging elements. Recently, natural fibres have gained attention due to their eco-friendly nature and availability.

Water hyacinth is an invasive aquatic plant causing environmental issues such as blockage of waterways and depletion of oxygen levels. Utilizing this waste material as fibre reinforcement in concrete provides both environmental and engineering benefits. Alkali treatment using NaOH enhances fibre bonding by removing impurities and increasing surface roughness.

This study focuses on evaluating the performance of concrete reinforced with water hyacinth fibre by analyzing workability and mechanical properties.

2. LITERATURE REVIEW

The application of fibre-reinforced concrete has gained significant attention in recent decades as an effective approach to overcome the inherent limitations of conventional concrete, particularly its low tensile strength and brittle behaviour. The inclusion of fibres in concrete improves its mechanical properties, crack resistance, and durability. With the growing demand for sustainable construction materials, natural fibres have emerged as a promising alternative to synthetic fibres due to their biodegradability, low cost, and environmental compatibility.

Several researchers have investigated the influence of natural fibres on the performance of concrete. Anita Das et al. (2022) studied the incorporation of natural fibres in varying proportions ranging from 0.25% to 1% and evaluated their effect on compressive and tensile strength. The study revealed that fibre inclusion significantly enhanced tensile strength and crack resistance due to the crack-bridging mechanism of fibres. However, it was also observed that higher fibre content led to reduced workability and a slight decrease in compressive strength, indicating the importance of optimizing fibre dosage.

Rahul Verma et al. (2023) focused on the effect of alkali-treated natural fibres on concrete properties. In their study, fibres were treated using sodium hydroxide (NaOH) solution to remove impurities such as lignin and waxy substances, thereby improving fibre surface roughness and bonding characteristics. The results demonstrated that treated fibres exhibited better mechanical performance compared to untreated fibres, with noticeable improvements in tensile and flexural strength. The study emphasized that chemical treatment plays a crucial role in enhancing fibre–matrix interaction.

S. Karthikeyan et al. (2024) investigated the use of water hyacinth fibre as a reinforcement material in concrete. The fibres were extracted, processed, and incorporated into concrete mixes in different proportions. The findings indicated that the addition of water hyacinth fibre improved tensile and flexural strength due to enhanced crack-bridging action. However, a reduction in workability was observed with increasing fibre content. The study identified an optimum fibre percentage at which maximum performance was achieved without significant loss of workability.

Neha Gupta et al. (2022) examined the durability aspects of fibre-reinforced concrete using natural fibres. The study focused on parameters such as water absorption, shrinkage, and crack resistance. The results showed that fibre addition reduced crack width and improved resistance to shrinkage cracking. It was also highlighted that proper fibre distribution within the concrete matrix is essential to achieve uniform performance and avoid weak zones.

Arun Kumar et al. (2023) explored the use of agricultural and aquatic waste fibres in concrete for sustainable construction. The study demonstrated that water hyacinth fibres improved ductility and energy absorption capacity of concrete. However, excessive fibre content resulted in reduced compressive strength and difficulties in mixing. The research concluded that water hyacinth fibre has strong potential as an eco-friendly reinforcement material when used in optimum proportions.

Further studies by K. Ramesh et al. (2023) focused on the flexural behaviour of fibre-reinforced concrete and reported that fibre inclusion significantly enhanced load-carrying capacity and post-cracking behaviour of concrete beams. The fibres helped in distributing stresses more

uniformly and prevented sudden brittle failure, thereby improving structural performance.

In addition, research conducted by Mohd Azreen Mohd Ariffin et al. (2023) highlighted the importance of fibre dispersion and mix design in achieving uniform strength characteristics. The study reported that fibre inclusion improved energy absorption capacity and post-cracking behaviour, although workability decreased with increasing fibre content.

Chen Wang et al. (2024) specifically examined the performance of alkali-treated water hyacinth fibre in concrete. The study showed that tensile and flexural strength increased significantly due to improved fibre–matrix bonding, while compressive strength exhibited slight reduction at higher fibre contents. The results confirmed that proper fibre treatment and optimum dosage are essential for achieving balanced performance.

Maria Gonzalez et al. (2019) investigated the effect of fibre length and dosage on concrete properties and concluded that shorter fibres improved workability, whereas longer fibres enhanced crack resistance and flexural strength. However, excessive fibre length and content negatively affected compaction and strength.

Ahmed S. Mohammed et al. (2021) studied the effect of alkali treatment on natural fibres and found that treated fibres provided better bonding, reduced crack formation, and improved tensile strength. The study emphasized the significance of chemical treatment in enhancing the performance of fibre-reinforced concrete.

