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Influence of ceramic waste powder (CWP) in strength and durability performance of kenaf fiber reinforced concrete

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ABSTRACT

Considering the demand for a more resource efficient, cost effective and eco-friendly construction material, this innovative work aims at exploring the implication of deploying the combination of kenaf fiber and ceramic waste powder as partial river sand replacement on the concrete's mechanical and durability characteristics. A two-phased experimental work is carried out. Initially, evaluating the impact of ceramic waste powder in varying proportions (20–80%) on the concrete's mechanical attributes, followed by the impact of kenaf fiber (0–2%) + optimum ceramic waste powder content on the concrete properties. Mechanical Characteristics after underwater immersion of the specimen for 7, 14 and 28 days were analysed, revealing that a 20% ceramic waste powder substitution led to a 9.2% increase in compressive strength, a 19.1% increase in flexural strength, and a 2.7% increase in split tensile strength at 28 days. Phase two assessed kenaf fiber (0–2%) inclusion alongside 20% ceramic waste powder. A 1% fiber addition resulted in a 35.7% rise in flexural strength and an 18% increase in split tensile strength, although compressive strength slightly declined. Durability was evaluated using acid attack and rapid chloride penetration tests. The 20% ceramic waste powder + 0.5% kenaf fiber mix showed reduced strength and weight loss under acid attack and exhibited low chloride permeability. The investigation proved that at optimal combination level the deployment of ceramic waste powder and kenaf fiber in concrete has the capability to produce better durability and mechanical qualities while fostering sustainability through waste reduction and the use of natural fibre. Further, without compromising the structural performance, this investigation advances the creation of ecologically friendly building materials.

Keywords: kenaf fiber; Ceramic Waste Powder; Mechanical properties; Acid attack; Chloride Penetration.

1. INTRODUCTION

Concrete has become one of the most harnessed man-made resources across the globe. However, regardless of how, the methods deployed for the production of concrete and its dependence on the virgin natural resources has raised environmental concerns. Moreover, the rising demand for concrete has increased the need for innovation in the construction industry to make the material used more resource efficient, cost effective and eco-friendly. Such being the case, numerous researches have been carried out in order to achieve sustainability and reduce environmental impact. Infusion and substitution of constituent materials either partially or fully with recycled or waste material is studied on a large scale. Of late, replacements for synthetic fibres with natural fibres have gained a lot of attention. Among these alternatives, natural fibers such as luffa, coconut coir, abaca, bamboo, jute and kenaf fiber have drawn attention due to their ability to enhance ductility, crack resistance, and sustainability. Proper surface treatment and optimized volume fraction of fibers have shown improved mechanical and durability performance in concrete composites [1–4]. In the context of inflated resource exploitation in the production of concrete, studies show that Natural River Sand (FA) and its over utilization plays a major role in inducing environmental sequels. This opens an opportunity to investigate the possible replacements for fines and its performance [5]. Industrial debris like marble dust, granite dust, crushed rock, ceramic waste, recycled glass, brick, plastic and rubber aggregates, fly ash etc are wielded as replacements and the concrete's strength and durability aspects are compared to classical concrete [6]. Ceramic waste powder (CWP), as a waste material has high potential as partial substitute for sand reducing the demand for natural river sand and further enhancing

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the concrete's properties [7–9]. In this approach, investigation is carried out on the prospects of deploying CWP as a partial alternative to fine aggregate and Kenaf Fibre (KF) as natural reinforcement in concrete as a suitable replacement for traditional concrete.

Studies reveal that kenaf fiber depicts notable increase in the toughness as well as causes initiation of distributed cracking in concrete [10]. It was also noted that when kenaf fiber is deployed in High strength concrete, a decline in the compressive properties whereas flexural and tensile properties improved [11]. On treating the kenaf fibers with Alkaline solution, surface roughness as well as the adhesion factor of the fiber is enhanced resulting in increased durability properties [12]. Further, prior investigation reveals that deploying a volume fraction between 0.5%–1% showed desirable enhancement in the concrete's tensile properties almost equalling in compressive characters [13–14]. Changing proportions of the fibre's length and volume also caused a change in the workability of the resulting concrete [15]. When compared to the standard specimen, kenaf fiber enhanced porosity and water absorption at a volume of 1.5% and length of 40 mm. However, only at a volume between 0.75% and 1.0% and a length of 20 mm to 30 mm of KF did the chloride penetration and resistance to sulphate and acid assault continue to be valid. Additional increase revealed a decline in the concrete's strength features (2023) [16]. The fact that there are only countable sources available for the exploitation of Ceramic waste powder as a replacement for fine aggregate suggests that this field has a lot yet to be explored. Studies and analyses of CWP's structural characteristics as a cement substitute in concrete have been conducted. But research on CWP as a replacement for fines is still under development. Having identical chemical components with river sand, CWP has high potential which can be harnessed to produce quality substitutes. Although ceramic waste powder has been studied as a binder replacement, in this study it is exclusively investigated as a fine aggregate substitute in concrete to obtain enhanced performance [17]. The structural attributes of both the partial and complete replacement of Fine Aggregate with ceramic waste tile was assessed and concluded that replacement below 60% resulted in the decreased water absorption and permeability, conversely improvising strength for replacement value up to 100% [18]. The replacement of fine aggregate with ceramic tile waste aggregate lowered the flowability in ultra-high-performance concrete, nevertheless, 100% replacement raised the strength parameters and internal curing along with gradation factors led to improvements in pore structure and ITZ [19]. It has been further acknowledged that ceramic waste powder displayed significant improvement in workability and strength properties [20]. Prior research shows that the optimum substitution value for Ceramic waste powder in place of fine aggregate in concrete in order to achieve improved mechanical properties was 10% for M25 grade of concrete [21]. Further, deploying ceramic waste powder with coir fiber at an optimum proportion of 20% exhibited improved strength characteristics [22]. According to the experimental findings, incorporating up to 10% bone china ceramic waste in self-compacting concrete resulted in enhanced mechanical properties [23]. The enhanced performance of self-compacting concrete was primarily attributed to the finer particle size and pozzolonic activity of bone china ceramic powder waste, combined with superior filling ability of granite waste [24]. Ecological and economic assessments indicated that self-compacting concrete mixes incorporating bone china ceramic waste powder and granite cutting waste exhibited reduced energy, lower carbon dioxide emissions, and decreased overall material costs [25].

