Mechanical Properties of Concrete with Coconut Shell and Fibre as Additives

Dr. Bindhu. K.R[1*], Miss Abiya B[2], Miss Hasna Haneef[2], Mr. Jinu David[2], Mr. Justin Mathew Joseph[2]

[1] Professor, Department of Civil engineering, College of Engineering Trivandrum, email-
[2] Department of Civil Engineering, College of Engineering Trivandrum

*Corresponding author: bindhukr@cet.ac.in

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ABSTRACT

Sustainability is a key in modern construction scenario. Even when the construction industry underwent a revolution in terms of equipment and materials used, the resultant impact on environment skyrocketed. This leads to the adoption of more sustainable approaches in construction like using coconut byproducts such as coconut fibre and shell as additives in concrete. Coconut fibre is abundantly available material which makes it a viable reinforcement material in concrete and the same goes for coconut shell which can be used as a partial replacement for conventional aggregate. This can further act as a new source of income for the coconut producers who get the benefit of the new demand generated by the construction industry. It is also an effective method of disposal of coconut husks and shells and thus reduces their negative impact on the environment. This project aims at studying the variation of strength of coconut fibre reinforced concrete (CFRC) with different percentages of coconut fibre (0.5%, 1%,1.5% and 2% by weight of cement), coconut shell aggregate concrete by replacing coarse aggregate with different percentages of coconut shell (15%, 30% and 45%) compared with that of conventional concrete. The optimum percentage of both fibres to be added and coconut shell to be used is determined by analyzing the strength aspects such as flexural, compressive and tensile strength. This project also includes the investigation on the mechanical properties of CFRC with coconut shell aggregate by incorporating coconut fibre and shell together in concrete matrix. The optimum percentage of coconut fibre in CFRC was obtained as 1% (by weight of cement) for peak flexural and tensile strength. The 15% replacement of conventional aggregate by coconut shell resulted in minimum reduction in the compressive strength of concrete which was found out as optimum percentage of coconut shell. From the present study it was found that the mechanical properties of coconut shell aggregate concrete with the addition of coconut fibre are comparable with the conventional concrete which leads to develop a sustainable concrete composite.

Keywords: Coconut fibre reinforced concrete, coconut shell aggregate concrete, flexural strength, compressive strength, tensile strength, sustainable concrete

1 Introduction

Concrete is one in every of the foremost important material of applied science field upon which construction field depend on and also one in all the foremost largely used material in world after water. Concrete is material composed of cement, aggregate, water and admixtures of which 60%-75% of volume consists of aggregate. The increased need of coarse aggregate led to the reduction of natural rock deposit alarmingly, that cause ecological imbalance. Therefore, consumption of natural stuff alternative to aggregate can protect the environment. Since concrete is robust in compression but weak in tension and flexure, it's reinforced using steel reinforcing bars. Despite of the benefits of steel fibres, its high material cost and high energy consuming

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process by production creates an adverse effect on environment which result in the search of latest environment friendly alternative. One such alternative is agricultural by-products.

Coconut is plant having multi-functional utility. India is that the third largest producer of coconut after Indonesia and Philipines. The properties of coconut shell like high strength and modulus properties, high lignin content that produces it weather resistant and low cellulose because of which absorb less moisture content comparing with other agricultural waste makes it suitable to be used as an alternate for aggregates. Also, the coconut fiber has reasonable specific strength, tenuity, and resistance to fungi, tough, durable and moreover biodegradable. Using the agricultural products of coconut in construction field can reduce the pollution and convey out sustainable environment.

Various researches were done on coir fibre concrete and concrete partially replaced with coconut shell aggregate. Danso (2017) studied on properties of coconut, feather palm and bagasse fibres as potential building materials. The properties of three natural fibres are investigated during this study for the aim of using them as reinforcement in soil blocks for producing environment friendly and low-cost housing. it's found that flexibility and rupture strength of fibres is tormented by its length to diameter ratio with low dry moisture content good for reinforcement. durability was found to scale back by 50% for damp and wet condition compared to dry fibre. Hassan et al., (2012) studied on durability of coconut fibre and located that the typical strength of coconut fibre is about 190.51MPa. Nadgouda (2015) conducted experimental studies for enhancement of properties of concrete by reinforcing it with coconut fibres. A concrete mix was designed to realize the minimum grade of M20 (by taking 1:1.5:3 as nominal mix). The investigation was done by taking 3%, 5%, and seven % (by the load of cement) of coconut fibre within the concrete mix found that flexural strength increases just in case of three mix but fibre content shouldn't be quite 3%. Ali (2013) studied on the use of coconut fibres and ropes as concrete reinforcement in mortar-free construction with novel interlocking blocks and located that thick and boiled fibres have higher lastingness compared to thin; medium, soaked chemically treated fibres. Dhandhania (2014) studied on the performance of coir fibre concrete and located that concrete with 0.25% coconut fibre have best crushing load (158 kN) compared to fifteen of it. Also, he concluded that coir has low thermal conductivity (0.12 kcal /m²hr/°C) that is natural cooling effect and there's no risk of corrosion. Krishna et al., (2017) focused on bringing out the contribution of coir fibre and sisal fibre to boost the ductility and strength properties of concrete and located that coir fibre delays and controls the tensile cracking of composite materials and it also enhances the ductility and energy absorption capacity. It can even be seen that the rise in ductility and strength of concrete was achieved for the addition of coir of 1.5% the burden of cement which was found to be the optimum percentage for M 30 mix.

