iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** IV **Month of publication:** April 2026

DOI: https://doi.org/10.22214/ijraset.2026.80714

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue IV Apr 2026- Available at www.ijraset.com

A Review on the Performance of Kenaf-Crete Incorporating Partial Replacement of Fine and Coarse Aggregates With C&D Waste

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***Abstract:** This study examines the structural performance and durability of a sustainable concrete composite which combines natural aggregates, construction and demolition (C&D) waste, and Kenaf fibre as an additive to enhance its overall performance." In total, two experimental mixes have been studied:M1 (replacing 50% coarse aggregate) and M2 (replacing 50% coarse aggregate and 45% fine aggregates). The outcomes show that although M1 mix reached the required design strength, M2 mix experienced a small decrease in compressive performance due to the increased porosity of the reused aggregate. However, in order to make up for this drawback, Kenaf fibers were added to the composite which helped increase ductility and improve the materials' resistance to microcracks. Tests related to the durability of the mixture (water resistance, acidity resistance) also differentiated between M1 and M2 mixes. Namely, the former had better water resistance and less vulnerability to acids due to a dense matrix within, thus making M1 mix a more attractive option for further applications with 25-30% CO2 emission reduction.*
Keywords— Kenaf Fibre Reinforced Concrete, Recycled Aggregate Concrete (RAC), Construction and Demolition (C&D) Waste, Durability and Mechanical Properties, Interfacial Transition Zone (ITZ)

I. INTRODUCTION

Today's construction industry finds itself at a point where it is important to make a decision regarding its sustainability. The construction and demolition industry uses about 40% of the total raw material used worldwide, but it produces huge amounts of C&D waste on an annual basis. The scarcity of natural aggregates like river sand and crushed stones means that there is a need for alternative measures and a shift from linear to circular economy whereby waste is used as valuable raw materials. This makes the recycling of aggregates in concrete production very popular today. [1]

The current development was aimed at creating a sustainable and strong construction material. Even though recycled aggregates prevent problems with waste disposal, their use results in high porosity and weak ITZ, which negatively affects performance characteristics. The research indicates that microstructure improvement and ITZ strengthening can positively impact recycled aggregate concrete performance. [2]. Natural fibres like kenaf can be used in order to circumvent such drawbacks. Kenaf fibre is a sustainable carbon-neutral fibre reinforcement which improves tensile strength and crack-resistance. Thus, it helps in increasing the toughness of cementitious matrix which is otherwise brittle. [3].

But the use of fibres and waste materials poses another problem: durability along with sustainability. Researchers have found out that although the use of kenaf fibres enhances crack bridging and protection from chemicals, it will also cause increased porosity and moisture absorption if not properly mixed. [4]. In the same manner, characteristics like water absorption capacity, acid resistance, and permeability play a crucial role in determining the longevity of recycled aggregate concrete systems. [5]. Such qualities stress the need for an optimal balance in materials to achieve not only mechanical properties but also environmental endurance

Hence, this investigation is not limited to merely assessing the strength parameters but also focuses on finding out the lifespan of recycled aggregate concrete reinforced with kenaf fibers. The purpose of conducting experiments like water absorption test and acid test on various mixes like M1 (coarse aggregate replaced) and M2 (entire aggregate replaced) is to evaluate their practical performance regarding serviceability. Finally, this study attempts to compare the various replacement methods as well as measure the advantage gained by keeping some amount of natural aggregates intact.

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II. LITERATURE REVIEW

A. Performance of Recycled Aggregates in Concrete

Research studies on the utilization of recycled aggregates have emphasized the need to understand the effect of the inherent characteristics of recycled aggregates on the quality of the end product concrete. The replacement of normal coarse aggregates by recycled aggregates does not usually cause any problems in relation to strength and performance. Nevertheless, high proportion use of recycled fine aggregates will lead to the formation of more pores in the concrete mix, which will increase the permeability of the mixture and hence lower the strength characteristics. As a result, care must be taken during the design of concretes using recycled fine aggregates [6].

B. Kenaf Fibre for Mechanical Reinforcement

Natural fibre-based reinforcement has been extensively investigated due to the capability of such reinforcement to improve the mechanical characteristics of sustainable composite structures. In particular, kenaf fibre was proven to have the potential of increasing tensile strength and making the concrete less fragile, especially in case of a higher percentage of recycled aggregates. The incorporation of natural fibres results in an improvement in fracture toughness and better crack resistance [7].

Using the appropriate proportion and length of kenaf fibre allows increasing the energy absorbing capabilities and ductility of concrete. This helps to make it less brittle for applications with the use of recycled aggregates. At the same time, there is evidence indicating that the incorporation of natural fibres leads to an increase in tensile and flexural strengths; at the same time, compressive strength becomes slightly lower [8].

The use of recycled materials along with natural fibres contributes to additional improvements in the performance of composites. In particular, hybrid systems consisting of recycled materials and natural fibres allow obtaining light-weighted cementitious composites with higher ductility and crack resistance [9].

