A study on mechanical and durability properties of coconut shell concrete using coconut fiber and sawdust

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Abstract. Sawdust was used as a partial replacement material for sand in coconut shell concrete and coconut fiber were also added with concrete to enhance the properties. The mechanical and durability properties studied are compressive strength test, split tensile test, flexural test, impact test and water absorption, volume of permeable pore voids, rapid chloride penetration test, sorptivity respectively. From the test conducted, the properties of coconut shell concrete with coconut fiber and sawdust gave a better result.

1. Introduction
Concrete is a universal material and does a major role in the construction industry. Concrete is a mix of cement, sand and coarse aggregate. Due to the continuous usage of sand and coarse aggregate, the availability of these resources comes to extinction. To preserve it and also its time to find an alternative material as a replacement to overcome this problem. Dumping of wastage causes a major issue in India. To overcome both causes, the usage of waste materials in concrete by replacing conventional material will give a big revolution in the construction industry. More than 960 million tonnes of solid waste are produced by various sectors like industries, agriculture, mines minerals, and others. Where 350 million tonnes are organic waste and 250 million tonnes are inorganic waste [1]. Agriculture waste product like rice husk, vegetable waste, sugarcane baggage, coconut husk, wooden mill waste, etc., Coconut is highly grown around 93 countries, with Indonesia, Philippines and India leaded with more than 80% of coconut production in world [2]. This coconut shell was a hopeful material for a replacement material instead of conventional aggregate. Concrete is material which is good in compression but weak in tension. To improve the tensile strength, steel reinforcement has been given to conventional concrete (CC) and enhance them. In the same way, coconut shell concrete also has weak tensile strength. To improve the tensile strength and mechanical properties of concrete coconut fiber has been added into it. Coconut shell concrete is said to be as lightweight concrete, to reduce the weight and also to minimize the usage of sand in concrete, sawdust is used. The optimum volume fraction of sawdust is found and used in CSC.

2. Significance of Study
The mechanical and durability of any material given under certain conditions will last according to them being exposed to environmental situations. Concrete is generally durable in any sort of natural environment. Property of mechanical and durability is affected when introducing deleterious material unknowingly along with the constituents and triggered when exposed to harmful conditions from that of the expected situation. When air penetrates through the concrete and facilitates air by encouraging movement inside; and corrosion of steel occurs. This increases the volume of steel and exerts a force on the concrete walls causing the concrete to crack and spall.

This study is to estimate the mechanical and durability with coconut fiber and sawdust. To study the parameters of mechanical tests like compressive strength, split tensile strength, flexural strength and impact strength, durability tests like water absorption, volume of permeable pore voids and sorptivity.

3. Materials and Mix Proportions
The binder conforming to the Indian Standard code of IS 12269:2013, Ordinary Portland Cement (OPC) of 53 grade is used. Table 1 elaborates about the chemical compositions of cement used. For fine aggregate river sand from Palar is being utilised and it is conformed to zone III, the Indian Standard of IS383: 2016 [3]. Coarse aggregate is replaced by crushed coconut shell in 12.5 mm sized aggregate. For a comparative study 12.5 mm crushed stone aggregate is also used for conventional concrete mix. Figures for the raw coconut shell (CS), coconut fiber and sawdust is shown in Figure 1-3 respectively. From all the previous study conducted, optimum aspect ratio and volume fractions were assumed for the same mix proportions of both CC and CSC. The mix proportions are 1:2.22:3.66:0.55 for CC with cement content of 320 kg/m³ and for CSC 1:4.47:0.65:0.42 with content of cement 510 kg/m³ [4,5]. Where, coconut specific gravity is 1.3 [6]. Coconut fiber with an aspect ratio of 83.3 was used and with 3% fraction of volume in CC proportion of mix in the same [7]. In similar way, for CSC proportion of mix, aspect ratio considered was 66.67 and volume fraction as 2%. Sand was replaced 5% by sawdust in all mixes. By using of sawdust in concrete weight of the concrete can be reduced up to 10% [8]. For the differentiation of mixes, it has been abbreviated as CC, CSC, conventional concrete with fiber (CCF), coconut shell concrete using fiber (CSCF), conventional concrete using sawdust (CCSD), coconut shell concrete using sawdust (CSCSD), conventional concrete using fiber and sawdust (CCF-SD) and coconut shell concrete using fiber and sawdust (CSCF-SD) respectively.