From the reviewed literature, it is evident that natural fibres have significant potential in improving the mechanical and durability properties of concrete. However, most studies have focused on commonly used fibres such as coir, jute, and sisal, while research on water hyacinth fibre remains relatively limited. Moreover, detailed studies on the combined effect of alkali treatment and fibre content on workability, crack resistance, and long-term durability are still insufficient. Therefore, further investigation is required to evaluate the feasibility and effectiveness of water hyacinth fibre as a sustainable reinforcement material in concrete.

3. MATERIALS AND METHODOLOGY

3.1 Materials

The materials used in this study include cement, fine aggregate, coarse aggregate, water, and water hyacinth fibres. All materials were tested in accordance with relevant Indian Standard (IS) codes to ensure their suitability for concrete production.

Portland Pozzolana Cement (PPC) conforming to IS 1489 (Part 1):2015 was used throughout the study. The physical properties of cement were determined by conducting fineness test, standard consistency test, and specific gravity test. The fineness of cement was determined using sieve analysis and the results are presented in Table 1.

Table 1: Fineness Test Results of Cement

Sl. No	Total Weight (g)	Weight Retained (g)	Average Residue (%)
1	100	5	
2	100	7	5.67
3	100	5	

The fineness of cement was found to be 5.67%, which is within the permissible limit of 10% as specified in IS 4031 (Part 1), indicating that the cement is sufficiently fine and suitable for use in concrete.

The standard consistency of cement was determined using the Vicat apparatus, and the observations are presented in Table 2.

Table 2: Standard Consistency of Cement

Sl. No	Weight of Cement (g)	Water (ml)	Water (%)	Penetration (mm)
1	400	104	26	37
2	400	112	28	28
3	400	120	30	24
4	400	128	32	20
5	400	136	34	14
6	400	144	36	5

The standard consistency of cement was obtained as 36%, which is slightly higher than the typical range but acceptable for PPC cement due to the presence of pozzolanic materials.

The specific gravity of cement was determined using the Le Chatelier flask method with kerosene to prevent hydration. The test results are summarized in Table 3.

Table 3: Specific Gravity of Cement

Parameter	Value
Weight of Empty Flask (W_1)	60 g
Weight of Flask + Cement (W_2)	124 g
Weight of Flask + Cement + Kerosene (W_3)	204 g
Weight of Flask + Kerosene (W_4)	164 g
Specific Gravity	3.02

The specific gravity value of 3.02 lies within the acceptable range of 2.9 to 3.1, confirming the quality of cement used.

Manufactured sand (M-sand) was used as fine aggregate. The physical properties were determined through specific gravity and sieve analysis tests. The specific gravity test results are shown in Table 4.

Table 4: Specific Gravity of Fine Aggregate

Parameter	Value
Pycnometer (M_1)	540.5g
Pycnometer + Fine Aggregate (M_2)	940.5g
Pycnometer + Fine Aggregate + Water (M_3)	1808 g
Pycnometer + Water (M_4)	1568 g
Specific Gravity	2.5

The value indicates that the fine aggregate possesses normal density and is suitable for concrete production.

The gradation of fine aggregate was determined by sieve analysis, and the results are presented in Table 5.

Table 5: Sieve Analysis of Fine Aggregate

Sieve Size (mm)	Weight Retained (g)	% Retained	Cumulative %	% Finer
3.35	80	8	8	92
2.36	120	12	20	80
1.18	290	29	49	51
0.60	260	26	75	25
0.30	120	12	87	13
0.15	60	6	93	7
Pan	70	7	100	0

The fineness modulus was calculated as 3.24, indicating that the sand is coarse and suitable for use in concrete.

Coarse aggregate of nominal size 20 mm was used in this study. The specific gravity of coarse aggregate was determined and the results are shown in Table 6.

Table 6: Specific Gravity of Coarse Aggregate

Parameter	Value
Container + Aggregate + Water	9.740 kg
Container + Water	6.570 kg
Surface Dry Aggregate	4.830 kg
Oven Dry Aggregate	4.330 kg
Specific Gravity	2.61

The value lies within the acceptable range, indicating suitability for concrete.

The gradation of coarse aggregate was determined using sieve analysis and is presented in Table 7

Table 7: Sieve Analysis of Coarse Aggregate

Sieve Size (mm)	Weight Retained (g)	% Retained	Cumulative %	% Finer
20	1880	62.67	62.67	37.33
16	400	13.33	76	24
12.5	320	10.67	86.67	13.33
10	350	11.67	98.34	1.66
6.3	50	1.67	100	0
4.75	0	0	100	0

The results confirm proper gradation, which is essential for achieving good strength and durability.

