Sustainable Production of Concrete using Coir Fibres

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Abstract. This paper reports the investigation conducted in India using coir fibres as an additive substance used in the preparation of sustainable concrete mixtures. It is meant to be used as energy-saving building components. The coir fibres were added in different percentages 2%, 4%, and 6%, and to compare the results of these the reference concrete was also prepared without coir fibres. The study focuses on investigating the different parameters such as workability, density, water absorption, compressive strength, flexural strength, and split tensile strength. The concrete blends were made while maintaining a constant water cement ratio of 0.52. The results of this study revealed that the addition of coir fibres in concrete mixes enhances the mechanical properties of concrete. An optimal percentage was proposed as 4 percent for the addition of coir fibres in concrete. It is possible to produce sustainable concrete with the use of coir fibres.

Keywords: Concrete; Coir fibre; Mechanical properties.

1. Introduction

Coconut fiber which is commonly termed as Coir. The name coir comes from kayar, a Dravidian word for cord, used in both Malayalam and Tamil in India. It is a product extracted from the husk of coconut shell. It is fibrous material found between the internal and outer shell of the coconut. Coconut farming is primary crop in some tropical and subtropical parts of Asian countries [1]. This fibre is generally used as floor mats, doormats, brushes and mattresses. The coir is generally of two types white coir and brown coir. The white coir is obtained from the unmetered coconut shell and the brown fibre is from the matured coconut shell. Both these types have some different properties because of their versatile nature [2]. The white coir is used for making finer brushes, string, ropes and fishing nets. Approximately 500,000 tons of coir is produced annually in the world [3]. The main producer of the coir are India and Sri Lanka where as other countries Thailand, Vietnam, Philippines and Indonesia also produces the coir but not at extent of Indian and Sri Lanka. These two countries are the main exporters in the world as per the Coir Board of India. The main advantages of coir are tough, durable, strong, anti-corrosive, thermally insulated and resistant to fungi. Because of these advantages the use of this natural material is become popular and attracted to researchers to use as alternative and non-conventional construction material. It can be obtained at very low cost and manpower with less technology. The unavailability of the necessary building materials, low employability and increased population cannot meet the demand of housing schemes in the developing countries of the world [4]. Figure 1 show the coir fibre derived from the coconut shell.
Different researchers in the past used this concrete coir fibre but only few of them examined the static and durable properties of modified concrete. There are various forms of fibres i.e. jute, sisal, coir and hibiscus cannabinus were used to examine the behaviour of concrete prepared with these fibres by Ramakrishna and Sundararajan [5]. From this study the authors stated that, the substantial changes were seen in the chemical compositions of the fibres after exposure to water, saturated lime and sodium hydroxide. Among these fibres the compressive and tensile strength of concrete with the coir fibre retains about 40% to 60% and 20% to 40% to that of reference concrete. The strength reduction is because of microbiological action happened when immersed in solution.

The incorporation of coir fibre (0.2% and 0.4%) in concrete mixes showed an improvement in the mechanical properties of concrete mixes [4]. They concluded that, this increase was due to the compactness and less porosity of the concrete achieved by the use of coir. Sethunarayanan et al., [6] in their study reported the feasibility of use of natural fibre in concrete for production of low cost housing. The effect of addition of 2%, 3% and 5% coir fibre with 2.5, 5 and 7.5 cm in length on concrete was investigated by Ali et al., [7]. The author found that is to say, the density of concrete reduced marginally with increased percentage of fibres in concrete. Also at 5% addition with 5 cm length of fibres improved flexural stiffness. The above stated fibre percentage and length showed an enhancement in the static and dynamic properties of concrete. The total toughness index was low in case of 5% and 5 cm length of fibres cause of the sufficient length is available to restrict the propagation and hold the crack. Some of the studies were also conducted by the previous researchers to understand the durability properties of concrete prepared with coir fibre. In one such durability study conducted by Tol et al., [8] reported that, the use of coir and sisal fibre in concrete showed an significant reduction when exposed to alkaline solution. The concrete prepared with sisal and coir fibre and immersed in Calcium Hydroxide solution over a period of 320 days lost their flexibility whereas the loss is comparatively lesser in sodium hydroxide solution. They also stated that, the concrete mixes manufactured with coir and sisal fibre significant loss in the toughness index after wetting drying cycles for 6months respectively. This loss was due to the mineralization of fibres and migration of hydration products present in the cement matrix. An experimental investigation was
carried out by Ali et al., [2] to determine the tensile and pull out strength by using coir fibres. The study showed that, the increase in diameter of rope increases the bond strength and pull out energy. The bond strength and pull out energy is reduced significantly by 15% and 13% with the use of chemical treatment as compared to that of soaked in water. The various prospect of use of coir fibre in concrete mixes as construction material was summarized by Aziz et al. [9] in their comprehensive study. They stated that, for quality product a special technique is needed to achieve the better result. For further developments in this, a design methodology and there aspects with limitations should be provided. They also stated that, the feasible and economical method should be developed to extract the fibres.

