Application of Coffee Husk Ash as Partial Replacement of Fine Aggregate in Concrete

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Abstract: The task of turning agricultural waste into practical construction and building materials has been placed before civil engineers. Coffee husk is produced in vast amounts due to the global commerce of coffee beans, which are incinerated into ash when used as fuel, producing coffee husk ash (CHA). Even though many researchers have worked on the utilization of CHA in concrete, they have been used as partial cement replacement but not as a replacement of aggregates. The experimental study of the performance of concrete on fine aggregate replaced partially with CHA is represented in this paper. The fine aggregate is replaced by 0%, 2%, 4%, 6%, and 8% by weight of CHA. The performance of the partially replaced fine aggregate with CHA is reviewed by considering the compressive strength and workability of fresh concrete and the splitting tensile strength, flexural strength, durability under acid and alkaline media, thermal conductivity, and rapid chloride permeability test of hardened concrete. The results indicate that the partial replacement of fine aggregate with 4% of CHA (CHA04) in concrete provides a positive impact to all the selected performance parameters. The compressive strength, flexural strength, and splitting tensile of the CHA04 mix were 43.4 MPa, 3.7 MPa, and 2.44 MPa, respectively, which were 28.4%, 19.35%, and 1.66%, respectively, greater than normal concrete mix (CHA00). Even the study of acid and alkaline attack on the CHA04 mix showed lesser strength reduction as compared to other mixes. The RCPT showed less chloride permeability, and the thermal conductivity is higher for CHA04, indicating lesser voids compared to other mixes. With the help of this investigation, it can be said that fine aggregate replacement with 4% CHA has the best strength and durability properties compared to regular concrete.

Keywords: coffee husk ash; waste management; fine aggregate replacement; strength performance; durability

1. Introduction

In the present day, the rapid growth in infrastructure has created a demand for construction materials [1–3]. The combination of fine aggregate, coarse aggregate, and cement undergoes hydration to form concrete. As a result of the expanding population, the construction of stores, public buildings, and other applications has evolved greatly [4,5]. Construction material sources are insufficient, so the researchers are looking into ways to turn waste materials into valuable ones, which can cut down on the need for natural resources and the prices, thereby also dealing with the problems associated with a lack of construction supplies and garbage disposal [6,7]. Sand from riverbanks is the most widely utilized fine aggregate, and since it is used so frequently in concrete, it has the largest global consumption. Due to increasing infrastructure development and resulting supply deficiencies, the demand for natural sand is relatively strong in emerging countries [8]. Because of this, emerging nations’ building sectors are under pressure to find substitute resources to meet the need for natural sand. On the other hand, the advantages of using...
by-products or aggregates obtained from waste materials are prominent in the areas of lowering load on environment and cost of waste management, lowering manufacturing costs, and enhancing concrete quality [9,10]. Many researchers are investigating alternative materials to fine aggregate, including waste-derived cenospheres, vermiculite, ceramic waste, eggshells, walnut shells, and others that can partially replace fine aggregate [11]. Other materials that can be used as an alternative for natural fine aggregate include manufactured sand, blast furnace slag, copper slag, crushed glass, fly ash aggregate, recycled aggregates, steel slag, etc. [12].

In this context, an attempt has been made to partially replace fine aggregate with coffee husk ash (CHA), which is a by-product of coffee beans. Due to the widespread commerce in coffee beans, plantations produce enormous amounts of coffee pulp and husk that are eventually disposed of in landfills [13]. Moreover, it generates around 250,000 tons of coffee waste every year globally [14]. Using a ton of fresh coffee, an estimated 0.18 tons of coffee husk and 0.5 tons of coffee pulp are produced [15]. Due to their lack of commercial value and the huge environmental difficulty associated with their disposal, they are possibly one of the main coffee by-products [16]. Coffee wastes are harmful to the environment due to their high polysaccharidal content and high fire potential, making them unsuitable for landfills or composting [17]. When the coffee husk is burned as a source of fuel in various small-scale industries and plantations, the organic compounds are oxidized, leaving behind inorganic minerals and elements that make up the ash. The composition of CHA varies depending on factors such as the type of coffee bean, the method of processing, and the temperature and duration of combustion [18].