C. Durability and Lifespan Assessment

The issue of durability plays an important role when considering recycled concrete aggregates, especially at high replacement rates. Research reveals that the use of recycled concrete aggregates in larger quantities causes higher water absorption and lower resistance to chloride ion penetration. This happens because of the porous structure of the mortar attached to the surface of recycled aggregate particles [10].

Surface treatment of recycled aggregate is known to be one of the most effective ways of improving durability. Methods like the elimination of weakly adhering mortar and enhancing aggregate surfaces can help minimize water absorption and increase resistance to chemical attacks. It is also important to mention that the assessment of durability of recycled aggregate concrete must necessarily include tests for acid resistance [11].

The other aspect to consider is permeability, which determines the ability of harmful components such as chlorides and carbon dioxide to enter concrete. Adequate mix design, including the reduction of the water-to-cement ratio and using appropriate mineral admixtures, can help prevent permeability [12].

D. Impact of Replacement Ratio of Recycled Aggregates

The ratio of recycled aggregates significantly influences the performance of concrete in terms of mechanics and durability. Studies have shown that replacing natural aggregates partially achieves good performance, whereas increasing the percentage of replacement causes a reduction in performance. Replacement of up to 50% of the coarse aggregate ensures sufficient strength, although it causes an increase in porosity due to poor bonding of the matrix [13].

On the other hand, replacement of the fine aggregate has greater impact because it raises water requirements and poor bonding, which leads to lower density and increased risk of crack formation [14].

E. Influence of Water Absorption and Porosity of Recycled Aggregates

The primary drawback of recycled aggregates is that these materials have a very high water absorption due to the presence of cementitious paste attached to them. This leads to an increase in the water-cement ratio, which leads to incomplete hydration reactions and weakens the bond formation. Thus, recycled aggregates are highly porous and absorb much more moisture than conventional aggregates [15].

Another characteristic of concrete made from recycled aggregate is that interconnected porosities in the concrete allow for water and other aggressive substances to penetrate into the concrete, affecting its durability [16].

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F. Effect of Natural Fibres on Cracking Resistance and Ductility

The use of natural fibres like kenaf helps greatly in increasing the ductility and crack resistance properties of concrete. These fibres work as bridges between the cracks formed in the microstructure and delay their growth and improve the toughness of the composite [17].

In addition, these natural fibres help in controlling the crack width and shrinkage cracking resistance property of concrete. As such, their effect is positive in improving serviceability [18]. Too much fibre quantity can have adverse effects on the compressive strength of concrete because

G. Combination of Recycled Aggregates and Fibre Reinforcement

When using recycled aggregates and fibre reinforcement together, one can achieve a good balance of both sustainability and efficiency. Although recycled aggregates lower compressive strength, fibres assist in increasing tensile strength and preventing cracks. Fibre reinforcement increases load transfer and prevents crack propagation in recycled aggregate concrete [19].

Fibres form a 3D network of reinforcement in the material, which leads to improved stress transfer in the weak matrix. Thus, it is effective for improving tensile properties while lowering compressive strength.

H. Performance in Durable Conditions when Exposed to Chemicals and Water

Durability in aggressive environments is one of the important issues in using recycled aggregate concrete. As recycled aggregate concrete has a porous structure, it becomes more vulnerable to attacks by water and chemicals. Research works have revealed that recycled aggregate concrete demonstrates poor durability against chemical and acidic agents because of its higher level of permeability [20].

Attack by any hazardous element will result in degradation of the hydration reaction and weakening of the structure. Hence, it is necessary to control the porosity rate and optimize the mix composition to ensure durability in the long term[21].

III. EXPERIMENTAL MIX PROPORTIONS AND DESIGN

The experimental program was carefully planned to test how Kenaf-Crete works using eco-friendly methods while still being strong. The mix design is based on M25 grade concrete, which's a standard for comparing how well it works with regular concrete. The main goal of this study is to see how recycled Construction and Demolition (C&D) waste and treated Kenaf fibre reinforcement affect concrete.

The mix proportions were chosen to see how increasing levels of aggregate affect the concrete while keeping the same amount of treated Kenaf fibres. Two different mix setups were used.

The first mix, M1uses 50% natural coarse aggregate and replaces it with recycled concrete aggregate while still using 100% natural fine aggregate. This mix is like an eco-friendly concrete that checks if partial replacement works and how well recycled coarse aggregates work in concrete.

The second mix, M2 is more eco-friendly by replacing 50% of coarse aggregate and 45% of aggregate with C&D waste materials. This mix is expected to be weaker and more porous making it harder to see how Kenaf fibres work. In both mixes treated Kenaf fibres are added as reinforcement. Kenaf is a fast-growing material that helps concrete resist cracks and be more flexible.

Using C&D waste in both M1 and M2 mixes is good for the environment. It reduces the need for resources like river sand and crushed stone, which lowers the environmental impact. This study aims to show that with more C&D waste the concrete can still work well with Kenaf fibre reinforcement.