Many authors carried out research in the area of Epoxy. In one such study carried out by Biswas et al. [10] Investigated the behaviour of coir fibre with epoxy on composites. Different lengths of fibre are used 5 mm, 20 mm and 30 mm along with 70 % epoxy. The incorporation of different lengths of coir fibre increased the micro hardness value of the composite. As length increases the micro hardness value increase. It was also reported that, the use of coir fibre with epoxy showed enhancement in mechanical properties of composites.

Coconut crop generates considerable amount of waste during their cultivation [11]. Coir pith is one of the wastes generated during this process and it can be used in cement matrix due to its shape and small size 0.075e1.2 mm. An attempt was made by Brasiliero et al. to use as fine aggregate in concrete mixes. He claimed that, coir particles can be used as fine aggregate in concrete mixes which showed nearly similar mechanical properties as that of ordinary concrete. Also they stated that, the concrete prepared with coir particles had more ductile which is positive sign for the structural point of view.

An attempt made by the Ruben et al. [12], reported that the use of coir fibre of lengths of 20mm, 25mm and 30 mm respectively at different percentage 0.5%, 0.75% and 1% showed an remarkable improvements in the compressive and tensile strengths of concrete mixes. Nadgouda [13] investigated that addition of coir fibre in concrete by 3%, 5% and 7% weight of cement improves approximately 12% mechanical properties of concrete as compared to that of reference concrete. Chandel et al. [14] investigated the feasibility of using coir fibers with lengths of 2mm at different percentages (1, 3, and 5%) by weight of cement added in the concrete production. According to the study, the compression strength, split tensile, and split tensile increased by 13%, 39%, and 14%, respectively, when comparison to reference concrete. According to Ferraz et al., [15], the inclusion of coir fibers had such a major impact on the mix's water holding capacity. Due to the extreme property of fibers, the addition of fibers increased the water absorption values. Das et al., [14] added the coir fibres in various percentages 5%,10%, 15% and 20% by weight of cement in mix to investigate the various mechanical properties of concrete mix prepared with coir fibres. They reported that, addition of fibres in concrete mixes increased the water absorption because of presence of hydroxyl group which is having a property to absorb the moisture content. They also tried to find an alternative solution to reduce this hydroxyl group property with Al₂O₃ as additives.

2. Materials
In line with IS1401-C-91, the Portland Pozzolan (PZ) was found to be appropriate for this study. But aggregate and refined again in 1997, according to IS -383-1970 the maximum aggregate was 20 mm and the recommended amount was 4.75 mm Drinking water is used in the process of preparing concrete. With a tensile strength of 21.5 kilograms per square millimeters, the cooked fibres were removed, and lengths of 18 mm were created. Table 1 states that the properties of cement, aggregate, aggregate, and Table 2 summarizes these results.

| Setting Time | Duration (minutes) |
|--------------|--------------------|
| Initial      | 30                 |
| Final        | 611                |

**Compressive strength**
Table 2. Properties of Aggregates

| Property                | Specific gravity | Absorption in terms of weight (% by volume) |
|-------------------------|------------------|---------------------------------------------|
| Fine aggregate (sand)   | 2.68             | 1.71                                        |
| Coarse Aggregate        | 2.89             | 0.50                                        |

