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RESEARCH ARTICLE

Effect on mechanical properties of lightweight sustainable concrete with the use of waste coconut shell as replacement for coarse aggregate

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Abstract
Concrete is one of the most important materials that are used in the construction industry all around the world. A larger part of the capacity in concrete is generally employed by the coarse aggregate. Due to the tremendous use of coarse aggregate in the construction industry, the material is getting degraded. In order to preserve the natural material, we are in search of an alternate material that can be used in concrete instead of the original one. So in this research work, it has been attempted to study the mechanical behaviour of lightweight concrete when we use waste coconut shell as coarse aggregate inside concrete. To improve the strength of the concrete, we also use the sisal fibres in various proportions ranging between 1 and 5% in accordance to the binder weight. After the mechanical property tests such as the compression test, spilt tensile strength, flexural test, modulus of elasticity test, and impact resistant test were conducted, finally it was concluded that there was increment in the compression strength up to 5%, and tensile strength was increased to 17% and elastic modulus to 7% when the fibre content used was 3%. Thus, with the use of these waste materials, it was found that the concrete's strength gets increased and it leads to the formation of sustainable concrete thus reducing the pollution in the environment.

Keywords Alternate · Waste material · Sustainable

Introduction

Concrete is the world's second most disbursed component and is a widely utilized building material (Meyer 2009). Concrete production tops ten billion tonnes each year, and due to global infrastructural developments, the use of concrete has increased. To attain a sustainable and eco-friendly structure, the construction industry needs clean and green concrete solutions. Coconut shell is a prominent waste product of humid agricultural industries such as India (Prakash 2017).

In the building industry, coconut shell is recycled and is frequently discarded as waste. A novel strategy in concrete production is the use of coarse aggregate as a coconut shell in the manufacture of lightweight concrete (Gunasekaran et al. 2017; Colangelo et al 2021; Prakash et al. (2020a, 2020b). In India, coconut shell contributes to approximately 60% of total home garbage, providing a huge disposal challenge. Coconut shell is generally dumped as garbage once the coconut is tattered from the shell. The waste coconut shell can be crushed to the desired extent and reused as coarse aggregate to manufacture lightweight concrete; it might be used in SSD condition. This form of concrete has the additional profit of reducing the cost of building material.

The cement manufacturing industry alone accounts for at least 5% of human-caused emissions, accounting for 25% of total world carbon dioxide emissions from the manufacturing sector. Furthermore, research has indicated that cement manufacture directly contributes to 85% of carbon dioxide emissions emitted during the lifespan of concrete buildings

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(Habert and Roussel, 2009; Lim et al. 2018). Comparing with the standard concrete, the lightweight concrete is 20 to 25% lighter (Lo and Cui 2002). Structural lightweight concrete has more flexibility, minimum dead weight, strong seismic response, and low cost for foundation (Nagarajan et al 2020). The primary drawback of lightweight concrete is it requires more cement to produce the same strength as normal concrete. This drawback can be solved by replacement of a portion of cement with pozzolanic manufacturing waste (Shafigh et al 2013).

On the other hand, adding fibres to construction materials has been a practice in many regions. Natural fibres used as subordinate reinforcement in concrete are more environmentally friendly substitute to synthetic fibres (Rokbi et al. 2019). Sisal fibres include a high percentage of cellulose, which gives greater tensile strength, and they do not captivate water. Because of its low cost, thermal properties, adequate tensile strength, excellent durability, scratch resistance, and availability, the sisal fibre is the most often used natural fibre in the construction industry.

In this study, it has been attempted to study the mechanical behaviour of lightweight concrete when we use waste coconut shell as coarse aggregate inside concrete. To improve the strength of concrete, we also use the sisal fibres in various proportions ranging between 1 and 5% in accordance to the binder weight. After, the mechanical property tests such as the compression test, spilt tensile strength, flexural test, modulus of elasticity test, and impact resistant test were conducted. This experimental work was performed at the Bannari Amman Institute of Technology in Sathyamangalam, Tamil Nadu, India.