Due to the higher concentration of CaO and K$_2$O along with the smaller concentration of silica (SiO$_2$) present in CHA, it functions as a cementitious and pozzolanic material when added to the cement [19]. The mechanical strength of the cement concrete is enhanced by the formation of calcium silicate hydrate (CSH gel) and the type of soil used in its preparation [20–22]. The coffee husk burning temperature affects the ash’s silica level, and the impurities in CHA are easier to eliminate at high temperatures; the appropriate burning temperature for coffee husk was estimated to be 600 $^\circ$C [23]. Although the silica concentration will increase due to the higher temperatures, the resulting silica is in crystalline form and is not in an active condition [19,24].

The economical housing practices deal with the decrease in the expenditure of construction without compromising the requirements of a good structure. It is anticipated that employing agricultural byproducts in place of traditional fine aggregate will encourage housing developers to adopt it in building construction [25]. The present study is concerned with the investigation of concrete produced by partially replaced fine aggregate with CHA, wherein fine aggregate is partially replaced with specified ratios of 2%, 4%, 6%, and 8% by weight of CHA. When evaluating the effectiveness of the partially replaced of fine aggregate with CHA, the workability of fresh concrete, compressive strength, splitting tensile strength, flexural strength, durability in acidic and alkaline environments, thermal conductivity, and the rapid chloride permeability test of hardened concrete are all considered.

2. Related Work

The partial replacement of fine aggregate in concrete has been a topic of research in the field of civil engineering for many years. The goal is to find alternative materials that can partially replace fine aggregate without compromising the durability and strength of concrete [26]. Waste glass is one of the most common materials used in concrete as partial replacement for fine aggregate. In a study conducted on the use of crushed glass as a partial replacement for fine aggregate in concrete, the glass improved the concrete’s compressive strength, flexural strength, and elasticity modulus. The study also revealed that the optimal replacement percentage of fine aggregate with crushed glass was 20%, giving increases in compressive and flexural strength by 4.33% and 10.99%, respectively [27].

Application of bagasse ash as partially replaced fine aggregate in concrete showed improvement in the strength properties of concrete. This study recommended the use of a
fine aggregate replaced with 10% bagasse ash as the optimum level, as it shows an increase in compressive strength of 6.66% when compared to a normal mix with zero percent fine aggregate replacement after curing the concrete for 28 days [28]. Another material that has been used for the partial replacement of fine aggregate in concrete is furnace bottom ash (FBA). To produce concrete with compressive strengths between 40 and 60 N/mm², it may be advantageous to substitute natural sand with 30% FBA sand. This can be done without negatively affecting the structural concrete’s permeation or drying shrinkage qualities [29].

A study conducted on the use of waste rubber tire as a partial replacement for fine aggregate in concrete resulted in a decrease in compressive strength of the concrete in the mixes with 0.35 \( w/c \) & 0.45 \( w/c \). However, it was found that in \( w/c \) 0.55, the compressive strength increases marginally, with 10% as the optimum percentage of replaced fine aggregate with waste rubber tire. At 0.55 \( w/c \), particles of rubber create efficient packing due to the better workability of this mix [30]. Similarly, in another study, the use of bottom ash and waste foundry as a partially replaced fine aggregate in concrete improved the workability and compressive strength of the concrete marginally. The study recommended a replacement level of 30% for optimal results. The mix with a replacement level of 60% for fine aggregate is not advised since the mix has high water content that also impacts on various strengths, so the maximum replacement level is taken as 50% [31].

The results of a study on the use of iron slag as a partial substitute for fine aggregate in concrete suggested a replacement level of 40% since it increased the material’s compressive strength, split tensile strength, and flexural strength [32]. Similarly, marble waste was used as a partial replacement for fine aggregate in concrete. The study showed that using marble waste as a partial replacement for fine aggregate improved the compressive strength of concrete by 20%. The optimal replacement percentage of fine aggregate with marble waste was found to be 40% [33]. The studies have been conducted using recycled waste such as recycled coal bottom ash and recycled PET as a partial replacement for aggregates, which showed improvement in the strength and durability properties of concrete [34,35]. Even waste products of the marble industry and crushed waste glasses were proven to be better partial replacement materials to be used as of aggregates in concrete [36–38].