Ceramic Waste Powder (CWP) in this study is exclusively used as a partial replacement for fine aggregate, not as a binder. The role of CWP is to improve the mechanical and durability characteristics of concrete by enhancing particle packing and contributing to microstructural densification. Amongst the several natural fibers which has gained significant attention especially in terms of improving toughness, ductility and crack resistance in concrete, kenaf fiber remains an excellent choice in terms of the environmental benefits and mechanical enhancements they offer. Similarly, CWP on the other hand is a potential river sand substitute which remains underexplored. Though individually these components result in concrete's enhanced performance, the combination of kenaf fiber along with ceramic waster powder as partial substitution for fine aggregate has not been explored. This study investigates the possibility of using this mixture to create an affordable, environmentally friendly substitute for conventional concrete that has mechanical and durability characteristics similar to those of standard mix.

2. MATERIALS

OPC 53 grade cement was used as the binding material and it is purchased from Coimbatore region. As per IS Code, the cement's specific gravity value, specific surface value, fineness, and consistency limit are 3.08, 3256 cm^2/g, 3.1%, and 27%, respectively. River sand collected from Coimbatore region is deployed as fines aggregate with specific gravity 2.63 and fineness modulus 2.32. Coarse Aggregate material used confirms to IS 383:1970 with a specific gravity value of 2.71 and fineness value 5.88. The results of the physical parameters of aggregate are shown in Table 1. Ceramic Waste Powder (CWP) containing silica, clay and feldspar obtained from industrial waste crushed and ground to the proper size with specific gravity 2.43 is used in increasing

Table 1: Physical attributes of aggregates.

S.NO	ATTRIBUTES	FINES	COARSE AGGREGATE
1	Specific Gravity	2.63	2.71
2	Fineness Modulus	2.32	5.88
3	% Water absorption	0.86	0.97

Table 2: Chemical makeup of ceramic waste powder (CWP).

CONSTITUENT	FINES	CWP
SiO_2	22.13	64.17
Al_2O_3	6.37	19.3
Fe_2O_3	6.12	8.34
CaO	47.98	1.89
MgO	4.83	1.94
SO_3	2.53	0.81
K_2O	0.76	1.83
Na_2O	0.43	2.62
LOI	2.89	2.3

Table 3: Mix proportions.

CEMENT	FINE AGGREGATE	COARSE AGGREGATE	WATER	WATER CEMENT RATIO
382	606	1040	177	0.46

proportions – 0%–80% as cement substitute. Table 2 represents the chemical composition of ceramic waste powder. Properly treated kenaf fiber (KF) with an average length of 30 mm and diameter 200 µm is used as an alternative natural reinforcement at varying length proportions and volume. Tap water is used for facilitating the chemical reactions.

3. MIX DESIGN

A control Concrete mix of M25 grade concrete was designed as per the guidelines of IS 10262, targeting a compressive strength of 25 MPa at 28 days. The water cement ratio was maintained at 0.46, and the mix proportions were determined based on weight batching with a ratio of 1:1.58:2.71. The detailed quantities of materials used per cubic meter of concrete are listed in Table 3. This control mix was used for comparative evaluation of all experimental mixes containing ceramic waste powder and kenaf fiber.

3.1. Workability

In Phase I (CWP) only, workability decreased with increasing replacement levels of fine aggregate. At 20% CWP replacement, the slump value reduced by 8.2% compared to control mix, attributed to the finer particle size and increased water demand of the CWP. However, the mix remained workable without the need of plasticizers. In phase II (Ceramic Waste Powder + kenaf fiber), the addition of kenaf fiber further reduced to slump significantly. At 1% fiber content the slump reduction was nearly 18.5% from the control. This is due to high surface area and absorption characteristics of kenaf fibers, which reduce free water availability. Mixtures containing up to 1% kenaf fiber remained compactable with mechanical vibration despite the decrease in workability. However, after 1.5%, the mixture showed signs of segregation and weak cohesiveness, which results in a true slump that is appropriate for pavements.