Overall, this experimental mix design combines being eco-friendly, with performance aiming to make a concrete that meets requirements while promoting waste utilization and resource efficiency using Kenaf-Crete

It is imperative to conduct comprehensive testing procedures to evaluate the performance of Kenaf-Crete especially where C&D waste is used as recycled material. The tests conducted will help us determine whether the incorporation of kenaf fibres and using the waste in place of natural aggregates meets the structural and durability criteria for sustainability in construction.

IV. MECHANICAL AND DURABILITY TESTS

A. Tests on Mechanical Properties

Tests on mechanical properties aim to ascertain the strength and ability of the concrete to carry loads. Since inclusion of C&D waste may make the concrete porous, the importance of such tests cannot be underestimated as they determine the reinforcing capabilities of the kenaf Fibers.

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1) Cube Compression Test

Cube compression test is among the most basic tests to determine the load carrying capabilities of the M25 concrete mix. This test helps us determine how the reinforced fibre matrix works and what effect the replacement of 50% coarse and 45% fine aggregates by the waste will have on the crushing strength.

2) Split Tensile Test

Concrete generally does not have good tensile strength, and this test will show the reinforcing capability of the kenaf fibres acting as bridges in the micro-cracks of concrete.

3) Flexural Strength Test

Flexural Strength tests how the concrete beam resists failure by bending forces. This test will be crucial in determining the extent to which the fibres improve the ductile properties and energy absorption capability of M1 and M2.

B. Tests on Durability Properties

Durability tests evaluate the properties of the concrete when subjected to rigorous environmental conditions. In this case, since the use of recycled aggregates and natural fibres may make the concrete vulnerable to chemical and moisture penetration, these tests would help establish that the concrete is "eco-friendly" while not reducing its durability throughout its lifecycle.

1) Water Absorption Test

This test was conducted to evaluate the pores present inside the concrete. This is especially important when considering fibre reinforced concrete with recycled aggregate where both kenaf and construction demolition wastes have different moisture properties than those of regular materials. Test procedure: Following standard guidelines (ASTM C642), the samples were first dried in an oven at $105^{o}C \pm 5^{o}C$. They were then immersed completely in water and tested.

2) Acid Attack Resistance Test

Resistance of Material to Acid Attack Chemical resistance was determined through acid immersion testing using an accelerated technique to mimic the material's behaviour under harsh conditions or industrial applications. Methodology: Samples from each mixture were submerged in a 5% solution of Sulphuric Acid for a certain curing time

V. MATERIAL PREPARATION

A. Recycled Aggregates Preparation

Recycled aggregates are made up of construction and demolition (C&D) waste that undergoes crushing and sieving to form crushed concrete and masonry pieces. Some processes in preparing recycled aggregates include:

Collection and sorting – the C&D waste is collected from demolished reinforced concrete buildings and pavement works.

Cleaning – the collected material is cleaned to get rid of different impurities such as dust, plaster, organic compounds, clay, and silt particles.

Crushing and sieving – the collected material undergoes crushing and then sieving to obtain the appropriate particle sizes for fine and coarse aggregates.

B. Processing of Kenaf Fibres

The Kenaf fibre is a natural bast fibre that is obtained from the stem of the Hibiscus cannabinus plant. The processing procedure of the Kenaf fibres involves:

Cleaning- In the initial process, the raw fibres are cleaned by washing them and then air-dried to get rid of any contaminants on their surface.

Chemical Treatment (Alkaline Treatment)- As a way of enhancing the adhesion between the Kenaf fibre and the cement matrix, the fibres are treated using 5% NaOH. The process enhances roughness. Eliminates contaminants that may be a source of degradation in the alkali medium of cement.

Drying and Cutting-The last stage involves air-drying the treated fibres after which they are cut to an appropriate length of around 65 to 70 mm.

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VI. SAMPLE TESTING AND RESULTS

A. Mechanical Test and Results

1) Compressive Strength

Based on the laboratory testing, the compressive strength development of the two experimental mixes is compared below (Shown in Fig 1) against the M25 grade standard.