Materials and Methods

Materials

In this investigation, ordinary Portland cement (OPC) of Grade 53 that met the standards of IS: 12,269–1987 was employed. Its specific surface area is 345 m^2/kg and specific gravity of 3.15. The cement's initial and final setting periods are 75 min and 150 min, respectively. The fine aggregate used is river sand meeting the requirements of Zone II. It has a specific gravity of 2.38 and a modulus of fineness of 2.95. The coconut shell was collected from a local coconut grove, located near Sathyamangalam, Tamil Nadu, India. The coconut shell was then broken into smaller pieces and sieved. Coconut shells ranging in size from 12.5 to 4.75 mm were utilized for coarse aggregate. Then, it is splashed by means of fresh water and then dried out by natural drying method.

The physical features of the coconut shell are itemized in Table 1. Sisal fibre was brought from SP Grade Natural at Gobichettipalayam, Erode district, Tamil Nadu, India. The properties of sisal fibre are itemized in Table 2.

Table 1 Physical properties of coconut shell

Properties	Values obtained
Size of the aggregate (mm)	12.5 to 4.75
Thickness of the aggregate (mm)	3.5–8.5
Specific gravity	1.21
Fineness modulus (FM)	6.20
Water absorption (%)	23
Bulk density (g/cm^3)	0.68
Abrasion value (%)	2.1
Impact value (%)	8.0

Table 2 Sisal fibre properties

Properties	Values obtained
Diameter of the fibre (mm)	0.3–0.4
Length (mm)	35 mm
Density (g/cc)	1.50
Water absorption (%)	8
Modulus of elasticity (MPa)	15,500–16,500
Tensile strength (MPa)	550–650

Mix proportion and procedure

According to the ACI, the specimen is prepared for the investigation. The cement and also fine aggregate were retained at same levels at 465 kg/m^3 and 755 kg/m^3. Sisal fibres were added to the concrete based on weight of the cement by 1%, 2%, 3%, 4%, and 5%. Water to cement ratio is kept constant at 0.35. The proportions of all the mixtures are listed on Table 3. For about 4 min, in the rotating drum mixer, the coconut shell aggregate and river sand were mixed to designate the classification of mixing followed by adding of cement for further 5 min. Then, water is included into the rotating drum and it is mixed for further 9 min. Lastly, sisal fibres are uniformly mixed to the sample and the mixture is positioned into moulds and compacted for the test. After 24 h, it demoulded and cured until the testing date.

Testing methods

According to ASTM C143, the slump test was performed before casting the specimens. After casting, the specimens were demoulded after 24 h. Using 150-mm cube specimens, the compressive strength was determined according to ACI. Modulus of elasticity is determined with two cylinders of diameter 150 mm and height 300 mm by ASTM C469. According to ASTM C496, the 28-day split tensile strength

Table 3 Mix proportion of the proposed sample

Mix design	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coconut shell aggregate (kg/m^3)	Water/binder ratio	Sisal fibre (%)
CS1	465	755	335	0.35	1%
CS2	465	755	335	0.35	2%
CS3	465	755	335	0.35	3%
CS4	465	755	335	0.35	4%
CS5	465	755	335	0.35	5%

Fig. 1 **a** Coconut shell. **b** Sisal fibre

is determined with three cylinders of diameter 100 mm and height 200 mm. As per ASTM D790, three prisms of size 100 mm × 100 mm × 500 mm were used to measure 28-day flexural strength. The capacity of the compressive testing machine is 1500 kN and the loading rate is 2.4 kN/s. Finally, the impact test was performed by adopting the drop hammer technique on concrete discs of diameter 150 mm and height 63 mm.