4. METHODS

A total of 180 specimens were casted (90 specimens per phase). In the first phase, 90 specimens (concrete cube, cylinder and prism) were casted with ceramic waste powder acting as an alternative material for sand with

20% to 80% replacement percentage. Cube specimens of standard size 150 mm × 150 mm × 150 mm is used for carrying out the compressive strength test, prismatic specimen of size 150 mm height and 150 mm with is used to carry out the flexural strength test and cylindrical specimens of size 150 mm diameter and 300 mm height is used for carrying out the split tensile strength test as per the IS standard requirements. The specimens were cured under water for 28 days and the compressive, flexural and split tensile tests were conducted on the 7^{th}, 14^{th} and 28^{th} days respectively to find the optimum replacement percent. In the second phase, another 90 specimens (concrete cube, cylinder and prism) were casted with constant percentage of CWP and kenaf fiber was added in varying proportion ranging from 0 to 2%. Concrete cubes were immersed in two different acid solutions 5% hydrochloric acid and 5% sulphuric acid by volume. The initial pH values of the solutions were 1.1 and were monitored periodically throughout a 60 days' immersion period. The acid solutions were stored in containers and the solution was replaced every 15 days to maintain acidic concentration. The temperature of the exposure environment was maintained at 26 degrees matching standard laboratory curing conditions. After 60 days' specimens were surface dried and changes in weight loss and strength loss were recorded. Additionally, rapid chloride penetration test was carried out in laboratory as a part of durability test. Strength and weight loss was determined in acid attack and chloride permeability was identified in the rapid chloride penetration test. 36 concrete cube specimens were casted and deployed for the acid attack for determining the strength and weight loss parameters. The overall research framework is shown in Figure 1. Phase I involved the assessment of mechanical properties of concrete with varying CWP replacement levels (20%–80%). Phase II evaluated the combined effect of 20% CWP and varying kenaf fiber content (0%–2%) on concrete properties, including strength and durability metrics.

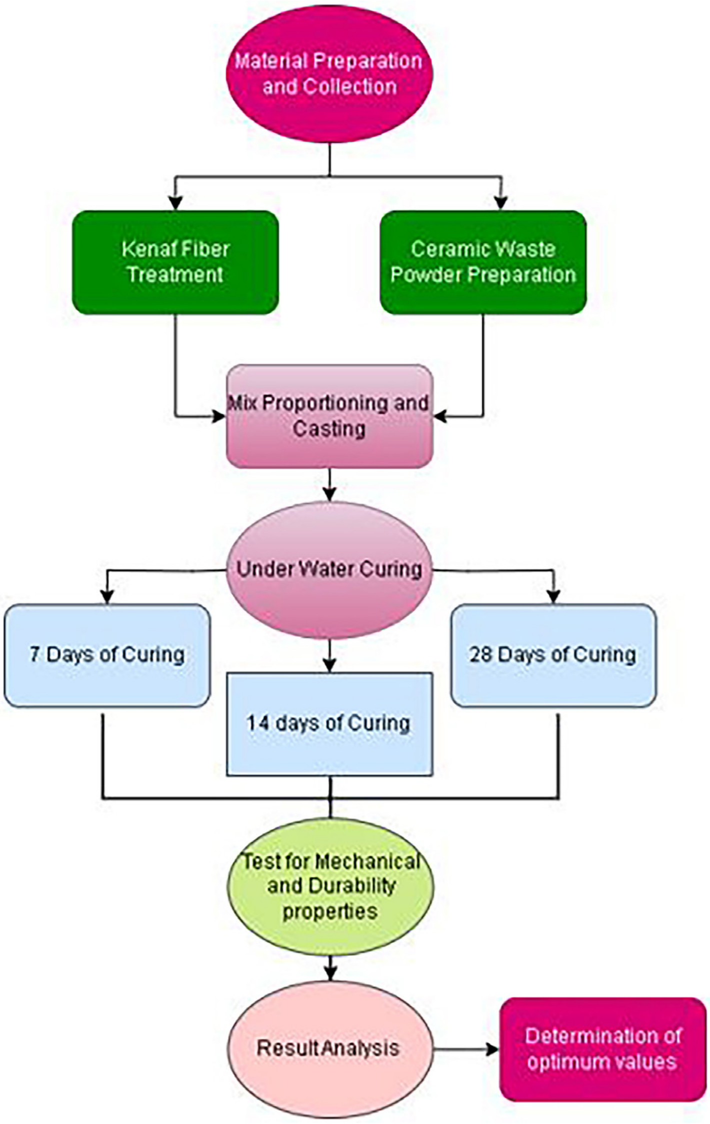

Figure 1: Overview of experimental methodology.

5. RESULTS AND DISCUSSIONS

5.1. Influence of ceramic waste powder on mechanical properties of concrete

The possible strength tests were conducted on the specimen to study the influence of CWP on the mechanical behaviour of concrete and the results obtained is elaborated as below.