Chandel et al., (2016) conducted a comparative strength study of coir fibre reinforced concrete (CFRC) over plain cement concrete (PCC) for M 20 mix. in keeping with this study the compressive strength of coir fibre reinforced (CFRC) is sort of 13% quite that of a clear cement concrete (PCC). The lastingness of CRFC is almost 40% over the PCC. The flexural strength of CFRC is 15% over that of PCC. The addition of coir in concrete also suggests that if the strength value is to be kept same for both CFRC and PCC, nearly 5% cement by weight is saved. Also, it's concluded that coconut fibre concrete helps in resisting cracks under the action of compressive and abrasion forces. Ruben et al., (2014) done an experimental study of coir fibre as concrete reinforcement material in cement-based composites and located that coir fibre utilized in cement improve the resistance of concrete from sulphate attack. The study also concluded that addition of coir fibre arrests the micro cracks present within the concrete. Wang et al., (2017) studied on the behavior of coconut fibre reinforced concrete (CFRC) under impact loading and located that coconut fibre reinforced concrete had better performance in resisting spalling and fragmentation. Kanojia et al., (2017) studied on performance of coconut shell as coarse aggregate in concrete and concluded that compressive strength of coconut shell concrete decreases gradually with increase in quantity of coconut shell and gain in strength after 7 days is significantly higher for coconut shell concrete than that for control concrete. Also found that replacement of conventional aggregate (M 20) by 40% of waste coconut shell reduces the density by 7.5%. Gunasekaran et al., (2012) studied on future study on compressive and bond strength of coconut shell aggregate concrete and located that coconut shell aggregate concrete doesn't deteriorate once coconut shell aggregates are encapsulated into the concrete matrix. it had been concluded that ultimate bond strength of coconut shell aggregate concrete under different curing conditions was much higher compared to the theoretical bond strength. Yashida et al., (2017) studied on durability properties of coconut shell aggregate concrete and located that water absorption, effective porosity, and sorptivity were found to be higher for coconut shell mixes than that of control mix. Abrasion resistance of coconut shell concrete specimens was found to be over that of control specimens. it had been concluded that, durability properties of coconut shell aggregate concrete is corresponding to normal concrete.

However, it is found that no previous studies have undergone by incorporating both coconut shell and coconut fibre together in concrete. So, this study aims at analyzing the strength properties of concrete by incorporating both coconut shell and coconut fibre and comparing it with the plain concrete.

2 Experimental Program

The present study is geared toward analyzing the variation in strength of coconut fibre reinforced concrete and coconut shell aggregate concrete as compared to the standard concrete. the assorted strength aspects like the compressive strength, enduringness and flexural strength of the concrete with coconut by products at their optimum percentages are to be evaluated. The optimum percentage of coconut fibre is decided for the height flexural strength of concrete with different percentages of coconut fibre (0.5%, 1%, 1.5% and 2% by weight of cement).The optimum percentage of coconut shell aggregate is evaluated for the height compressive strength of concrete with varying percentages of coconut shell aggregate (15%, 30% and 45% by volume of coarse aggregates). The process include collection of raw materials, testing of materials, mix design as per IS 10262 (2019) for M25 mix , casting ,curing and testing of specimens and analysis of results. Standard mix design procedure was adopted as per IS 10262- 2019 for M25 mix. the varied properties like bulk density, relative density, fineness modulus of fine aggregate, coarse aggregate, coconut shell was tested as per IS 2386 (Part 111)- 1963. The OPC 53 grade cement was used and tested for normal consistency, initial and final setting time as per IS4031 -1988. M sand used is more experienced 4.75 mm sieve conforming to the grading zone 11. The coarse aggregate of size 20mm and 12 mm were used. The dried coconut shell without organic waste was collected and and it had been broken manually by hammer specified the coconut shell aggregate comes within the range of 20mm to 5mm and it had been submerged in water for twenty-four hrs before using it in casting. The coconut fibre strands were withdraw 5cm, washed for about half-hour for removing the dust and other residual particles in it. at that time the coconut fibre is treated by boiling for about half-hour at 100oC. Then it absolutely was dried under sun for removing the moisture.