![Figure 1. Coconut Shell.](image1)
![Figure 2. Coconut Fiber.](image2)
![Figure 3. Sawdust.](image3)
4. Results and Discussion

4.1. Mechanical Properties

4.1.1. Compression Strength. This test is done to find how much the specimen can resist the load it is subjected to. Cubes of size 100x100x100 mm were being casted and tested at 28, 56 and 90th day as shown in Figure 4. Different mixes are taken with different aspect ratio as found in aspect ratio and volume fraction. Table 1 shows the replacement percentage distribution.

![Compression Strength Test](image)

**Figure 4. Compression Strength Test.**

| Days | CC  | CCF (3%) | CSC | CSCF (2%) | CCSD (5%) | CSCSD (5%) | CCF-SD | CSCF-SD |
|------|-----|----------|-----|-----------|-----------|------------|--------|---------|
| 28   | 30.5| 39.6     | 26.40| 28.30     | 29.47     | 28.13      | 34.43  | 30.01   |
| 56   | 31.70| 40.6     | 26.67| 29.45     | 31.01     | 28.92      | 36.70  | 32.17   |
| 90   | 32.15| 41.34    | 26.75| 30.70     | 31.63     | 29.47      | 37.10  | 33.22   |

The 28th day compressive strength of CCSD is 29.47 N/mm² and for the mix CCF-SD is 34.43 N/mm² which has 14.4% higher value comparing to CCSD. The strength of CSC is 26.40 N/mm² and for the mix CSCSD is 28.30 N/mm² which has 6.15% higher value comparing to CSC. For CSCF is 28.30 N/mm² and for the mix CSCF-SD is 30.01 N/mm² which has 5.69% higher value comparing to CSCF.

4.1.2. Split Tensile Strength. Test specimen are cylindrical in shape of size 100x200 mm. The cylindrical specimen is placed horizontally on the compression testing machine, expecting a vertical crack across the area of diameter. Mix with replacement of sawdust in 5% and fiber in 3% in CC and in CSC 2% of fiber were done. The test has been carried out for 3, 7 and 28th day as shown in Figure 5. In Table 2 further details are given.
Figure 5. Split Tensile Strength.

Table 2. Split Tensile Strength Test Results (N/mm²).

| Days | CC    | CCF (3%) | CSC | CSCEF (2%) | CCSD (5%) | CSCSD (5%) | CCF-SD | CSCF-SD |
|------|-------|----------|-----|------------|-----------|------------|--------|---------|
| 3    | 2.35  | 2.83     | 1.29| 2.77       | 1.69      | 1.09       | 2.95   | 1.89    |
| 7    | 3.82  | 3.11     | 2.12| 3.19       | 3.28      | 2.06       | 4.23   | 2.97    |
| 28   | 4.02  | 4.19     | 2.82| 3.93       | 3.98      | 2.46       | 4.86   | 3.19    |

The 28th day split tensile strength of CCSD is 3.98 N/mm² and for the mix CCF-SD is 4.86 N/mm², which has 18.10% higher value comparing to CCSD. The CSC is 2.82 N/mm² and for the mix CSCSD is 2.46 N/mm². For CSCEF is 3.93 N/mm² and for the mix CSCF-SD is 3.19 N/mm² which satisfies IS codal provisions.

4.1.3. Flexure Strength. In flexural testing, 100x100x500 mm sized beam is taken without any additional reinforcement. With 3-point loading method, continuous load is being applied till the specimen breaks as shown in Figure 6. The test has been carried out for 3, 7 and 28th day. Results are given in the Table 3.