Potable water free from impurities was used for mixing and curing of concrete.

Water hyacinth fibres were collected from nearby water bodies and cleaned thoroughly. The fibres were subjected to alkali treatment using sodium hydroxide (NaOH) solution to improve surface roughness and bonding characteristics. The treated fibres were washed and dried before use in concrete.

3.2 Methodology

The methodology adopted in this study involves a systematic experimental procedure to evaluate the influence of water hyacinth fibre on the properties of concrete. The entire process includes fibre preparation, mix design, casting of specimens, curing, and testing of both fresh and hardened concrete.

Water hyacinth fibres were initially collected from natural water sources and thoroughly cleaned to remove impurities and unwanted organic matter. The cleaned fibres were then subjected to alkali treatment using sodium hydroxide (NaOH) solution for a specified duration to enhance fibre surface characteristics. After treatment, the fibres were washed with clean water to remove excess alkali and then dried under ambient conditions before being incorporated into concrete mixes.

Concrete mix design was carried out to obtain suitable proportions of cement, fine aggregate, coarse aggregate, and water. A control mix without fibre and fibre-reinforced mixes with varying percentages of water hyacinth fibres were prepared. The fibres were added in measured quantities and mixed uniformly to ensure proper dispersion within the concrete matrix.

The proportions adopted for different mixes are presented in Table 8.

Table 8: Mix Proportions of Concrete

Mix Type	Cement	Fine Aggregate	Coarse Aggregate	Water	Fibre Content (%)
Control Mix	1	1.5	3	0.5	0
Mix 1	1	1.5	3	0.5	0.5
Mix 2	1	1.5	3	0.5	1
Mix 3	1	1.5	3	0.5	1.5

Fresh concrete was prepared by thoroughly mixing all constituents in dry and wet conditions to achieve a uniform mixture. The workability of fresh concrete was evaluated using the slump test in accordance with IS standards. It was observed that the addition of fibres reduced the workability due to increased internal friction and fibre interlocking.

Concrete specimens were cast in standard moulds for different tests. Cube specimens of size 150 mm × 150 mm × 150 mm were prepared for compressive strength tests, cylindrical specimens of 150 mm diameter and 300 mm height were prepared for split tensile strength tests, and beam specimens of size 100 mm × 100 mm × 500 mm were prepared for flexural strength tests. The details of specimens used in the study are presented in Table 9.

Table 9: Details of Test Specimens

Specimen Type	Size	Test Conducted
Cube	150 × 150 × 150 mm	Compressive Strength
Cylinder	150 × 300 mm	Split Tensile Strength
Beam	100 × 100 × 500 mm	Flexural Strength

The concrete was placed in moulds in layers and compacted properly to remove entrapped air and ensure uniform density. After casting, the specimens were left undisturbed for 24 hours and then demoulded. The demoulded specimens were cured in water for periods of 7, 14, and 28 days to allow proper hydration of cement.

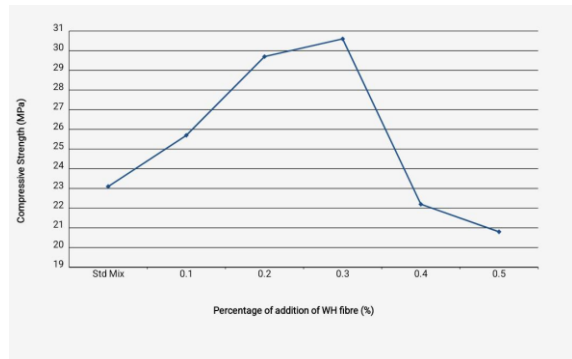
The hardened concrete specimens were tested to determine their mechanical properties. Compressive strength tests were conducted on cube specimens using a compression testing machine, while split tensile strength tests were carried out on cylindrical specimens. Flexural strength tests were performed on beam specimens using a universal testing machine. All tests were conducted in accordance with relevant IS code provisions.

In addition to strength tests, durability studies such as sulphate attack tests were also conducted to evaluate the resistance of fibre-reinforced concrete under aggressive environmental conditions. The overall methodology was designed to assess both fresh and hardened properties of concrete and to determine the optimum fibre content that provides improved performance while maintaining workability.