2.1 Target Strength for Mix Proportioning

$$f'_{ck} = f_{ck} + 1.65\,S$$

Where, f'_{ck} = target average compressive strength at 28 days, f_{ck} = characteristic compressive strength at 28 days = 25 N/mm^2, S = standard deviation = 4 N/mm^2 (from Table 1, IS 10262: 2019)

Therefore, target strength = 25 + 1.65 * 4 = 31.6 N/mm^2.

2.2 Water Content

Water content is obtained from water- cement ratio and cement content of 370 kg/m^3.

Water content= (cement content) x (water- cement ratio) Estimated free water content = 185 Litre

2.3 Proportion of Volume of Coarse Aggregate and Fine Aggregate

From table 5 of IS 10262 : 2019, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (zone 2) for water cement ratio of 0.50 = 0.62.

Therefore, proportion of volume of fine aggregate = 1 – 0.62= 0.38

2.3.1 Mix Calculations

Volume of concrete = 1 m^3

Volume of cement = (mass of cement / (specific gravity of cement * 1000))

= (370 / (3.15* 1000)) = 0.1175 m^3

Volume of water = (mass of water / (specific gravity of water * 1000)) = (185 / (1 * 1000)) = 0.185 m^3

Volume of all in aggregate = (a - (b + c)) = 1 – (0.1175 + 0.185) = 0.6975 m^3

Mass of coarse aggregate =

(d * volume proportion of coarse aggregate * specific gravity of coarse aggregate * 1000)

= 0.6975 * 0.62 *2.76* 1000 = 1194 kg

Mass of fine aggregate= (d * volume proportion of fine aggregate * specific gravity of fine aggregate * 1000)

=0.6975 * 0.38* 2.65 * 1000= 702.4 kg

2.3.2 Mix Proportion

Cement = 370 kg/m^3

Water = 185 kg/m^3

Coarse aggregate = 1194 kg/m^3

Fine aggregate = 702.4 kg/m^3

Water cement ratio = 0.5

Mix Proportion = 1:1.9:3.23 (by weight)

2.4 Casting of Concrete Specimens

Six cubes (150mm x 150mm x 150mm), 3 cylinders (150mm diameter and 300mm height) and 2 beams (100mm x 100mm x 500mm) were casted for determining 7 day and 28 day compressive strength of cubes, 28 day split tensile strength of cylinder and 28 day flexural strength of beams. Careful procedure was adopted in the batching, mixing and casting operation. Concrete is mixed by concrete mixer . The proportion of each material for concrete was measured by weight. The dry ingredients are mixed and water is added slowly until the concrete is workable.

First the control mix was casted, designated as CM. The control specimen casted is shown in the figure 1. Then concrete specimens with different percentages of coconut fibre (by weight of cement) were casted for the purpose of analyzing the performance of coir fibre reinforced concrete. The adopted percentages of coir fibre are 0.5%, 1%, 1.5% and 2% designated as CF1,CF2, CF3 and CF4 respectively.

Fig. 1 Casting of Control Specimens

Then Concrete specimens that are partially replaced with different percentages of coconut shell (by volume of coarse aggregates) were casted for the purpose of analyzing the performance of coconut shell aggregate concrete. The adopted percentages of coconut shell are 15%, 30% and 45% designated as CS1, CS2 and CS3 respectively. At last, concrete specimens incorporating coir fibre and coconut shell together in concrete matrix were casted and the effectiveness of above coconut by products in the performance of concrete is analyzed. Specimens were casted by varying the percentages of coir fibre (0.5%, 1% and 1.5%) for fixed percentages of coconut shell aggregate (15% and 30%).The specimens were designated as CS1CF1, CS1CF2, CS1CF3 for 15% coconut shell with 0.5%, 1%, 1.5% coconut fiber respectively and CS2CF1, CS2CF2, CS2CF3 for 30% coconut shell with 0.5%, 1%, 1.5% coconut fiber respectively. The mix after casting were kept in water for curing and strength test were done on seventh and twenty eighth day

2.5 Testing of Specimens

The mechanical properties of concrete specimens were analyzed by conducting the following tests.