5.1.1. Compressive strength

Compressive Strength Test on the specimen was conducted as per IS 516:1959 and Figure 2 depicts the results obtained after compressive strength analysis on the specimens with varying CWP content ranging from 20–80% after being immersed under water for 7, 14 and 28 days. The test results indicated that at the end of 28 days of curing, 9.2% increase in the concrete's compressive strength was achieved compared to standard sample which declined further as the replacement percentage increased CWP in place of sand. This improvement in the strength may be attributed to the pozzolanic reaction of CWP with $Ca(OH)_2$ leading to the formation of CSH gel which enhanced the bonding matrix. Further, the finer CWP particles act as micro fillers, improving the particle packing and reducing voids. However, beyond 20% replacement, the strength declined due to the dilution of the cementitious matrix and insufficient hydration products. Similar trends were reported by Mohammad Hossein et al. (2019) who noted an optimal mechanical response at lower replacement ratios and a decline thereafter due to the loss of binder cohesion.

5.1.2. Flexural strength

Flexural Strength Test on the specimen were conducted on the specimens as per IS 516:1959 and Figure 3 depicts the results obtained after Flexural behaviour analysis on the specimens with varying CWP content ranging from 20–80% after being immersed under water for 7, 14 and 28 days. The test results indicated that at the end of 28 days of curing, 19.1% increase in the concrete's flexural strength was achieved compared to standard

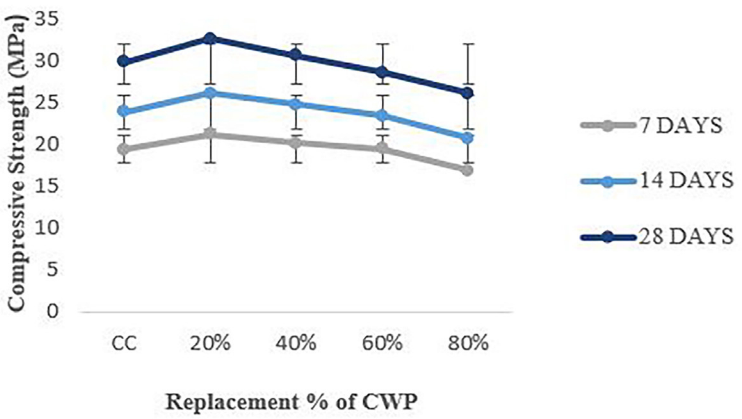

Figure 2: Compressive strength of concrete with different % of CWP replacing fine aggregate at 7, 14 and 28 days.

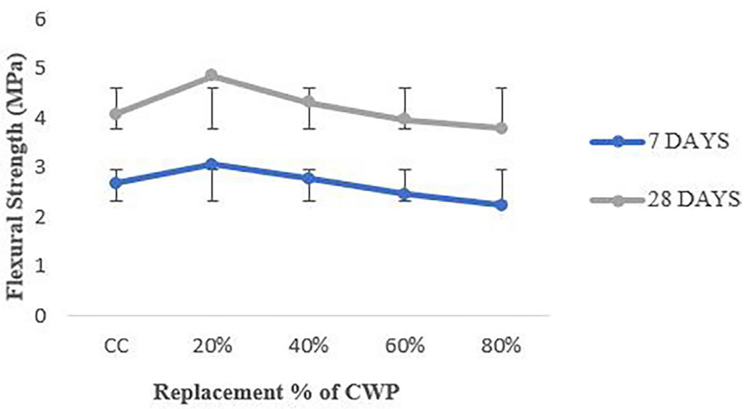

Figure 3: Flexural Strength variation with increasing CWP content after 7 and 28 days.

sample which declined further as the replacement percentage increased CWP in place of sand. Denser packing, improved particle distribution, and the pozzolanic reaction may all contribute to a modest increase in flexural strength. Sudden failure is avoided and crack resistance is improved by the decreased porosity. Concrete's resistance to tensile stress may be impacted by a drop in natural sand over 15%, which may have a detrimental effect on interfacial bonding. Flexural strength declines above 20% replacements because of insufficient cementitious matrix and decreased aggregate interlocking.

5.1.3. Split tensile strength

Split tensile Strength Test on the specimen was conducted as per IS 5816:1999 and Figure 4 depicts the results obtained after tensile strength analysis on the specimens with varying CWP content ranging from 20–80% after being immersed under water for 7, 14 and 28 days. The test results indicated that at the end of 28 days of curing, 2.7% increase in the concrete's tensile strength was achieved compared to standard sample which declined further as the replacement percentage increased CWP in place of sand. This marginal improvement is primarily because of the enhanced microstructure and reduced porosity from fine CWP particles. However, at higher CWP levels, the decrease in the bond strength between the aggregate and cement paste led to the performance deformation. Split tensile strength usually stays the same as regular concrete. By better distributing stresses, the enhanced density and microstructure stop cracks from spreading.

5.2. Influence of 20% ceramic waste powder and kenaf fiber in mechanical properties of concrete

5.2.1. Compressive strength

Figure 5 shows the results of compressive strength study on specimens with a constant 20% replacement of sand with CWP content and different percentages of kenaf fiber ranging from 0–2% in the sample after immersing in water for 7, 14, and 28 days. The test findings revealed that after 28 days of curing, the specimen containing 1% kenaf fiber and 20% CWP as sand replacement showed a drop in compressive strength when compared to the standard sample. As the fiber fraction in concrete increased, the compressive behaviour revealed a decreasing trend in the values.