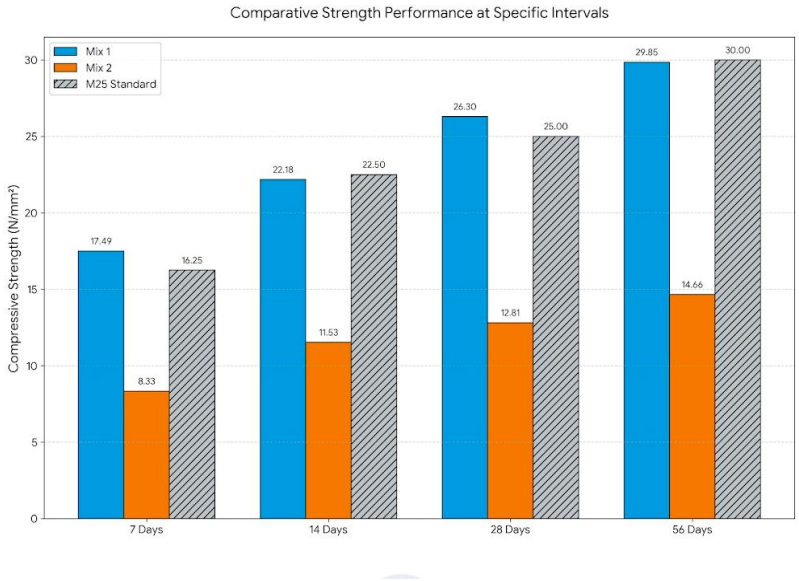




FIGURE-1

Results Analysis

M1 (50% Coarse RA) - Successfully met the target strength. It achieved 26.30 N/mm^2 at 28 days, surpassing the strength criteria for M25 concrete.

Mix M2 (50% Coarse + 45% Fine RA) - Could not meet the standards. It obtained only 12.81 N/mm^2 in 28 days, achieving roughly 51% of the expected strength.

The major reason for Mix M2 to fail is its poor compressive strength, due to excessive replacement of both coarse and fine aggregates.

The technical reasons for this are:

Higher Porosity of Fine Recycled Aggregates - As opposed to Mix M1, which used only natural sand, Mix M2 contained 45% of recycled fine aggregate, which consists of a large amount of adhered mortar and dust, causing a higher water requirement for the mix, thus forming a porous mixture.

Interfacial Transition Zone Weakening - The ITZ region is the weakest spot in concrete. In Mix M2, there is an additional weakness known as "double weakness":

- ITZ around 50% coarse recycled stone.
- ITZ within the mortar because of the 45% fine recycling. This caused several weak paths in the cube, making it prone to collapse under relatively low stress compared to M1.

The Disruption of Water Cement Ratio- The recycled C&D waste has very high water absorption properties as compared to natural aggregates. Even if the ratio is maintained in design calculations, the recycled fine aggregates will absorb all the water meant for cement hydration, thus leaving behind an "un-hydrated" or "thirsty" mixture with poor binding.

Effect of Kenaf Fiber Addition in Weak Matrix -Although Kenaf fibres have excellent tensile resistance properties, their effect on the bulk compressive strength cannot be compensated. The mortar matrix in M2 was so porous that the fibres did not have enough material to anchor onto to resist compression although tensile tests were successful.

2) Split Tensile Strength

Comparative Analysis against the M25 Standard -The M25 standard stipulates that the compressive strength of concrete must be 25 N/mm² within 28 days and the split tensile strength must be around 3.5 N/mm

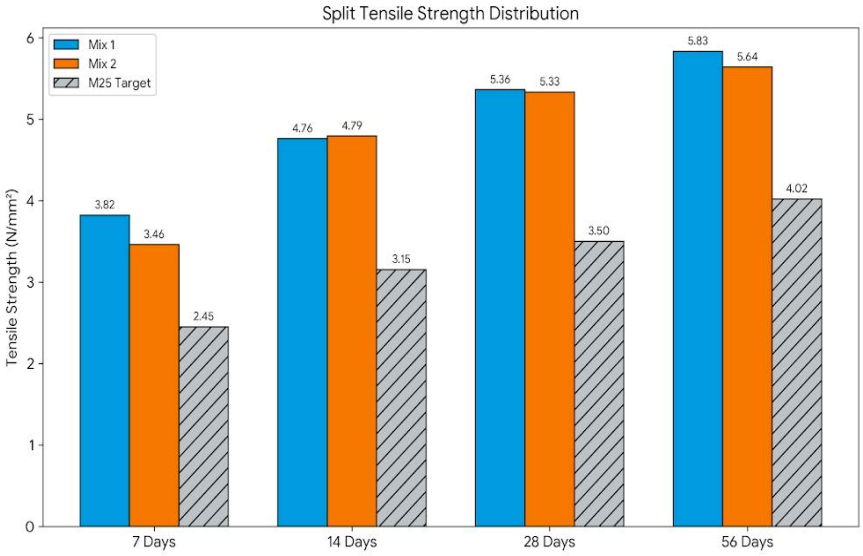




FIGURE 2

M1 (50% coarse replacement) - This mix fully meets the requirements. It attained a compressive strength of 26.30 N/mm² and a split tensile strength of 5.36 N/mm² after 28 days. The concrete has similar characteristics with the conventional M25 concrete, but it is more environmentally friendly.