2.5.1 Compressive Strength Test (as per IS 516:1959)

Compressive strength is that the capacity of a material or structure to resist axial loads tending to cut back the scale. The specimens are cast into cubes of 15 x 15 x 15 cm are tested by compression testing machine after 7 days and 28 days of curing. The load is applied gradually at a rate of 140kg/cm2 per minute till the specimen fails. The load at the failure divided by area of specimen gives the compressive strength of concrete.

2.5.2 Split Tensile strength Test (as per IS 516:1959)

Tensile strength is that the capacity of a material or structure to resist tension. Split lastingness tests are conducted on standard cylinders of dimension 15cm diameter and 30cm depth by loading under a compression testing machine. Split Tensile Strength is obtained by equation 1as,

Split Tensile Strength, $f_t = \frac{2P}{\pi dl}$ -- (1)

where; P is the maximum load applied to specimen, d is diameter of specimen and l is length of specimen.

2.5.3 Flexural Strength Test (as per IS 516:1959)

Flexural strength of concrete is taken into account as an index of enduringness of concrete. Tensile stresses are likely to develop in concrete thanks to drying shrinkage, rusting of steel reinforcement, temperature gradients and plenty of other reasons. Beam tests are conducted to work out flexural strength of concrete. In flexural tests on beam theoretical maximum durability is obtained inside of beam and is termed modulus of rupture, which depends on dimension of beam and position of loading. The test is conducted on beams of dimension 10 cm x 10 cm x 50cm. The flexural strength is given by equation 2 and 3 as,

$$f_b = \frac{Pl}{bd^2} \quad \text{when 'a' >13.3 cm -------- (2)}$$

$$f_b = \frac{3Pa}{bd^2} \quad \text{when 11 <'a'< 13.3 cm --------(3)}$$

Where, 'a' is the distance between line of fracture and near support b is the width of specimen, 'd' is the depth at point of failure, 'l' is the span of beam which is 40 cm and 'P' is t[illegible] al photographs showing the testing, split tensile strength testing and fle[illegible]

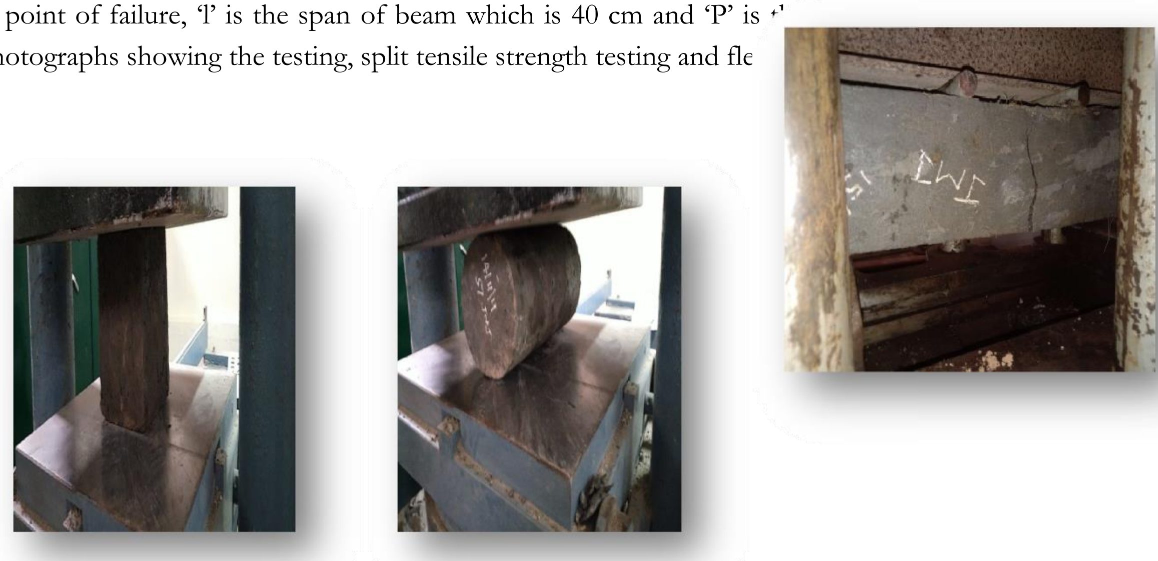

Fig.2 Testing of Specimens

3 RESULTS AND DISCUSSIONS

The mechanical properties such as compressive strength test, splitting tensile test and flexural strength test were performed on cubes, cylinders and beams for control mix, CFRC of different fibre proportions viz. 0.5%, 1%, 1.5% and 2%, coconut shell aggregate concrete with different shell proportions viz. 15%,30%, and 45% and CFRC with coconut shell respectively.