The physical and mechanical characteristics of these materials, as well as the physical, fresh, hardened, and micro-structural examination of industrial-waste-based concrete, are the main topics of a review on the use of industrial waste materials in concrete as a fine aggregate replacement. As a result of substituting copper slag, imperial smelting furnace slag, and class F fly ash for sand, concrete has increased strength and durability characteristics, but its slump rises as the rate of replacement rises. More thorough research is required on the clincher from palm oil and ferrochrome slag. According to the review, substitutes for fine aggregate can be made from industrial wastes like steel, waste foundry sand ISF, copper, coal bottom ash, blast furnace, class F fly ash, and ferrochrome. These are almost identical to natural sand in terms of bulk density, grain size distribution, and specific gravity, apart from foundry sand, which does not adhere to ASTM C33 [39] or IS-383-2016 [40] grading standards. It is possible to replace 20% of the sand with waste foundry sand without negatively impacting the mechanical and physical qualities. Additionally, using up to 30% of steel slag instead of sand in concrete mixtures produces positive results. Steel slag is an industrial waste product that can replace sand in construction projects to increase strength and durability. Granulated blast furnace slag negatively affects tensile and compressive strength, while ISF slag positively improves mechanical characteristics and abrasion resistance. Bottom ash is a type of fine aggregate that can be used. Ferrochrome slag can be utilized as a sand substitute, and the durability properties can be improved by replacing 30% and 50% of the sand with GBFS and FBA, respectively. Compared to control concrete, palm oil clincher gives better compressive strength and flexural strength due to pozzolanic reaction [41].

The use of CHA in concrete as partial replacement of fine aggregate has not yet been extensively studied. It is a new and niche material which is neither used as a partial replacement to fine aggregate or as a binder material in concrete. The present study
addresses the replacement of the fine aggregate in concrete with coffee husk ash. The improvement in performance of the concrete with coffee husk ash as partial replacement to fine aggregate is studied. Additionally, the durability of the concrete using CHA as partial replacement to fine aggregate is studied in acidic and alkaline environments.

3. Materials and Methods

The materials required for concrete i.e., cement, coarse aggregate, fine aggregate, and coffee husk ash are procured, and their physical and chemical properties are determined. The coffee husk ash is procured from coffee plantations from Karnataka, where coffee husk is incinerated as fuel. Due of its excellent compressive strength and durability, ordinary Portland cement of grade 53 was selected as a construction material in this investigation. The chemical and physical properties of the cement used is given in Table 1.

<table>
<thead>
<tr>
<th>Component</th>
<th>OPC 53</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>58.66</td>
</tr>
<tr>
<td>SiO₂</td>
<td>21.27</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>8.79</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.56</td>
</tr>
<tr>
<td>MgO</td>
<td>1.94</td>
</tr>
<tr>
<td>K₂O</td>
<td>-</td>
</tr>
<tr>
<td>Na₂O</td>
<td>-</td>
</tr>
<tr>
<td>SO₃</td>
<td>2.52</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.35</td>
</tr>
<tr>
<td>LOI</td>
<td>1.48</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>3.12</td>
</tr>
<tr>
<td>Specific surface area/fineness (m²/g)</td>
<td>0.33</td>
</tr>
</tbody>
</table>

3.1. Fine and Coarse Aggregate

The fine aggregate used in the study is sand with 2.36 mm to 1.16 mm size as major portion. The fine aggregate ensures that the concrete achieved the desired performance. The fineness modulus and specific gravity of the sand used were 3.61 and 2.59, respectively. The sand used as fine aggregate is partially replaced with coffee husk ash in varying percentages such as 2%, 4%, 6%, and 8%. The coffee husk ash has particle sizes like that of sand, with major portion size between 2.36 mm and 1.16 mm. Due to its abundance in alkaline and alkaline earth metals, CHA may be able to replace traditional feldspars, which are currently utilized as fluxes in clay-based ceramic formulations but are becoming increasingly expensive and scarce [25]. Calcium carbonate, calcium silicate, calcium phosphate, and potassium sulphate make up most of the CHA’s mineral composition [26]. The coffee husk ash is shown in Figure 1, and its chemical composition is shown in Table 2.

![Coffee husk ash](image-url)
Table 2. Chemical and physical properties of Coffee husk ash.