Figure 6. Flexure Strength Testing
Table 3. Flexure Strength Test Results (N/mm²).

| Days | CC  | CCF (3%) | CSC  | CSCF (2%) | CCSD (5%) | CSCSD (5%) | CCF-SD | CSCF-SD |
|------|-----|----------|------|-----------|-----------|-----------|--------|---------|
| 3    | 2.08| 2.89     | 1.93 | 2.83      | 1.85      | 1.55      | 2.85   | 2.09    |
| 7    | 3.45| 4.82     | 2.42 | 3.41      | 3.26      | 2.37      | 4.53   | 2.89    |
| 28   | 4.23| 4.90     | 3.81 | 6.3       | 4.15      | 3.18      | 5.33   | 4.12    |

The 28th day flexural strength of CCSD is 4.15 N/mm² and for the mix CCF-SD is 5.33 N/mm² which has 22.13% higher value comparing to CCSD. The flexural strength of CSC is 3.81 N/mm² and for the mix CSCSD is 3.18 N/mm². For CSCF is 6.3 N/mm² and for the mix CSCF-SD is 4.12 N/mm² which satisfies IS codal provisions.

4.1.4. Impact Strength. Application of sudden load on the specimen is called as impact test. Specimen of thickness 63.5 mm and diameter 152.4 mm were used. Blows were counted until the view of initial crack in the specimen as shown in Figure 7. The test has been carried out for 3, 7 and 28th day. Results are shown in the table 4.

![Impact Strength Testing](image)

**Figure 7.** Impact Strength Testing.

Table 4. Impact Strength Test Results.

| Days | CC  | CCF (3%) | CSC  | CSCF (2%) | CCSD (5%) | CSCSD (5%) | CCF-SD | CSCF-SD |
|------|-----|----------|------|-----------|-----------|-----------|--------|---------|
| 3    | 8/12| 50/55    | 9/13 | 60/68     | 62/76     | 69/81     | 65/79  | 72/91   |
| 7    | 9/15| 90/105   | 13/20| 91/108    | 119/129   | 121/133   | 154/172| 162/188 |
| 28   | 16/20|123/178  | 25/30|117/163    | 151/165   | 160//177  | 182/198| 190/201 |
The 28th day impact strength of CCSD is 165 blows and for the mix CCF-SD is 198 blows which has 1.2 times higher value comparing to CCSD. The impact strength of CSC is 30 blows and for the mix CSCSD is 177 blows which has 5.9 times higher value comparing to CSC. For CSCF is 163 blows and for the mix CSCF-SD is 203 blows which has 1.2 times higher value comparing to CSCF.

4.2. Durability Properties

4.2.1. Water Absorption Test. A long-term process of curing for 28, 56, 90 days, the specimens are allowed to dry and cut in exact centre part of cylinder collected 100 mm diameter and 100 mm thickness of cast cylinders. After weighted cylinders were placed in oven at 100°C – 110°C for a duration of 24 hours as shown in Figure 8. After collecting the specimens from oven, it is dried at room temperature for 24 hours and weighed till the weight becomes constant. This constant value is determined as mass (A). Again, the specimens are cured for 48 hours. This weight of surface dried specimen is (B). The percentage of water absorption were calculated by using Equation 4.1. The Water Absorption Test results are mentioned in table 5.

\[
\text{Water absorption \%} = \left( \frac{B - A}{A} \right) \times 100
\]  

Table 5. Water Absorption Test Results (%).

| Days | CC  | CCF (3%) | CSC | CSCF (2%) | CCSD (5%) | CSCSD (5%) | CCF-SD | CSCF-SD |
|------|-----|----------|-----|-----------|-----------|------------|--------|---------|
| 28   | 4.16| 4.53     | 11.32| 11.38     | 6.98      | 11.13      | 9.45   | 14.21   |
| 56   | 3.87| 4.11     | 10.63| 10.84     | 6.47      | 11.01      | 8.89   | 13.32   |
| 90   | 3.65| 3.91     | 10.12| 10.56     | 6.11      | 10.88      | 8.21   | 12.07   |

Literature state that the water absorption of CC is limited to 5.0%. In this study, in all the case of CC mixes it was found that the water absorption was less than 5%. However, it is not fulfilled in case of CSC mixes. But, the water absorption of CSC mixes is comparable with the other lightweight aggregate concrete. Light weight concrete with pumice aggregates registered water absorption of about 4.8 –
16.7%. Literature shows even higher water absorption rates of 14 – 22% for structural light weight concrete with pumice aggregate and similar results for pumice concrete with water absorption value in the range of 19.1- 22.2%.