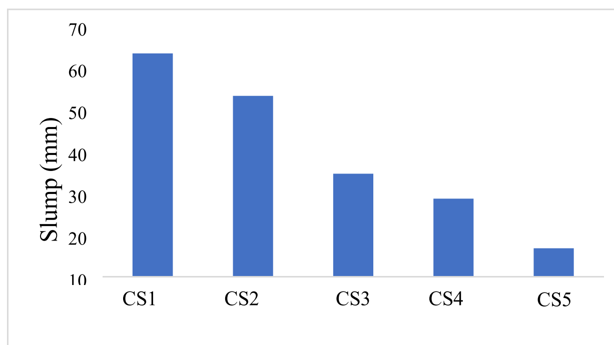

Fig. 2 Slump value with addition of sisal fibre

Results and discussion

Slump test

The level of the concrete structure is determined not only by the element quality, but also by flowability of the concrete mix during travel and installation, and during the compaction. The workability is a quality that indicates the effort necessary to work on fresh concrete with the minimum deterioration of consistency. Mehta and Monteiro (2006) stated that for satisfactory compaction and finishing, a slump of 50 to 75 was sufficient for lightweight concrete. Atiş (2003) found that when the number and length of jute fibres expanded, the workability of mortar and cement paste was diminished. In this study, the water was fixed for all mixtures. The addition of sisal fibre has reduced the value of the slump. Figure 1 shows that with the inclusion of sisal fibres, the slump value has been reduced. The inclusion of 1%, 2%, 3%, 4%, and 5% sisal fibre reduced the slump value by 8%, 22%, 29%, 51%, and 63% respectively. As a result, the combination containing 1% sisal fibre had the low droop but can be sufficiently consolidated (Fig. 2).

Compressive strength test

Table 4 shows the compressive strength values of proposed concrete mixes at 28 days for various sisal fibre concentrations. The inclusion of sisal fibre boosted strength in this investigation. The combination containing 3% sisal fibre had the maximum compressive strength among the different percentages of incorporated sisal fibre. Prakash et al. (2019a, b) obtained greater than 35 MPa compressive strength in proposed concrete. Furthermore, by introducing polypropylene

Table 4 Compressive strength of proposed concrete

Mix design	Compressive strength (MPa)
CS1	35.8
CS2	36.9
CS3	37.8
CS4	35.6
CS5	32.6

Table 5 Split tensile strength of the concrete

Mix design	Split tensile strength (MPa)
CS1	3.05
CS2	3.50
CS3	3.81
CS4	3.45
CS5	3.10

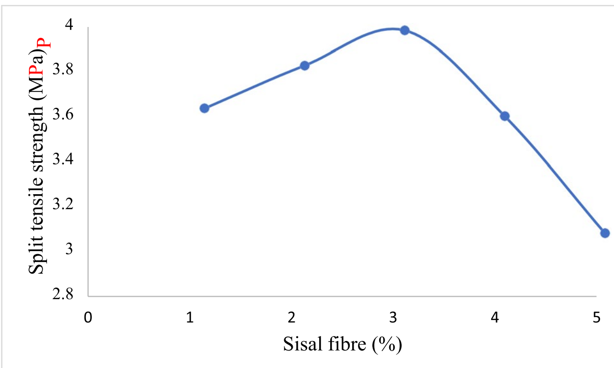

Fig. 3 Compressive strength with inclusion of sisal fibre

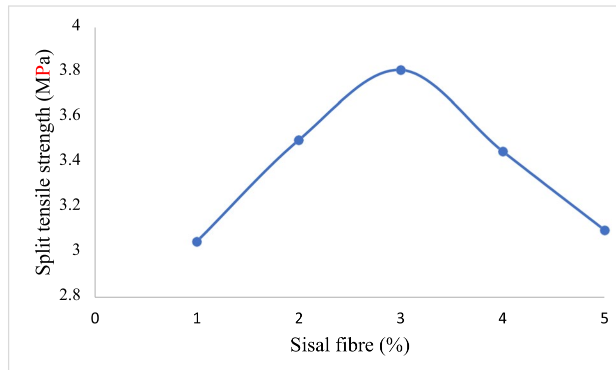

Fig. 4 Split tensile strength with addition to sisal fibre

fibre, Prakash et al. (2020a, b) increased the compressive strength of proposed concrete to above 36 MPa. With the inclusion of sisal fibre, further 5% increase was obtained in this research. When the load gets increased, it will induct crack expansion in the concrete. This study exposed that with the inclusion of sisal fibres, the compressive strength of coconut shell concrete gets increased up to 5% (Fig. 3).

Split tensile strength test

The most significant property of concrete is tensile strength which is vulnerable to cracking due to tensile loading, with its deadweight. Thus, by conducting splitting tensile and flexural strength tests, the concrete's tensile strength is determined. In general, lightweight concrete has weak tensile strength. Steel fibre–reinforced coconut shell concrete demonstrated a substantial rise in split tensile strength. The polypropylene fibre raised coconut shell concrete's split tensile strength by 22% (Prakash et al. 2020a, b). The value of split tensile strength of sisal fibre–reinforced concrete is shown in Table 5. The use of sisal fibre improves the overall strength of proposed concrete. By including 3% sisal fibre, it is resulted that maximum increase in split tensile strength of 17% is obtained. By adding coir fibre to coconut shell concrete, it enhances the split tensile strength considerably (Mandal et al. 2018) (Fig. 4).