4. Results and Discussion

4.1 Workability of Fresh Concrete (Slump Test)

The workability of fresh concrete was evaluated using the slump test in accordance with relevant IS standards. The slump test was carried out using a standard slump cone apparatus consisting of a frustum of a cone having a height of 300 mm, bottom diameter of 200 mm, and top diameter



of 100 mm. The cone was placed on a non-absorbent surface and filled with fresh concrete in three equal layers. Each layer was compacted with 25 strokes using a standard tamping rod to ensure proper compaction and removal of entrapped air.

After filling and leveling the top surface, the cone was carefully lifted vertically, allowing the concrete to subside. The difference between the original height of the cone and the height of the subsided concrete was measured as the slump value. This procedure was repeated for all mixes with varying fibre content.

Inference:

As per IS 456:2000, the slump value indicates concrete workability:

- True slump: 0.3% fibre content shows true slump (80 mm).
- Medium workability: Slump values (50-100 mm) indicate medium workability.

IS 456 categorizes workability based on slump:

- Low (< 50 mm)
- Medium (50-100 mm)
- High (> 100 mm)
- 0.1% fibre: Improves workability (slump increases to 100).
- 0.3% fibre: Maintains normal workability (slump returns to 80).
- Increasing fibre content (0.2-0.5%): Reduces workability (slump decreases).

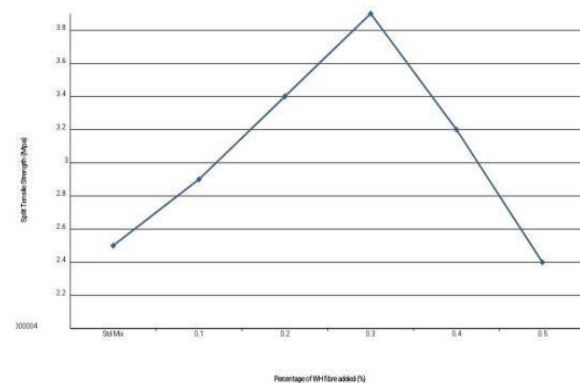
This suggests optimal fibre dosage for workability is likely between 0.1% to 0.3%

4.2 Compressive Strength Test

The compressive strength of concrete was determined using cube specimens of size 150 mm × 150 mm × 150 mm as per IS 516:2021. The specimens were cast in steel moulds and compacted properly using tamping rods to remove air voids. After casting, the specimens were kept undisturbed for 24 hours and then demoulded. The demoulded specimens were cured in water for the

required curing period to ensure proper hydration of cement.

Before testing, the specimens were removed from curing, wiped to



remove surface moisture, and placed in a compression testing machine (CTM). The load was applied gradually and uniformly at a constant rate until failure occurred. The maximum load at failure was recorded, and compressive strength was calculated as the ratio of load to cross-sectional area.

Fig 4.2(a) Compressive Strength graph

Inference:

The compressive strength test results indicate that fibre addition enhances strength up to an optimum level. The fibres help in controlling microcracks and improving stress distribution. Alkali-treated fibres improve bonding, leading to better load transfer. However, excessive fibre content results in poor compaction, void formation, and reduced strength.

4.3 Split Tensile Strength Test

The split tensile strength of concrete was determined using cylindrical specimens of size 150 mm diameter and 300 mm height, following IS 5816 standards. The specimens were cast and cured in a similar manner as cube specimens.

During testing, the cylinder was placed horizontally between the platens of the compression testing machine. A uniform load was applied along the length of the cylinder through packing strips to ensure even distribution. The load was increased gradually until the specimen failed along its vertical diameter.

The tensile strength was calculated using the standard formula based on applied load, diameter, and length of the specimen

Fig 4.3 Graph showing split tensile strength

4.4 Flexural Strength Test

The flexural strength of concrete was determined using beam specimens of size 100 mm × 100 mm × 500 mm as per IS 516 standards. The beams were cast, compacted, and cured under standard conditions.

The test was conducted using a universal testing machine (UTM) under two-point loading conditions. The beam specimen was placed on two supports, and load was applied at two points symmetrically placed from the supports. The load was increased gradually until failure occurred.

The flexural strength was calculated based on the maximum load, span length, and dimensions of the specimen.