<table>
<thead>
<tr>
<th>Components &amp; Properties</th>
<th>Amounts</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>17.611%</td>
</tr>
<tr>
<td>SiO₂</td>
<td>15.00%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.744%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2.727%</td>
</tr>
<tr>
<td>K₂O</td>
<td>61.099%</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.00%</td>
</tr>
<tr>
<td>MgO</td>
<td>0.494%</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.977%</td>
</tr>
<tr>
<td>MnO₂</td>
<td>0.302%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.421%</td>
</tr>
<tr>
<td>Loss of ignition</td>
<td>-</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>2.5</td>
</tr>
<tr>
<td>Specific surface area/fineness (m²/g)</td>
<td>1.70</td>
</tr>
</tbody>
</table>

Crushed stones of 10 mm downsize were used as coarse aggregate with fineness modulus and specific gravity values of 2.7 and 2.65, respectively. The major portion of crushed stones used as coarse aggregates were between 10 mm and 4.75 mm size. Crushed stone is an extensively used material in construction due to its durability, strength, and availability. The coarse aggregates are sourced from quarries and consist of mechanically crushed rocks and stones of various sizes. The irregular shape and rough texture of crushed stone particles provided better interlocking and bonding within the concrete matrix, enhancing its overall strength and load-bearing capacity. The grain size analysis of sand, coffee husk ash, and crushed stone used in concrete is shown in Figure 2.
3.2. Concrete Mix Design and Proportions

The concrete was designed for M20 grade. The mix design of M20 grade concrete was carried out as per IS:10262-2019 [42] and then fine aggregates were replaced by coffee husk ash as 2%, 4%, 6%, and 8% weight. The proportion of aggregate replacement was decided based on trial-and-error method. The mixing of concrete mix has been carried out using machine for uniform mix and to produce better quality and quantity of concrete. The concrete mix have been prepared with varying percentages of coffee husk ash as a replacement for fine aggregate.

The fine aggregate is mixed with different percentages of CHA, which are named as given in Table 3.

Table 3. Mix proportion ratios as per IS:10262-2019 [42].

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Mix ID</th>
<th>Replacement Levels</th>
<th>Cement</th>
<th>FA</th>
<th>Coffee Husk Ash</th>
<th>CA</th>
<th>w/c Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CHA00</td>
<td>0%</td>
<td>1</td>
<td>1.66</td>
<td>–</td>
<td>1.99</td>
<td>0.45</td>
</tr>
<tr>
<td>2</td>
<td>CHA02</td>
<td>2%</td>
<td>1</td>
<td>1.62</td>
<td>0.04</td>
<td>1.99</td>
<td>0.457</td>
</tr>
<tr>
<td>3</td>
<td>CHA04</td>
<td>4%</td>
<td>1</td>
<td>1.59</td>
<td>0.07</td>
<td>1.99</td>
<td>0.462</td>
</tr>
<tr>
<td>4</td>
<td>CHA06</td>
<td>6%</td>
<td>1</td>
<td>1.56</td>
<td>0.10</td>
<td>1.99</td>
<td>0.467</td>
</tr>
<tr>
<td>5</td>
<td>CHA08</td>
<td>8%</td>
<td>1</td>
<td>1.52</td>
<td>0.14</td>
<td>1.99</td>
<td>0.473</td>
</tr>
</tbody>
</table>

The slump test has been performed to observe workability, and the slump was maintained within the range of 50 mm for proper workability, easy handling, and placing in all cases. The slump obtained in the experimental procedure for various replacement levels has been provided in Table 4.

Table 4. Slump in different proportions.

<table>
<thead>
<tr>
<th>Replacement Levels with CHA</th>
<th>Slump in (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal concrete</td>
<td>50</td>
</tr>
<tr>
<td>2% replacement</td>
<td>48</td>
</tr>
<tr>
<td>4% replacement</td>
<td>42</td>
</tr>
<tr>
<td>6% replacement</td>
<td>34</td>
</tr>
<tr>
<td>8% replacement</td>
<td>25</td>
</tr>
</tbody>
</table>

It was found that as the percentage of CHA increases, the slump values decreased. To compensate for the poor workability caused by the addition of CHA, more water was required to achieve the desired slump value. CHA typically has higher water absorption characteristics compared to regular fine aggregate materials like sand. As a result, when CHA was used, it tends to absorb more water from the mix, leading to a reduction in the available water content for proper workability of the concrete [25].