Mix M2 (50% coarse + 25% fine replacement) - This mix does not meet the criteria for compressive strength. It attained 12.81 N/mm² (51% of the specified requirement) within 28 days, and it can be regarded as M10 concrete. On the other hand, it fully meets the criteria for tensile strength it attained 5.33 N/mm² indicating that the replacement of fine aggregates severely affects crushing resistance but not tensile capacity when reinforced with fibres(shown in **Fig 2**)

Effect of Kenaf Fibre in the Concrete Mixes

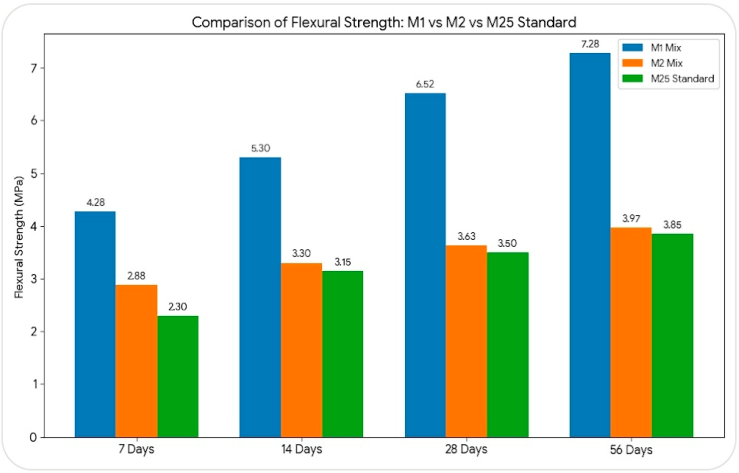
The Kenaf fibre reinforced in 5% NaOH for ensuring the presence of strong bonding with the cement completely altered the nature of failure of concrete from being brittle to becoming ductile.

- Internal Micro Reinforcement - The Kenaf fibre provided internal three-dimensional reinforcement within the concrete matrix. For M1, the fibres helped in filling up the spaces between the large stones at the matrix interface while M2 received a skeleton of fibres, which helped in keeping the weaker and porous mortar in place.
- Crack Arrest & Ductility - Concrete with recycled aggregate usually experiences quick failure once the cracking starts since it tends to get split due to the lack of fibre reinforcement. However, this time around, the Kenaf fibre reinforced cracks arresting capacity as the Kenaf fibres bridged the cracks as soon as it started forming.
- Tensile Optimization - It should be noted that the effect of the fibres is best experienced in terms of tensile strengths since the tensile strength of even M2 remained higher than 5.0 N/mm² despite low compressive strength.

C. Flexural Strength

It can be seen from the experimental results that there exists a considerable difference in the flexural strength exhibited by the two mixes. The M1 Mix showed superior flexural strength properties than the M2 Mix and even the standard M25 concrete over the whole duration of experimentation. The high modulus of rupture of the M1 Mix indicates that the interfacial transition zone between the cement paste and aggregate has been extremely well optimized since ITZ usually constitutes the weakest link during flexural loading.

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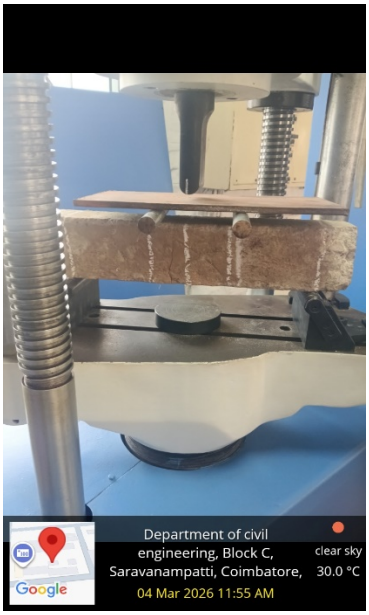


FIGURE 3

Early Age Acceleration of Strength in M1 - One of the most important observations of this experiment was the accelerated early age gain in the strength properties of the M1 Mix. It should be noted that Mix M1 managed to acquire its flexural strength at an early stage as compared to the requirement for standard M25 concrete that takes almost 28 days. The accelerated gain in strength may be due to highly reactive hydration reactions or because of some certain additives.

Compliance and Representation of Standards - M1 is a high-performance mix, while Mix M2 is a representative of the scientific approach to the development of standard design M25. M2 showed a gradual increase in strength characteristics according to the expected curve typical for standard M25. At 28 days,M2 achieved design requirements, confirming its high reliability for all general construction purposes.

Long Term Flexural Strength Development and Maturity of Hydration - Both mixes demonstrated a progressive increase in their strength values during the period from 28 to 56 days. Such an increase is an indicator of perfect curing conditions and hydration of dicalcium silicate. Progressive flexural strength increase at the end period of curing confirmed that internal microstructure was still strong enough to prevent cracks due to hydration products filling interstitial spaces.

Effects of Kenaf Fibre Reinforcement:

The outstanding performance of Mix M1 is mainly due to the effect of mechanical bridging by Kenaf fibre reinforcement.

Fibres-Matrix Interaction - In fibre reinforced concrete, fibres play a major role as the load bearing element after cracking of the brittle matrix. The excellent flexural strength of Mix M1 demonstrates a proper stress transfer mechanism, whereby the Kenaf fibres provide a 3D skeleton that prevents crack propagation much better than the control M25.