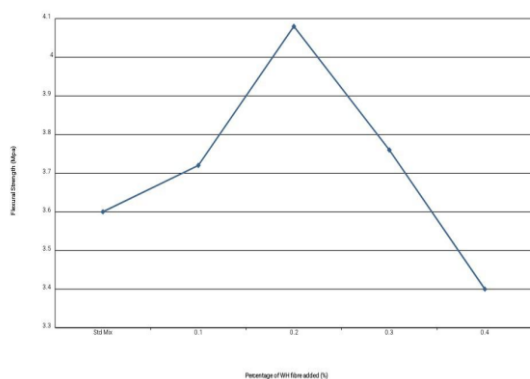


Fig 4.4 Graph showing Flexural strength of beam

Inference:

From the experimental results, it is observed that the flexural strength of concrete increases with fibre addition up to 0.2%, achieving the maximum value, and decreases with further increase in fibre content due to reduced workability and fibre agglomeration. Thus, 0.2% is the optimum fibre content.

At 0.5% fibre content, the specimen failed before proper loading, which indicates that excessive fibre content adversely affects the structural integrity and workability of concrete.

For M20 grade concrete, the theoretical modulus of rupture is given by:

$$f_{cr} = 0.7\sqrt{f_{ck}} = 0.7\sqrt{20} = 3.13 \text{ N/mm}^2$$

The experimental flexural strength values are found to be close to the theoretical value, indicating that the concrete exhibits expected flexural behaviour and adequate resistance to cracking.

4.5 Durability Study (Sulphate Attack Test)

The durability of concrete was evaluated by conducting the sulphate attack test in accordance with the procedure adopted in the experimental program. This test is essential to assess the resistance of concrete against aggressive chemical environments, particularly sulphate-rich

conditions that can lead to deterioration, expansion, and loss of strength.

Cube specimens of size 150 mm × 150 mm × 150 mm were cast using different fibre contents and cured in water for 28 days to ensure proper hydration. After curing, the specimens were removed from water, surface dried, and their initial weights were recorded. The specimens were then immersed in a sulphate solution for a specified period to simulate aggressive environmental exposure.

During the exposure period, the specimens were periodically observed for visible changes such as surface deterioration, cracking, or disintegration. After the completion of the exposure period, the specimens were removed, cleaned, and weighed again to determine the loss in weight. The compressive strength of the specimens after sulphate exposure was also determined using a compression testing machine.

Where:

W_1 = Compressive strength of cube cured in water

W_2 = Compressive strength of cube exposed to sulphate solution

A higher percentage loss indicates lower resistance of concrete to sulphate attack, while a lower loss reflects better durability performance

Table 10: Sulphate Attack Test Results

Proportions	Compressive strength in	Compressive strength in	% Increase
$\% \text{ loss of compressive strength} = \frac{W_2 - W_1}{W_1} \times 100$			
Std	23	21.8	-5.22%
0.1%	25	23.5	-6.00%
0.2%	29.6	27.8	-6.08%
0.3%	30.6	28.2	-7.84%
0.4%	22.1	20.0	-9.50%
0.5%	20.7	18.5	-10.63%

Inference:

From the results obtained, it is observed that the compressive strength of all concrete specimens decreases when exposed to sulphate solution compared to those cured in normal water. This confirms that sulphate attack has a detrimental effect on the durability of concrete due to chemical reactions with hydrated cement products, leading to the formation of expansive compounds and internal damage.

Incorporation of water hyacinth in concrete influences its resistance to sulphate attack. At lower percentages (around 0.2%–0.3%), the concrete shows comparatively better performance, with a lower percentage reduction in compressive strength. This may be attributed to improved particle packing and reduced permeability at optimal levels.

However, at higher percentages of water hyacinth

(beyond 0.3%), the compressive strength decreases significantly under sulphate exposure. This is due to increased porosity, poor bonding within the concrete matrix, and higher susceptibility to chemical attack.

Hence, it can be concluded that a small percentage of water hyacinth can be beneficial for improving durability, while higher replacement levels negatively affect the sulphate resistance of concrete. Therefore, the optimum percentage is identified in the range of 0.2%–0.3% based on durability performance

5. Conclusion

Based on the experimental investigation carried out on concrete incorporating water hyacinth as a partial replacement material, the following conclusions can be drawn. The incorporation of water hyacinth has a significant influence on both the mechanical and durability characteristics of concrete, and its performance varies with the percentage of replacement adopted in the mix.

The results of the compressive strength tests indicate that concrete with lower percentages of water hyacinth, particularly in the range of 0.2%–0.3%, exhibits comparatively higher strength values when compared to other mixes. This improvement can be attributed to the filler effect, where the fine particles of water hyacinth contribute to better particle packing, reduced voids, and a denser microstructure within the concrete matrix. However, beyond this optimum range, a gradual reduction in compressive strength is observed due to increased porosity, inadequate bonding between cement paste and the added material, and a consequent reduction in the load-carrying capacity of the concrete.