The concrete mixes were then cast into concrete cubes of dimensions of 100 mm × 100 mm × 100 mm as per IS:10086-1982, beams of dimensions 500 mm × 100 mm × 100 mm, and cylinders of diameter 150 mm and height 300 mm as per IS:10086-1982 [43]. The concrete cubes, beams, and cylinders cast are shown in Figure 3.
3.3. Curing and Testing

Curing of concrete cubes has been performed using the normal water curing method for 7, 28, and 56 days. For the cylinder and beam, it was performed for 28 days only. The effect of partially replaced fine aggregate with coffee husk ash has been assessed after curing through different strength tests. The compressive strength, flexural strength, and split tensile strength of the cured concrete cubes, beams, and cylinders with various percentages of CHA as a replacement for fine aggregate are tested separately as per IS:516-1959 [44]. A compression test was performed by applying the rate of loading of 2.3 KN/s as per IS 516 Part-1 Sec-1 [45] for the different specimens. The quality of the concrete and the effect of the replacement material on its properties were thus evaluated. The tests result of concrete with replacement material are analyzed for the intended application of the concrete. The strength and other properties of concrete are compared with that of control mix without replacement material to verify the improvement and optimize the concrete mix with replacement material.

The durability was also checked by conducting compressive strength tests on coffee-husk-ash-incorporated concrete blocks in acidic and alkaline environments. The concrete specimens were first cured in water for 28 days and then subjected to acidic or alkaline environments for the next 28 days. Later, these concrete specimens were checked for compressive strength. When assessing the quantity of heat transferred via conduction by cement-based materials like concrete, thermal conductivity (k-value) is a required consideration. Buildings’ energy consumption is directly impacted by how much heat is lost through their walls and roofs [45]. For determining the thermal conductivity of insulation materials, the guarded hot plate is a useful technique. The test samples are fixed between hot and cold plates. The test samples are exposed to a constant stream of heat. Specimens with a diameter of 180 mm and thickness of 20 mm were prepared as per IS:3346-1980 [46], which permits a maximum thickness of 50 mm. Heat flow and the difference in mean temperature between the specimen surfaces are used to calculate thermal conductivity.

Accelerated chloride permeability experiments were performed on concrete specimens that were standard cylinders (100 mm dia, 50 mm thick). The experiment was conducted after 28 days of curing, as per ASTM C1202-1994 [47]. All the results of total charge passed through standard specimens in 6 h (the RCPT values), taken as a measure of the chloride permeability. The rapid chloride permeability test setup consisted of the diffusion cell with two chambers. Next, 0.3 M of NaOH solution and 3 M of NaCl solution were prepared. In one chamber, a 3 M concentration of NaCl solution was added, while in another, 0.3 M of NaOH solution was added.

4. Results and Discussion

The concrete cubes, beams, and cylinders were cast with different percentages of coffee husk ash. They were then tested as per IS:516-1959 [48] to determine the various properties.

Figure 3. Cubes, cylinder, and beam in molds.
As part of the test, compressive strength, split tensile strength, and flexural strength were all determined.

4.1. Compressive Strength of Concrete with Ambient Curing

The compressive strengths of the CHA concrete mix at 7 and 28 days are presented in Figure 4.

![Figure 4: Compressive strength test results.](image)

According to the test results, the best compressive strength values of 31.8 MPa, 38.55 MPa, and 39.3 MPa at 7, 28, and 56 days, respectively, were obtained from the concrete mix made of 4% CHA fine aggregate, which represents improvements in the compressive strength of up to 46.2%, 49.13%, and 7.9%, respectively, as compared to the normal mix. However, up to 4% CHA concrete mixes showed compressive strength values that are considerably higher than those of the plain mixes in the 7-day, 28-day, and 56-day concrete mixes.