Rapid Strength Development through Mechanical Locking- The very good 7-day strength of M1, exceeding even the 28-day strength of the M25 grade, is due to the immediate effect of the fibre skeleton. While in normal concrete there is only chemical reaction responsible for strength development, here there is additional mechanical locking providing immediate strength gain.

VII. DURABILITY TEST

A. Water Absorption Test:

Comparison Between Mix M1 & M25 Standard Mix - The performance of Mix M1 is satisfactory since its absorption decreases with time, suggesting that the mix is well-hydrated. The mix is highly comparable with the M25 standards. Although it surpasses the ideal 28-day age criterion (2.79% vs. 2.50 after 56 days).

Comparison Between Mix M1 & M25 Standard Mix -Mix M2 shows high absorption throughout all stages. It fails to meet the durability standards for M25 grade concrete.

%), it can be said to be a satisfactory mix for general purposes due to significant improvement in its pore size

Reasons for Poor Performances of M2

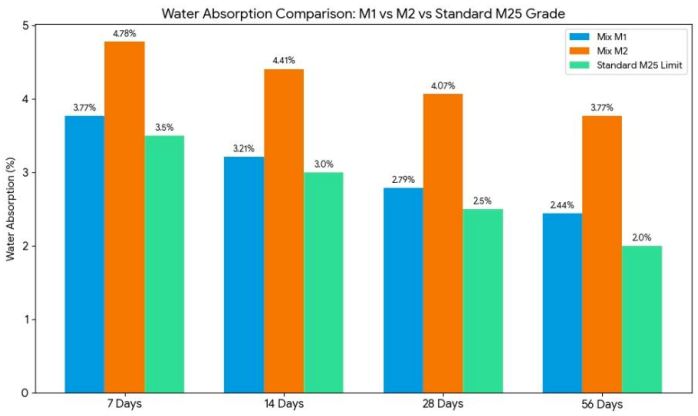
There are several reasons behind the poor performance of Mix M2. Most of the reasons can be linked back to its composition and proportion. The following points describe some of the reasons behind its poor strength and durability properties.

High Absorption of Water - One of the main causes behind the poor performance of the given mix is due to its high water absorption capacity. It was found from the water absorption test data that the absorption of water by the concrete mix exceeds the limit of 4% after 28 days. This high value of water absorption clearly indicates that the concrete has high levels of capillary pores. The most probable cause for this situation is the use of an excessive water-cement ratio in the concrete mix. It is a well-known fact that the addition of excessive water into the concrete creates voids within the concrete after it hardens. This leads to increased capillaries and thus increasing the porosity of concrete.

Lack of Density- The lack of density is another vital reason why M2 has failed. The strength of M2 is found to be about 12.8 MPa after 28 days, which is much lower than what would normally be seen in structural concrete like M25.This is due to poor compaction and insufficient cement paste. In an ideal concrete mixture, there is sufficient cement paste that fills up the spaces between the aggregates. However, in M2, the large volume of water dilutes the cement paste, resulting in a weak binder. Hence, the cement concrete mixture is less dense and porous.

High Permeability-High permeability is yet another critical issue concerning Mix M2, being related to its high porosity. Since there are continuous pore paths in the material, water and other corrosive substances can readily enter inside the concrete. It means that the concrete will be exposed to rapid degradation from different elements in the environment such as:

- Chemical attacks (e.g., acid attack, sulphate attack)
- Water penetration



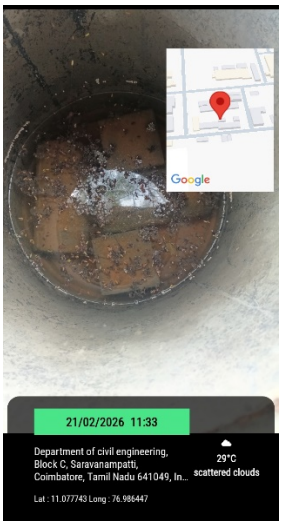


FIGURE 4

B. Acid Resistance Test

Mix M1 Performance Assessment- Mix M1 shows fair resistance to acidity attack. In the beginning, Mix M1 shows a strength loss of 13.37%. This strength loss is slightly higher than what would be considered ideal when designing concrete for durability purposes. On the contrary, Mix M1 shows significant improvement on the strength loss after 56 days. At 56 days, the strength loss drops to 8.50%.This implies that with time, there is an increase in density of the concrete matrix. This might be attributed to further hydration reactions and bonding between materials in the cementitious system. This improvement in strength loss signifies the improvement in durability of concrete. From the results obtained, Mix M1 is only marginally acceptable as it does not meet the durability requirements of high-performance concrete. However, its improvement with time is promising for durability.

Mix M2 Performance Assessment-The mixture M2 shows very poor resistance to acid attacks, where the value of strength loss exceeds 13%, rising to 18% initially. In contrast to M1, an increase in curing time does not show any enhancement in the acid resistance of M2. Such degradation signifies the fact that the internal structure of the mixture M2 is extremely sensitive to harsh chemicals over the entire service life. The mixture M2 fails to meet the minimum standards of durability for grade M25 concrete. The higher value of strength loss suggests that it cannot be used as a structural material when exposed to chemicals.