Similarly, the split tensile strength results follow a comparable trend, wherein the inclusion of water hyacinth at lower percentages enhances the resistance to tensile stresses to a certain extent. This may be due to the improved internal structure and reduced micro-cracking at optimum replacement levels. On the other hand, at higher percentages, the tensile strength decreases significantly, which can be attributed to the disruption of the internal matrix continuity and weaker interfacial bonding between the constituents of the concrete.

The flexural strength test results also indicate that the addition of water hyacinth affects the bending performance of concrete. At optimum percentages, the flexural strength remains within acceptable limits, suggesting that the concrete is capable of resisting bending stresses effectively. However, an increase in the percentage of water hyacinth beyond the optimum level results in a noticeable decline in flexural strength due to reduced cohesion and increased internal voids, which adversely affect the structural integrity under flexural loading conditions.

From a durability perspective, the sulphate attack test results reveal that all concrete specimens exposed to

sulphate solution exhibit a reduction in compressive strength when compared to those cured in normal water. This clearly indicates that sulphate ions adversely affect the durability of concrete by reacting with hydrated cement compounds, leading to the formation of expansive products, internal stresses, cracking, and eventual deterioration of the concrete structure. Nevertheless, it is observed that concrete specimens containing 0.2%–0.3% water hyacinth demonstrate comparatively lower strength loss, indicating improved resistance to sulphate attack at optimum replacement levels.

The water absorption test further supports the durability characteristics of the concrete, as it is observed that the water absorption increases with an increase in the percentage of water hyacinth. Higher water absorption indicates greater permeability, which facilitates the ingress of harmful agents such as sulphates and moisture into the concrete. This, in turn, leads to reduced durability and long-term performance of the concrete. Therefore, controlling the percentage of water hyacinth is essential to ensure adequate durability characteristics.

Overall, it can be concluded that water hyacinth, when used in small and controlled percentages, can be effectively utilized as a sustainable and eco-friendly material in concrete. It contributes to the reduction of environmental pollution caused by the uncontrolled growth of aquatic weeds, while also providing an alternative material in construction practices. The study indicates that the optimum percentage of water hyacinth lies in the range of 0.2%–0.3%, where a balance between mechanical strength and durability is achieved. Beyond this optimum range, a decline in both strength and durability properties is observed. Hence, careful consideration must be given to the selection of replacement levels to ensure satisfactory performance of the concrete

6. References

1. Das, A., Singh, R.K., et al. (2022) 'Use of natural fibres in concrete for enhanced mechanical performance and sustainability', *Heliyon*, 8(10), pp. e39773.
2. Verma, R., Sharma, P., et al. (2023) 'Effect of alkali-treated natural fibres on concrete properties', *Journal of Materials in Civil Engineering*, 35(6), pp. 04023045.
3. Karthik, A., Maris, R.C., Suligaikumar, R., Vishnu, K. and Vishwa, S. (2024) 'Study on mechanical and thermal properties of water hyacinth cement composites', *International Journal of Advanced Research*, 12(3), pp. 532–547.
4. Gupta, N., Mishra, A., et al. (2022) 'Durability study of natural fibre reinforced concrete', *Construction and Building Materials*, 330, pp. 127–138.
5. Kumproa, K., Kunasri, J., Thiamsorn, W. and Nuntiya, A. (2024) 'Utilization of water hyacinth fiber and ash in concrete blocks', *Journal of Engineering and Innovation*, 17(2), pp. 45–56.

6. Ramesh, K., Suresh, D., et al. (2023) 'Flexural behaviour of fibre reinforced concrete', International Journal of Structural Engineering, 14(4), pp. 321–335.
7. Mohd Ariffin, M.A., Ahmad, N.A., et al. (2023) 'Performance of agricultural and aquatic waste fibres in concrete', Construction and Building Materials, 363, pp. 129–140.
8. Wang, C., Chen, Y., et al. (2024) 'Use of water hyacinth fibre in concrete for mechanical performance enhancement', Journal of Cleaner Production, 292, pp. 126041.
9. Gonzalez, M., Lopez, J., et al. (2019) 'Effect of fibre length and dosage on concrete performance', Construction and Building Materials, 223, pp. 106–117.
10. Mohammed, A.S., Alhassan, I., et al. (2021) 'Influence of alkali-treated fibres on concrete properties', Journal of Cleaner Production, 292, pp. 125–134.