With proper mix design and curing, the strength gradually increased over time and even exceeded the strength of control concrete without CHA for the 4% mix. This is because when moisture is present, CHA, a pozzolanic substance, can combine with calcium hydroxide to produce further cementitious compounds, such as calcium silicate hydrates (C-S-H). This pozzolanic reaction can contribute to the early strength gain of concrete when CHA is used. However, as the reaction progresses over time, the availability of unreacted CHA decreases, leading to a decrease in strength [49,50]. Additionally, CHA has a high water demand due to its porous nature. As the percentage of CHA increases, more water is required to maintain the desired workability of the concrete mix. However, excessive water content can lead to a higher water–cement ratio. Thus, the concrete weakens and its strength reduces [25].

4.2. Compressive Strength of Concrete in Acidic and Alkaline Environment

The CHA concrete mix was first cured underwater for 28 days and then was under the influence of an acidic or alkaline environment for the next 28 days. The acidic environment was achieved through the usage of H2SO4 and HCl. The alkaline environment was conceived using sea water. The compressive strength tests were performed on the concrete cubes under the influence of acidic and alkaline environments, and the results are shown in Figure 5.
will depend on various factors, such as the CHA content, mix proportions, and exposure values that are considerably higher than those of the plain mix.

respectively. It is observed that the flexural strength values tend to first decrease below the standard mix. However, up to 4% CHA concrete mixes showed compressive strength values that were considerably higher than those of the plain mix. However, up to 4% CHA concrete mixes showed compressive strength values that were considerably higher than those of the plain mix under the influence of \( \text{H}_2\text{SO}_4 \).

In the case of concrete with partially replaced fine aggregate using increasing percentages of CHA, the presence of CHA may offer some benefits. Coffee husk ash contains silica and other pozzolanic materials that can react with calcium hydroxide and form additional C-S-H gel, potentially improving resistance to sulphate attack. However, the extent of this benefit and its impact on the compressive strength in the presence of sulfuric acid will depend on various factors, such as the CHA content, mix proportions, and exposure conditions [51].

The compressive strengths of the CHA concrete mix under the influence of HCl for 28 days are as shown in Figure 5. The concrete mix containing 4% CHA fine aggregate gave the best compressive strength value of 17.8 N/mm\(^2\) in the tests, representing an improvement in compressive strength of up to 28.4% above the control mix. However, concrete mixes with up to 4% CHA demonstrated compressive strength values that were significantly higher than those of the plain mix.

The compressive strengths of the CHA concrete mix under the influence of seawater for 28 days are presented in Figure 5. In accordance with the test results, the concrete mix with 4% CHA fine aggregate produced the best compressive strength value of 43.4 N/mm\(^2\), representing an improvement in compressive strength of up to 28.4% in comparison to the standard mix. However, up to 4% CHA concrete mixes showed compressive strength values that are considerably higher than those of the plain mix.

4.3. Flexural and Split Tensile Strength of Concrete

The flexural strengths test was conducted on concrete beam specimens, and the experimental setup is shown in Figure 6. Figure 7 shows the flexural and split tensile strength test results. According to the flexural strength test results, the 28-day flexural strength values are 3.1, 2.6, 3.7, 2.8, and 2.4 for the normal, 2%, 4%, 6%, and 8% mixes, respectively. It is observed that the flexural strength values tend to first decrease below

![Figure 5. Compressive strength test results under acidic and alkaline environments.](image-url)
the plain mix strength by 16.13% for the 2% replacement mix, increase above the plain mix strength by 19.35% for the 4% replacement mix, and then decrease below the plain mix strength by 9.68% and 22.58% as the CHA content is increased by 6% and 8%, respectively. Therefore, the 4% mix gives the highest flexural strength after curing for 28 days. The correlation between the compressive strength and flexural strength can be observed through the equation, which states that flexural strength is equal to 0.7 times the square root of compressive strength as per IS 456 2000 [52], and the same has been observed in the present study. The correlation coefficient for the concrete is observed to be 0.6 for the compressive strength and flexural strength in the present study.