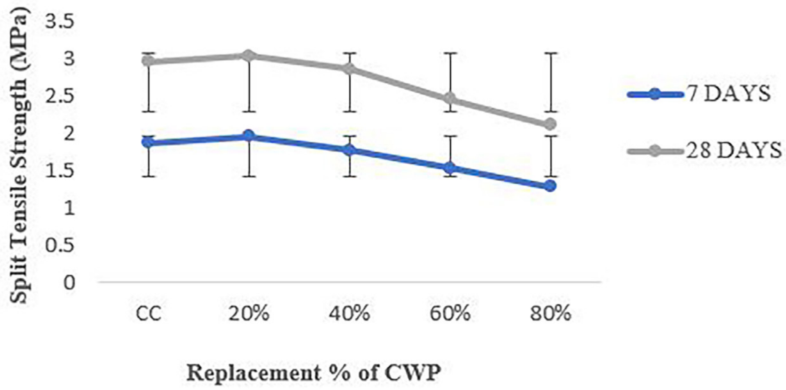

Figure 4: Split Tensile Strength results for concrete with increasing CWP percentages at 7 and 28 days.

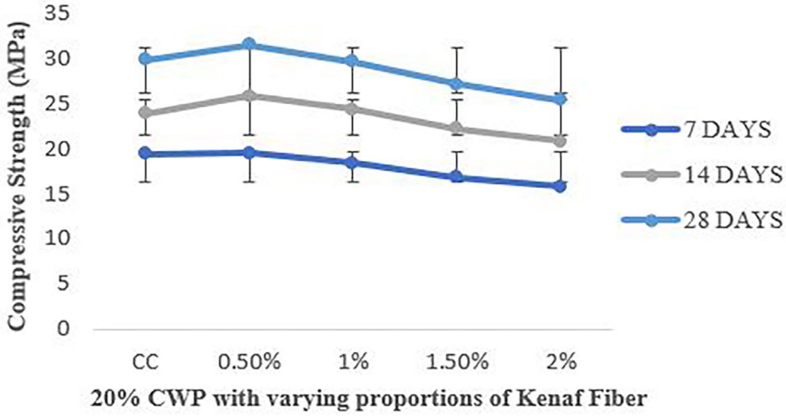

Figure 5: Compressive strength of concrete with 20% CWP and varying kenaf fiber contents after 7, 14 and 28 days.

This can be attributed to increased air entrainment and reduced workability due to fiber addition, which leads to potential voids and weak spots. Moreover, non-uniform fiber distribution act as stress concentrators, reducing compressive load-bearing capacity. Although fibers offer flexibility, if they are not evenly distributed, they may somewhat lower compressive strength. kenaf fiber, at about 0.5% by volume, improves post-failure ductility and crack resistance while preserving compressive strength. Fibers that are more than 0.5% can lower workability, raise air content, and have a detrimental effect on compressive strength.

5.2.2. Flexural strength

Figure 6 shows the results of compressive strength study on specimens with a constant 20% replacement of sand with CWP content and different percentages of kenaf fiber ranging from 0–2% in the sample after immersing in water for 7, 14, and 28 days. The test findings revealed that after 28 days of curing, the specimen containing 1% kenaf fiber and 20% CWP as sand replacement showed almost 35.7% increase in Flexural response when compared to the standard sample. As the fiber fraction in concrete increased, the Flexural response seemed to reveal a decreasing trend in the values.

This substantial improvement is due to the ability of the fibers to bridge cracks, which enhances post-cracking ductility and energy absorption. The CWP matrix contributes to a denser, more uniform structure that supports fiber interaction. The fibers' capacity to disperse stress and postpone the formation of cracks under bending loads results in an improvement in flexural strength. Fiber content above 1% may result in void formation and clumping, which lowers flexural strength. In addition to kenaf fibers' ability to control cracks, CWP increases matrix density, which raises flexural strength. Concrete that contains 1% fibers is more resistant to cracking without sacrificing strength.

5.2.3. Split tensile strength

Figure 7 shows the results of compressive strength study on specimens with a constant 20% replacement of sand with CWP content and different percentages of kenaf fiber ranging from 0–2% in the sample after immersing in water for 7, 14, and 28 days. The test findings revealed that after 28 days of curing, the specimen containing

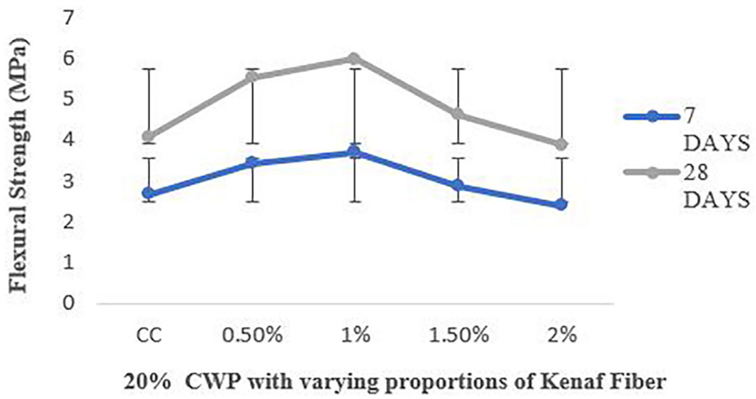

Figure 6: Flexural strength of concrete with 20% CWP and kenaf fiber at 7 and 28 days.