Table 3. Typical Properties of Coir fiber

| Sr. No | Property                | Values             |
|--------|-------------------------|--------------------|
| 1      | Color                   | Brown              |
| 2      | Diameter                | 0.20 to 0.40 mm    |
| 3      | Fiber Length            | 20 to 200 mm       |
| 4      | Specific Gravity        | 0.86               |
| 5      | Water Absorption        | 3% to 4%           |
| 6      | Bulk Density            | 140 to 150 kg/m³   |
| 7      | Tensile Strength        | 80 to 120 N/mm²    |

3. Experimental Approach

3.1 Design of a concrete mix

It is manufactured with an exact water cement of 0.52 on the basis of BIS 10262:2009 [15]. The coir fibers have property to absorb the water to reduce the impact of this the fibers were soaked in water for 24 hours. After 24 hours they were taken out from the water and kept open to air for drying. The coir fiber was added in the concrete mix at varying percentages of 2%, 4% and 6% by weight of cement. To obtain the homogenous mix all the constituents are dry mixed for 3 min in a mixture and then potable water is added. Table 4 shows material required for one cubic meter of concrete.

Table 4. Material Requirement for concrete

| Mix                     | B0   | B2   | B4   | B6   |
|-------------------------|------|------|------|------|
| Water (lit/m³)          | 197  | 197  | 197  | 197  |
| Cement (kg/m³)          | 375  | 375  | 375  | 375  |
| Fine aggregate (sand) (kg/m³) | 700  | 700  | 700  | 700  |
| Natural coarse aggregate (kg/m³) | 1068 | 1068 | 1068 | 1068 |
| Coir fibre (Kg)         | -    | 7.90 | 15.80| 23.70|
| Dose of superplasticizer % by weight of cement | - | 0.20 | 0.30 | 0.50 |

Note:
B0- Reference concrete mixture
B2- Concrete with 2% coir fiber addition
B4- Concrete with 4% coir fiber addition
B6- Concrete with 6% coir fiber addition
3.2 Experimental Program

According to standard procedures, the properties of the fresh and hardened concrete mixture were observed and quantified. The workability of fresh concrete was tested according to BIS-9 (1959). This specification used concrete specimens with a thickness of 150 mm and beams with a thickness of 600 mm as specified in BIS: 5-1958 (2002) to establish the compressive strength. The 300 mm × 150 mm concrete test specimen was used for determining the tensile strength of the concrete. As samples of all specimens were placed in a curing tank for 7 days and 28 days, they were demoulded and placed in the analysis tank for a total of 7 and 28 days.

4. Outcome of the Experimental Approach

4.1 Flowability Test

The flowability test was conducted on the concrete mixtures prepared with and without addition of coir fibers. The results of the test are shown in Figure 2.

![Figure 2. Effect of coir fibers on slump](image)

As a preliminary test showed an increase in slump after it was drastically reduced, in order to get a flow between 75 and 100 millimeters the superplasticizer Fosroc Auramix 350 Di was used [16]. The decline in the slump was due to fibre congestions in the mixture that reduced concrete flowability. The absorption of water by the coir fibre in concrete was another possible reason for a reduction in flowability.

4.2 Density

These density values have been established after a total of 28 days curing period of concrete with or without coco fibers are shown in Figure 3.
Figure 3. Coir's Effect on Density

From the above Figure 3 it was observed that, the addition of coir fibers in the concrete mixes decreased the density significantly. The reference concrete recorded the highest density, while the concrete with 6 percent coir fibers had the lowest mass density. The decrease was almost 8% as compared to that of reference mix. Lesser the density will produce less inertia forces against lateral forces which will be beneficial to reduce the dimensions of the structure which can withstand to earthquake forces.

4.3 Water Absorption

Figure 4 presents the water absorption tests on all of the concrete specimens.

Figure 4. Water absorption effect of coir fibers

Results of the water absorption test indicate that the depth of absorption has increased in all the concrete mixes produced with addition of coir fibers. The water absorption of concrete mixes increased approximately by 4%, 13% and 26% at 2%, 4% and 6% addition of coir fibers as compared to that of reference mixture. It clearly indicates that, addition of coir fibers have some issue in porosity of concrete. Very contradictory results were obtained by the previous researchers in there study. Some of the researchers stated that, water absorption values decreased with addition of fibers and it depends upon the length of fibers added in the mixtures [7]. Another reason for increase in the
water absorption in coir fiber added mix is the presence of hydroxyl group in coir fibers. This hydroxyl group is polar in natures which are high in absorbing moisture [14].