Table 6 Concrete's modulus of elasticity

Mix design	Modulus of elasticity (MPa)
CS1	15,180
CS2	15,350
CS3	15,780
CS4	15,670
CS5	15,430

Modulus of elasticity

The concrete's modulus of elasticity is a significant mechanical constraint that represents the material's capacity to distort elastically. Lightweight aggregates feature larger pores and are stiffer than traditional aggregates. The concrete's modulus of elasticity values at various sisal fibre concentrations are shown in Table 6. The inclusion of sisal fibre to the coconut shell concrete resulted in small increase of elastic modulus. After adding up to 3% fibre, the modulus of elasticity increased, but after adding 4% and 5% fibre, it dropped. The inclusion of sisal fibres to coconut shell concrete enhanced its flexural strength by 7% in this study. The inclusion of sisal fibre to coconut shell concrete at 1%, 2%, and 3% enhanced its flexural strength by around 1%, 4%, and 7%, respectively. However, the inclusion of 4% and 5% fibre

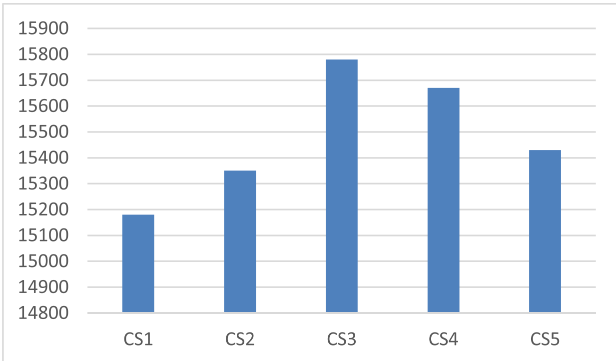

Fig. 5 Modulus of elasticity of designed mix

reduced the proposed concrete's flexural strength marginally (Prakash et al 2020a, b, 2019a, b) (Fig. 5).

Impact strength test

Impact is the sudden load created on the specimen. Cementitious compounds with crop fibre produce similar results as of synthetic fibres. Increasing the quantity of banana fibre in concrete enhanced its impact resistance (Sudarisman and Prabowo 2015; Prakash et al. 2019a). The impact characteristics of a cement mortar panel reinforced with jute fibre were enhanced by Zhou et al. (2013). Because the fibres are covered over fissures, the impact energy may be captivated and crack progression inside the concrete is stopped. The impact energy of the proposed specimens rose by 36%, 50%, 70%, 85%, and 96% after adding 1%, 2%, 3%, 4%, and 5% fibre, respectively, in this investigation.

Result

From this investigation, it can be concluded that inclusion of sisal fibre up to 3% shows good increment in the strength properties. It is obtained that there was an increment in the compression strength up to 5%, tensile strength was increased to 17%, and elastic modulus to 7% when the fibre content used was 3%. Thus, with the use of these waste materials, it was found that the concrete's strength gets increased and it leads to the formation of sustainable concrete thus reducing the pollution in the environment. It also increased flexural strength substantially.

Concrete's modulus of elasticity was somewhat enhanced. The fibre addition leads to a substantial inclusion in impact energy. Coconut shell is a renewable and certainly accessible resource, utilized as a biodegradable construction material. The use of sisal fibre improved the mechanical qualities of coconut shell concrete, making it suitable for structural purposes.

Author contribution Karthiga Shenbagam Natarajan, Dhivya Ramalingasekar, Sushmita Palanisamy, and Mohanraj Ashokan have equally contributed for this work.

Availability of data and materials All the necessary data are given in the paper in detail.

Declarations

Ethics approval This is the work done by me and the PG students; it is not published anywhere else by us.

Consent to participate All the authors of this paper have given their consent to participate and act as one of the authors.

Consent to publish The authors give consent for the publication of identifiable details, which can include photograph(s) or case history and details within the text.

Competing interests The authors declare no competing interests.

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