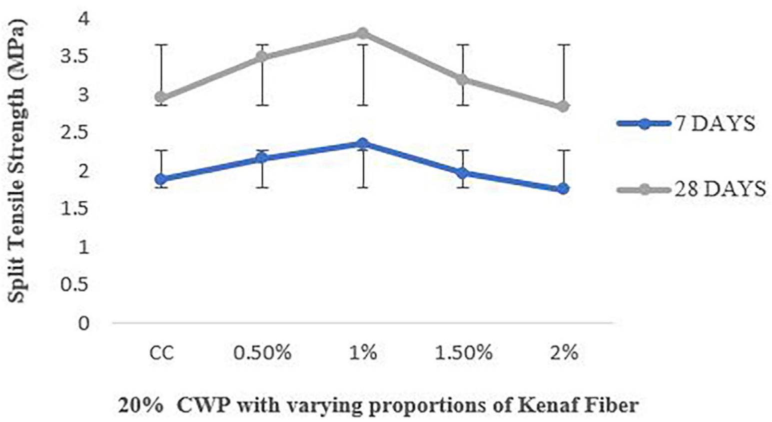

Figure 7: Split tensile strength results of concrete with 20% CWP and kenaf fiber at 7 and 28 days.

1% kenaf fiber and 20% CWP as sand replacement showed almost 18% increase in tensile properties when compared to the standard sample. As the fiber fraction in concrete increased, the tensile properties seemed to reveal a decreasing trend in the values.

The fibers improve post-crack tensile performance and bridge microcracks. With 20% CWP and 1% fiber content, the split tensile strength is marginally better than that of traditional concrete. Effective fracture management and stress redistribution usually result in improved split tensile strength.

5.3. Durability studies

The durability properties for the optimum values of CWP and kenaf fiber in concrete in comparison with the standard specimen is assessed and elaborated as below.

5.3.1. Loss in strength due to acid attack

Figures 8 and 9 depicts the loss in the strength of concrete specimen due to HCl and H_2SO_4 attack respectively for sample with 20% replacement of sand with CWP alone and sample with 20% CWP + 0.5% kenaf fiber when compared to the standard specimen. While the strength loss in concrete sample with 20% CWP due to HCL and H_2SO_4 is 2.5% and 3.2% lesser than the standard sample and for the specimen with 20% CWP and 0.5% kenaf fiber the strength loss observed is 1.8% lesser than the standard sample for both the acids.

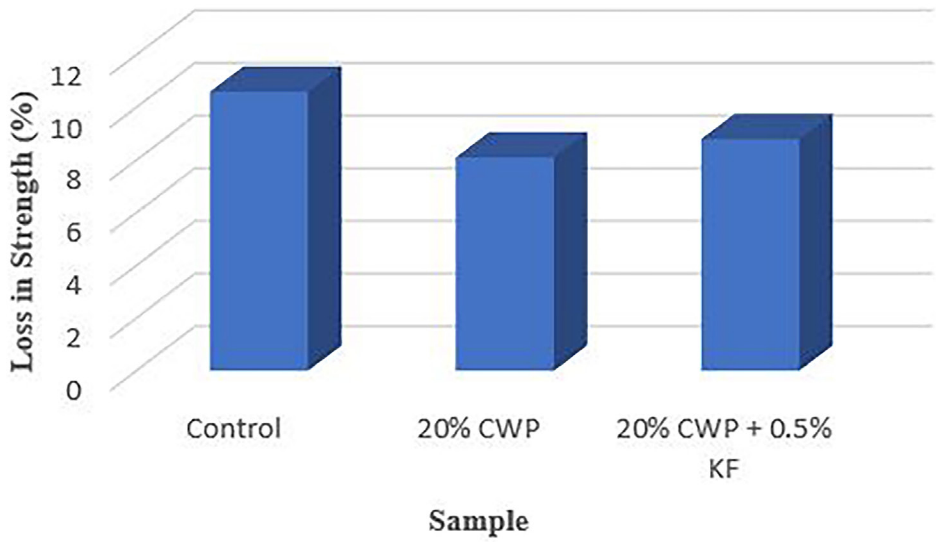

Figure 8: Percentage strength loss of concrete specimens exposed to HCl for 60 days.