4.4 Compressive strength
Figure 5 shows the results of the compression testing. All concrete mixes showed considerable increase in compressive strength at every percentage of coir fibre. In contrast to the reference concrete mix, the pressure strength for the concrete mix grew by 1%, 12% and 7% at 2%, 4% and 6% at seven days. At 28 days the compressive strength increased by 2 percent compared to reference mixtures by 7 and 2 percent respectively. At 2 percent and 4 percent coir fibers, the compression strength increased significantly. Moreover, compared to the B4 mix the strength decreased by around 5 percent, but the value was still higher than the B0 reference mix. Due to bleeding during mixing it may be the reason the strength was slightly reduced. The Abdullah et al. [23] also reported this fact.

4.5 Flexural strength
The variation in the flexural strength at 7 and 28 days of curing of concrete mixes are shown in Figure 6.
At 7 days and 28 days all concrete mixtures showed a significant increase in bending strength. At 7 days bending strength was increased by 3%, 6%, and 1%, compared to the reference mix of 2%, by 4% and 6%. Their strength is increased by 6%. At a time of 28 days the bending strength was 4%, 6% and 2 percent compared to the reference mix at above mentioned coir fiber additions. Based on the tensile strength property of coir fiber, the increase in bending strength properties was. This makes the strong bond between the cement paste and coir fingers which restrict the propagation of cracks and enhances the flexural strength [17].

There is a slight deviation in the flexural strength was also seen at 6% addition of coir fibers mix. The flexural strength is depends upon various components present in the concrete mixture like fine and coarse aggregate proportion, diameter and length of the coir fibers, water cement ratio and generation of bond between the cement paste and coir fibers [18] [19].

4.6 Split tensile strength
Figure 7 displays the findings of the split tensile strength of the reference concrete and the modified concrete mixes.

From the above graph, it is obvious that the improvement of concrete's tensile strength is significant when mixed with coco fibers can be seen. The split tensile strength of concrete mix at 7 days increased by 6%, 17% and 7% at 2%, 4% and 6% addition of coir fibers as compared to that reference mix. At 28 days the strength increased by 4%, 6% and 2% at above said percentages additions. There is small decrease in the strength was seen at higher percentage addition i.e. at 6% but the values are still higher than the reference concrete mixture. The reason for the increase and decrease was similar as discussed in compressive and split tensile strengths results.

Conclusions
This study focuses on the investigating the mechanical performance of concrete mixtures prepaid with addition of different percentage of coir fibers. The various properties were investigated and the following conclusion were dawn,

- The addition of coir fibers had significant impact on the workability of concrete mixes and this can be compensated with the proper dose of superplasticizers. Addition of coir fibers leads to congestion which decreases the workability to maintain the sufficient flow need to add superplasticizers.
- Addition of coir fibers decreases the density of concrete which will be beneficial for making structure lightweight without compromising the mechanical strength.
There is an increase in water absorption was seen need to investigate deeply with the help of some microscopic study. The water absorption increased because of presence of hydroxyl group in coir fiber which having tendency to absorb moisture.

The compressive strength showed significant enhancement due to addition of coir fibers up to 4% after that slightly decreased but still higher than control mix. This may be due to congestion of fibers.

Due to the elasticity of the fibers, modified concrete showed great improvement after being subjected to flexural and tensile tests with inclusion of coconut husks.

From the experimental investigation it was found that the optimum percentage for addition of coir fibers is 4%.

Overall, the concrete prepared with addition of coir fibers showed enhanced performance in mechanical properties. There is need to investigate the durability properties of concrete mixtures prepared with addition of coir fibers with different water cement ration and different grades of concrete. So that we can use this ecofriendly material in sustainable construction practice.

Future studies will examine various fiber grades of concrete that have been impregnated with the dried coconut husk husks in order to investigate their mechanical and long-durability properties.

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