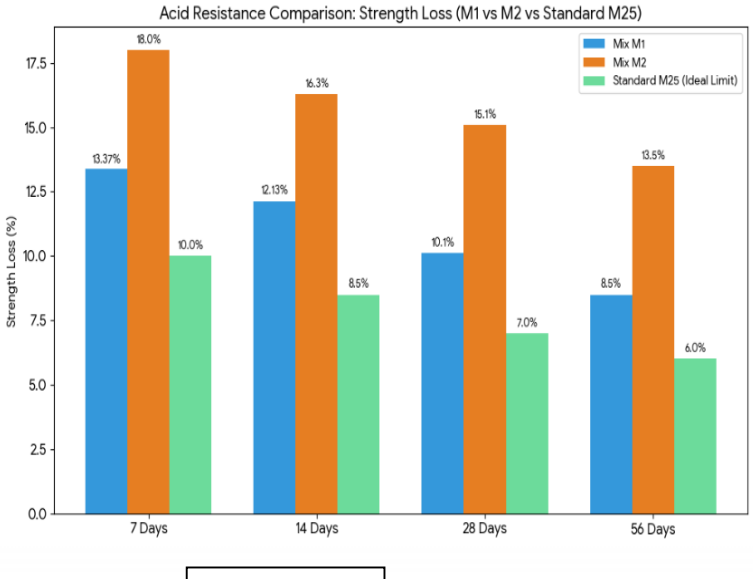




FIGURE 5

Reason For Failure in Mix M2

Chemical Sensitivity - It should be noted that concrete always has some alkalinity due to the presence of various compounds, like calcium hydroxide Under the influence of acids (sulfuric acid), such alkaline components interact with acids and decompose. According to the analysis of the results, the strength of the material is extremely low, which can be explained by the fact that not only the outer layer but the whole concrete core is affected by the acid attack. In other words, there is no resistance of the material to the corrosive effect.

High Permeability - One of the most important factors that have caused M2's failure is high permeability. The data obtained after water absorption testing demonstrates that M2 has much more pores than M1.Such pores form passages that provide an easy passage of aggressive chemicals to the depth of the material. Sulfuric acid interacts with calcium and causes the destruction of hydration products, which, in turn, leads to the loss of mass and structural destruction of the concrete.

Low Initial Density- The second mixture tested, mix M2, also faces the problem of low initial density, as seen from its relatively low compressive strength from previous mechanical tests. Lower density is an indication of insufficient packing of particles and lack of adequate cementing action. The fragile structure thus created does not have sufficient resistance against the scaling and erosion effects of acid. Furthermore, low density means that the aggregate-cement paste bond is weak, leading to deterioration in no time.

VIII. CONCLUSION

The mechanical properties and durability of the kenaf fibre reinforced concrete incorporating C&D wastes as recycled aggregate were examined in this study. As observed from the analysis above, it can be said that the percentage replacement of the aggregate has a considerable influence on the strength and durability parameters of the concrete.

In this regard, Mix M1, having a 50% coarse aggregate replacement rate, exhibited acceptable mechanical strength. The **compressive strength** attained by Mix M1 was 26.30 N/mm² at 28 days, which is higher by 5.2% compared to the targeted M25 grade concrete compressive strength of 25 N/mm². On the other hand, Mix M2, with a 50% coarse and 45% fine aggregate replacement rate, had a compressive strength of 12.81 N/mm², a reduction by 51% from the target strength.

Thus, it is evident that the high application of the recycled aggregate, particularly fine aggregates, in the concrete causes a substantial reduction in compressive strength owing to an increase in porosity and weak interfacial bond strength.

Regarding **split tensile strength**, both mixes surpassed the conventional split tensile strength of 3.5 N/mm². Mix M1 had a split tensile strength of 5.36 N/mm², while Mix M2 attained 5.33 N/mm², showing a slight variation of 0.56%.

As for the results of the, again, there is evidence of better performance of the M1 mix. Indeed, **flexural strength** of the M1 mix exceeded the strength values typical for ordinary M25 concrete. Meanwhile, Mix M2 demonstrated lower levels of flexural strength, and although the mixture developed its strength during the curing process, the flexural strength value remained worse in comparison with the other sample because of weaker matrix structure. The reason for the lower flexural performance of the M2 mix in comparison with M1 is a worse interfacial transition zone and higher porosity of M2. Despite that, in case of both tested materials, the addition of kenaf fibres resulted in better ductility and delay of cracks formation.

In analysis about durability of the mixes, we can conclude that M1 performed better. Thus, the **water absorption** coefficient of M1 at 56 days of curing amounted to only 2.79%, which differs from the acceptable level of 2.5% by only 11.6%. On the contrary, water absorption of the M2 mix exceeded 4%, which is almost twice the accepted norm.