![Figure 6. Flexural and split tensile strength tests.](image)

**Figure 6.** Flexural and split tensile strength tests.

![Figure 7. Flexural and split tensile strength test results.](image)

**Figure 7.** Flexural and split tensile strength test results.

Figure 6 shows the breaking of the cylinder during the split tensile test. According to the test results, the 28-day split tensile strength values are 2.4, 2.38, 2.44, 1.84, and 1.46 for the normal, 2%, 4%, 6%, and 8% mixes, respectively. It is observed that the split tensile strength values tend to first decrease slightly below the plain mix strength by 0.83% for the 2% replacement mix, increase above the plain mix strength by 1.67% for the 4% replacement mix, and then decrease below the plain mix strength by 23.33% and 39.17% as the CHA
content is increased by 6% and 8%, respectively. So, the 4% mix gives the highest split tensile strength after curing for 28 days. The split tensile strength is around 8–12% of compressive strength (split), which is satisfactory in the present study. The correlation coefficient of 0.7 is observed between the split tensile and compressive strengths.

4.4. Thermal Conductivity and Rapid Chloride Permeability Test

When CHA was introduced into the concrete, mixed additional voids or air pockets were created within the material. These voids acted as insulating regions that impeded heat transfer through the concrete, resulting in a lower overall thermal conductivity. The comparison of the thermal conductivity of different mixes is shown in Figure 8. It was observed that the 4% mix gave the highest thermal conductivity, as the concrete was having many fewer voids compared to the other mixes. Therefore, due to the lower number of voids, there was a smooth flow of heat transfer.

![Figure 8. Comparison of thermal conductivity of different mixes.](image)

After 28 days of curing, accelerated chloride permeability tests were performed on standard cylindrical specimens of concrete that were 100 mm in diameter and 50 mm thick, as per ASTM C1202-1994 [47]. The test setup is shown in Figure 9.

The RCPT values, used as a gauge of chloride permeability, showed that the entire total charge flowed through standard specimens in six hours. RCPT values have been analyzed for control and varying percentages of CHA from 2–8% and the results are shown in Figure 10.

It was observed that the RCPT values were in the range of 2000 to 4000 coulombs. This is an indication of better resistance to chloride penetration. The increase in the amount of CHA replacement has shown an increase in the pores. Therefore, as the CHA percentage in the mix increased, the voids also increased. As the voids increased, the chloride permeability also tended to increase. But while comparing the altered mixes with normal mix, the chloride permeability is low due to the smaller particle size of the CHA, which tend to occupy the spaces which were left unaided by the natural fine aggregate. Thus, the replacement of fine aggregate with CHA from 2–4% in concrete gives better resistance to chloride penetration compared to normal concrete.
percentage increases when the number of days of curing is lower.

When the number of days of curing is lower, the workability of concrete increases. This is due to the reduced amount of water in the mix, which leads to better compaction and denser concrete. For the early ages of curing (0–2 days), the workability is low due to the high water content and insufficient cement hydration. As the curing period increases, the workability increases due to the improved cement hydration and densification of the concrete matrix.

Innovative solutions and seek suitable replacements. In this case, CHA was used partially to improve the workability of concrete. The results show that the use of CHA as a fine aggregate replacement improves the workability of concrete for the early ages of curing.

5. Conclusions

The non-renewability of fine aggregate (i.e., river sand) leads us to come up with innovative solutions and seek suitable replacements. In this case, CHA was used partially with sand and incorporated with concrete to improve the compressive strength and other properties of concrete made with it. From the study, the following findings can be made.

The optimum addition of CHA as a partial replacement for fine aggregate is in the range of 4%. However, the workability of concrete decreases as CHA percentage increases. This means that CHA concrete has a higher water demand. Therefore, it is recommended to use not more than 4% CHA as fine aggregate replacement in order to obtain the workability during slump flow.

The compressive strength, flexural strength, and split tensile strength increase with the increase in CHA percentages up to the optimum replacement of 4%. However, the percentage increases when the number of days of curing is lower.

Figure 9. RCPT chambers.

Figure 10. Rapid chloride permeability test results.

Figure 8. Comparison of thermal conductivity of different concrete mixes.
The compressive strength in both acidic and alkaline solutions when cured for 56 days showed increases of 13.97% and 28.4% in the samples immersed in HCl and H₂SO₄, respectively, and 28.4% when immersed in sea water for 4% CHA replacement when compared to normal OPC mix. Therefore, fine aggregate replacement by 4% CHA is recommended for improving durability.

When CHA was introduced into the concrete mix, overall thermal conductivity was reduced. The rapid chloride permeability test confirms the lower penetration of chloride through concrete with CHA.

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