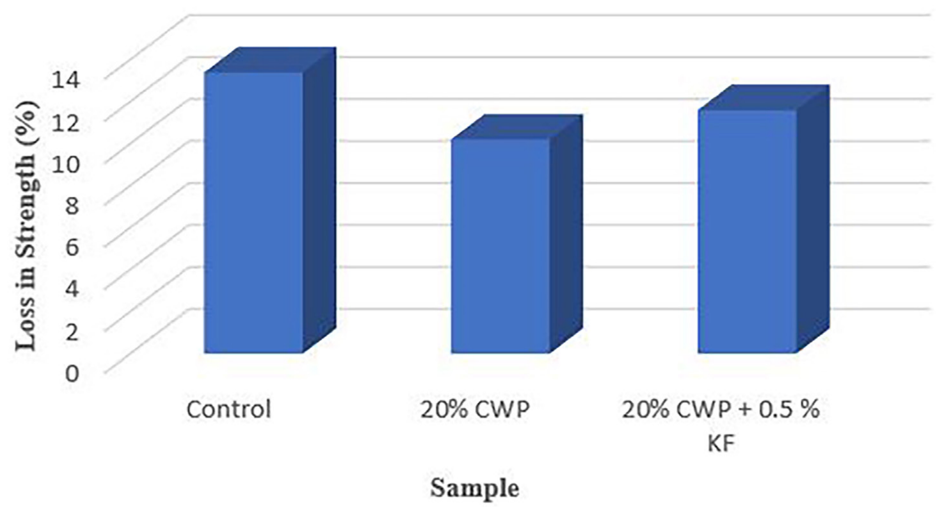

Figure 9: Percentage strength loss of concrete specimens exposed to H_2SO_4 for 60 days.

In hydrochloric acid, by raising matrix density and decreasing calcium hydroxide concentration, using CWP as a 20% substitute for sand strengthens concrete's resistance to hydrochloric acid assault. The concrete matrix's spaces are filled by the finer CWP particles, which lower porosity and prevent acid penetration, initially preserving strength. The fibers resist cracking and acid penetration over the first 28 days because they are largely intact. By strengthening fracture resistance and lowering acid penetration, the 0.5% kenaf fiber addition increases the concrete's early resistance to HCl attack.

In the sulphuric acid attack, Calcium hydroxide is used by the pozzolanic reaction of ceramic waste powder, enhancing the material's initial resistance to acid assault. Acid penetration is slowed by the filler effect of CWP, which refines the pore structure. Gradual cracking brought on by gypsum and ettringite production over time results in a greater loss of strength. Gypsum and ettringite, which result from the reaction of sulphuric acid with calcium hydroxide and other cementitious materials, produce expansion, cracking, and spalling. Over time, natural fibers like kenaf may deteriorate due to acid absorption, losing their capacity to reinforce. This may lead to microcracks that let additional acid seep farther into the matrix of the concrete.

5.3.2. Loss in weight due to acid attack

Figures 10 and 11 depicts the loss in the weight of concrete specimen due to HCl and H_2SO_4 attack respectively for sample with 20% replacement of sand with CWP alone and sample with 20% CWP + 0.5% kenaf fiber when compared to the standard specimen. While the weight loss in concrete sample with 20% CWP due to HCL and H_2SO_4 is 2.14% and 1.84% lesser than the standard sample and for the specimen with 20% CWP and 0.5% kenaf fiber the weight loss observed is 2.66% and 2.08% lesser than the standard sample for HCL and H_2SO_4 respectively.

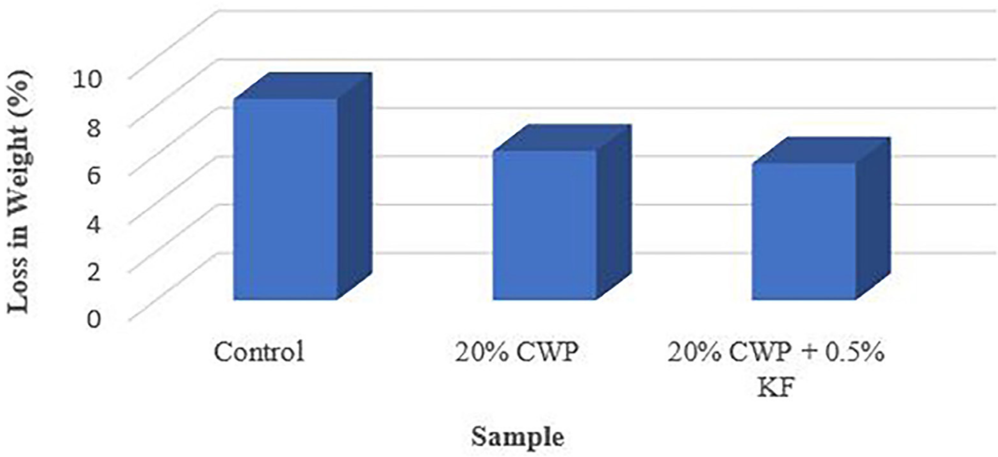

Figure 10: Weight loss in concrete specimens after 60 days HCL exposure.