The **effect of acidity** on the mixes was another aspect that demonstrated the differences in their durability. Mix M1 initially had an 13.37% strength reduction but then improved its performance by reducing the strength loss to 8.50% after 56 days; hence, there is an increase in performance by about 36.4%. Conversely, mix M2 had a maximum strength loss of 18%; hence, an increase of more than 111% compared to the final strength loss of M1, which demonstrates that it lacks chemical resistance and durability.

In summary, the experiments conducted prove that a mix with aggregates partially replaced by waste, such as M1, will have balanced performance, while an excess replacement percentage like that of mix M2 causes severe compressive strength losses greater than 50%, as well as durability loss.

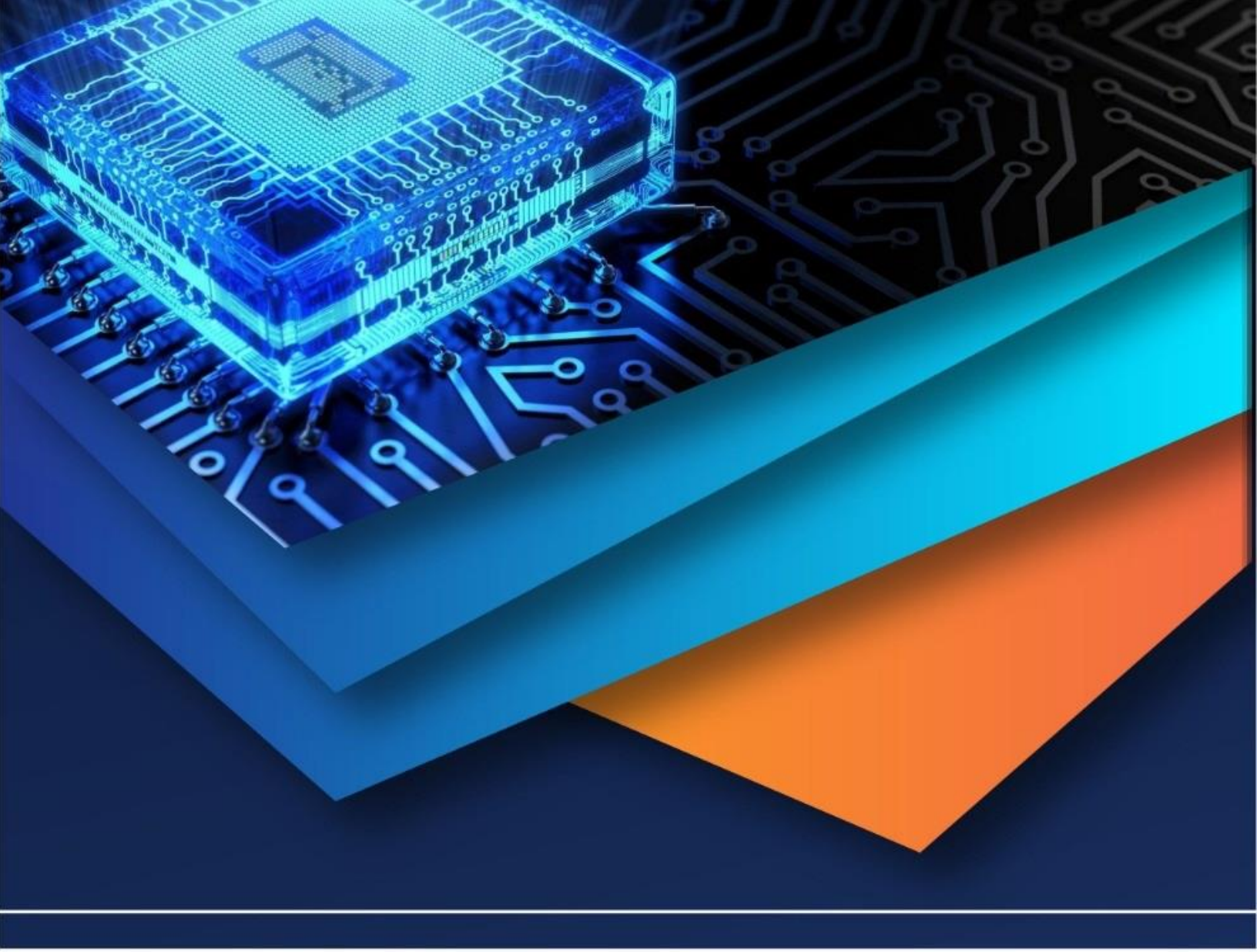
In conclusion, although the use of kenaf fibres provides notable improvements in tensile strength, flexural strength, and crack resistance, they are not enough to offset the decrease in compressive strength owing to high porosity. An optimal mix design is thus necessary for achieving the right combination of sustainability and structure. From the findings, Mix M1 could be a good choice in terms of both sustainability and structural performance while Mix M2 would be inappropriate due to its decreased strength and durability.

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