4.2.2. Volume Of Permeability Of Pore Voids (VPV). Water has been filled in suitable container and boiled for 1 hour. In boiled water, 24 hours oven dried specimens at 110 °C (A) were used. The specimens are immersed and boiled for 5 hours continuously. After boiling, specimens were allowed to cool at room temperature 22° – 25°C for 14 hours and the mass of each specimen is noted as (B). Samples are tied with copper wire and is immersed in water using spring gauge as shown in Figure 9,10. This weight was denoted as (C). The percentage of volume of voids were calculated by using Equation 4.2 and mentioned in Table 6.

\[
\text{Water absorption \%} = \left(\frac{B - A}{B - C}\right) \times 100
\]  

(2)

Table 6. VPV test results (% of voids).

| Days | CC   | CCF (3%) | CSC  | CSCF (2%) | CCSD (5%) | CSCSD (5%) | CCF-SD | CSCF-SD |
|------|------|----------|------|-----------|-----------|------------|--------|---------|
| 28   | 14.33| 15.67    | 20.14| 24.97     | 15.78     | 22.14      | 16.77  | 23.12   |
| 56   | 12.76| 14.34    | 18.93| 23.22     | 14.34     | 21.22      | 15.89  | 22.31   |
| 90   | 11.08| 13.15    | 17.35| 21.79     | 13.11     | 20.39      | 15.07  | 21.23   |

The results show that the all mixes used in this study reduces the VPV capacity.

4.2.3. Sorptivity Test. This test measures the fluid that is introduced into the body of the material by the capillary force exerted by the pore structure. The absorption test was carried out using ASTM C 1585. Cylinders measuring 100x200 mm were made for 28, 56, 90 days for various mixtures. Samples are cut with diameter of 100 mm and a thickness of 50 mm in the centre of the core. After drying, the samples are dried at 50 °C for 7 days and then dried at room temperature for 3 days. The sample is sealed with insulated tape. The weight of each sample is removed and the started time is zero when immersed in water at the depth of 5 to 10 mm as shown in Figure 8. With a sauce pan, water is filled and recorded with the help of a stopwatch at that time. The samples are placed on a PVC pipe as shown in Figure 11. Samples are weighted at the chosen time (1, 2, 3, 4, 6, 9, 12, 16, 20, 25, 30, 45 and 60 minutes). Before weighing, the samples are dried on the paper and cloth thoroughly [9]. The sorptivity value is determined based on the following Equation 4.3 and shown in Table 7.
\[ i = S t^{0.5} \]  

where, \( i \) represent cumulative water absorption and \( S \) stands for coefficient of sorptivity, \( t \) denotes time.

Figure 11. Sorptivity Test.

| Days | CC  | CC (3%) | CSC | CSC (2%) | CCSD | CSCSD | CCF-SD | CSCF-SD |
|------|-----|---------|-----|----------|------|-------|--------|---------|
| 28   | 0.083 | 0.088 | 0.133 | 0.142 | 0.092 | 0.147 | 0.098 | 0.155 |
| 56   | 0.076 | 0.081 | 0.089 | 0.102 | 0.087 | 0.113 | 0.085 | 0.128 |
| 90   | 0.071 | 0.075 | 0.067 | 0.072 | 0.081 | 0.077 | 0.074 | 0.087 |

It is observed after 28 days in all mixes, the sorptivity measures are less than 0.1 mm/min\(^{0.5}\) hence, this study proves that both the concrete is said to be high quality.

5. Conclusion
This study is about using alternative materials in construction to enhance its properties. The economy is growing very fast and there is also a faster construction happening in and around the places where we live. Therefore, there has always been an increase in demand for construction materials which has decreased the natural resources from which it has been designed and also it deteriorated the environment. From this study, we have understood that by using coconut shells as an aggregate and coconut fiber it enhances the mechanical properties of concrete like compression, tensile, flexure, and impact strength. Also, it gives better research when compared to conventional concrete. Since all these materials are naturally available materials it does not harm the environment inside and outside the structure. Based on this study it concluded that using coconut shells, coconut fiber, and sawdust in construction can wise several properties and give better results and it’s a solution to reduce the dumping of natural waste in the environment.

6. References
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