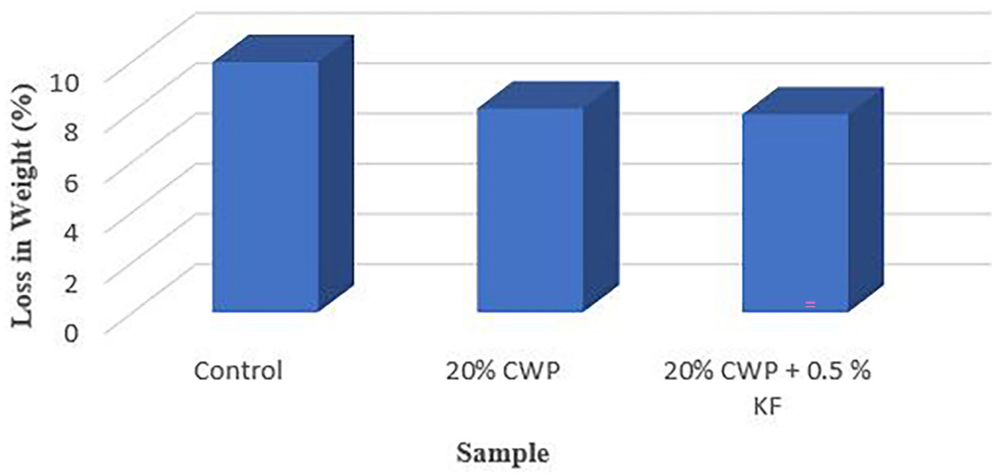

Figure 11: Weight loss in concrete specimens after 60 days H_2SO_4 exposure.

Table 4: RCPT results.

CONCRETE SAMPLE	CHARGE PASSED (COULOMBS)	CHLORIDE PERMEABILITY
Control	1973.68	Low
20% CWP	1841.36	Low
20% CWP + 1% KF	1769.28	Low

In the hydrochloric acid attack, Concrete that contains 20% ceramic waste powder (CWP) instead of sand has better resistance to HCl attack and loses less weight than normal concrete. Because of its improved matrix density and lower calcium hydroxide concentration, ceramic waste powder-induced concrete exhibits less weight loss in the early phases. By bridging cracks early on, the fibers reduce acid penetration and initial weight loss. Weight loss is initially decreased by the combination of 0.5% kenaf fibers and 20% CWP, but steady degradation results from continued exposure.

In sulphuric acid attack, Because of its pozzolanic qualities, ceramic waste powder reduces the amount of material susceptible to acid attack by consuming free $Ca(OH)_2$ during secondary reactions. By acting as microfillers, the tiny CWP particles lower porosity and restrict the entry of sulphuric acid. Although gypsum and ettringite continue to form, the mass loss is less severe due to the decreased $Ca(OH)_2$ availability. Weight loss during the initial phase is limited by enhanced matrix density from CWP and early crack control by kenaf fibers.

5.3.3. Rapid chloride penetration test (RCPT)

RCPT results for control sample, 20% Ceramic Waste powder and 20% Ceramic Waste Powder with 1% optimum kenaf fiber is shown in Table 4. The fine particle size and pozzolonic activity of CWP lead to the formation of C-S-H gel, which densifies the matrix and refines the pore structure. As micro fillers, the tiny CWP particles lessen porosity and the possible channels for chloride ions. Chloride ion penetration is slowed by CWP-modified concrete's denser matrix and reduced porosity. By bridging micro cracks and lowering entry points for chloride ions, the fibers increase crack resistance. The thick matrix produced by CWP guarantees long-term resistance to chloride intrusion, even if kenaf fibers may deteriorate over time. By preventing early cracks, kenaf fibers help to prevent chloride intrusion.

The increasing trends in performance indicate that the CWP's pozzolanic activity assists with strength enhancement up to optimal grade and beyond 20% there is dilution of the cementitious matrix. The fiber bridging effect of kenaf enhances tensile and flexural performance but slightly impairs compressive strength due to potential fiber clustering. These findings align with prior research by Elsaid et al. (2011) and Zhou et al. (2020), reinforcing the role of fiber treatment and optimized dosage. The enhanced acid resistance and low chloride permeability are attributed to densified microstructure due to CWP and crack-bridging by fibers, supporting conclusions by Mohammad Hossein et al. (2019).

To build on the findings of this study, future research should investigate the long term durability performance of concrete containing CWP and KF under freeze thaw cycles, sulphate exposure and alkaline environments. Additionally, microstructural analysis techniques such as scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) should be employed to validate the observed improvements in strength and durability.

6. CONCLUSION

1. Optimal mechanical performance was achieved at 20% CWP replacement for river sand resulting in 9.2% higher compressive strength, 19.1% higher flexural strength and 2.7% higher tensile strength.
2. Addition of 1% kenaf fiber with 20% CWP enhanced flexural and tensile strengths by 35.7% and 18% respectively, though a marginal drop in compressive strength was observed.
3. Adding 0.5% kenaf fiber with 20 5 CWP however improved the compressive strength and it is considered as the optimal fiber proportion to be added to the concrete mix.
4. Durability assessments with optimal CWP and kenaf fiber proportion in concrete confirmed superior resistance to HCl and H_2SO_4 acid attacks, with strength and weight loss reductions of up to 3.2% and 2.66% compared to control.
5. The combination of 20% CWP and 0.5% kenaf fiber exhibited low chloride permeability (1769.28 Coulombs), improving long-term durability.

6. The use of ceramic waste powder and kenaf fiber not only improve performance but also promotes economy principles in construction materials. As limited literature exists on the specific combination, the results provide a unique contribution to sustainable concrete development and serve as a foundation for further research in hybrid eco-friendly mixes.

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