3.1 Coir Fibre Reinforced Concrete

Four different mixes of CFRC designated as CF1, CF2, CF3 and CF4 were casted incorporating 0.5%, 1%, 1.5% and 2% of coir fibre respectively and strength properties are determined. The improvement of strength properties for the mixes with varying percentages of coir is
presented in table 1.

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Table 1 Mechanical Properties of CFRC

Mix	7 Day Compressive Strength (MPa)	28 Day Compressive Strength(MPa)	Split Tensile Strength (MPa)	Flexural Strength (MPa)
CONTROL MIX (CM)	25.72	37.79	2.91	4.41
CF1	28.48	39.63	3.38	5.29
CF2	**33.72**	**41.76**	**3.88**	**6.51**
CF3	28.92	39.01	3.51	6.37
CF4	27.1	36.47	3.47	4.61

The table indicates that the 28 days compressive strength increases from 37.79 MPa of control mix to 41.76 MPa with incorporation of 1% coir fibre (CF2). However, from 1.5%, there is a reduction in compressive strength.

The variation in split tensile strength and flexural strength values is shown in figure 3. The percentage increase in the split tensile and flexural strength of concrete with change in the fibre content is shown in figure 4. From figures it is found that split tensile and flexural strength of concrete goes on increasing with an increase in the fibre content in the concrete mix up to 1%. A considerable increase in the strength compared to control mix is observed in the concrete mix CF2 with 1% fibre. After that strength goes on decreasing with an increase in the fibre content. The split tensile strength increases from 2.91 MPa to 3.88 MPa and the flexural strength increases from 4.41 MPa to 6.51 MPa in case of CF2.The split tensile strength of CF2 increases by 33% and flexural strength increases by 47% compared to control mix. And hence the optimum fibre content in CFRC is obtained as 1%.

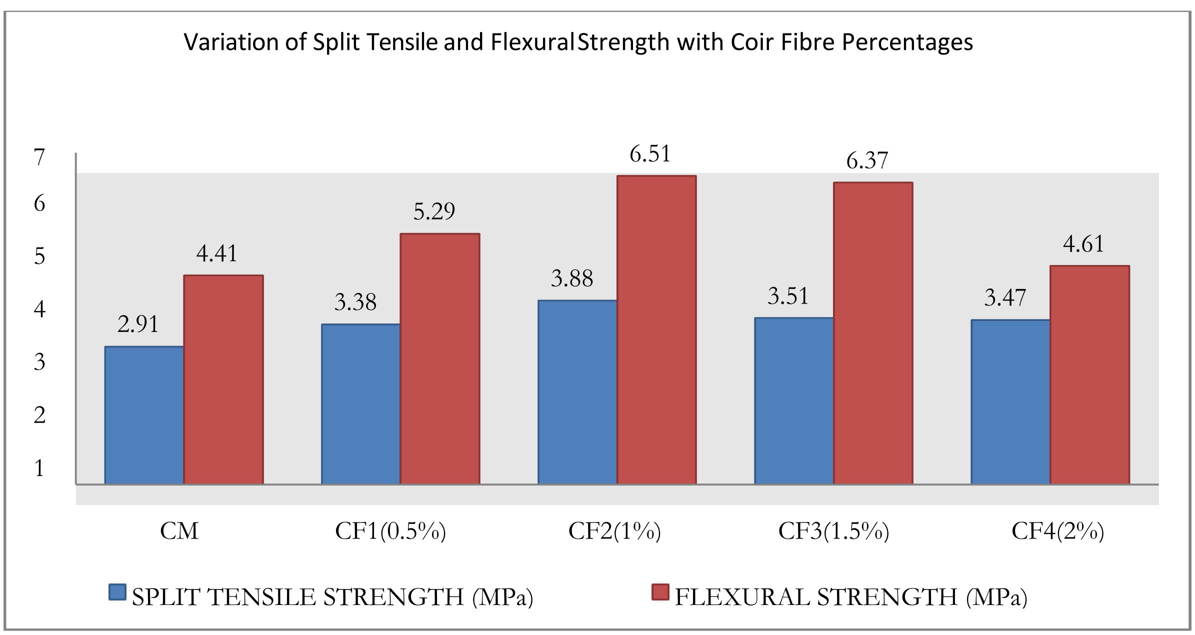

Fig.3 Variation in Split Tensile and Flexural Strength of CFRC

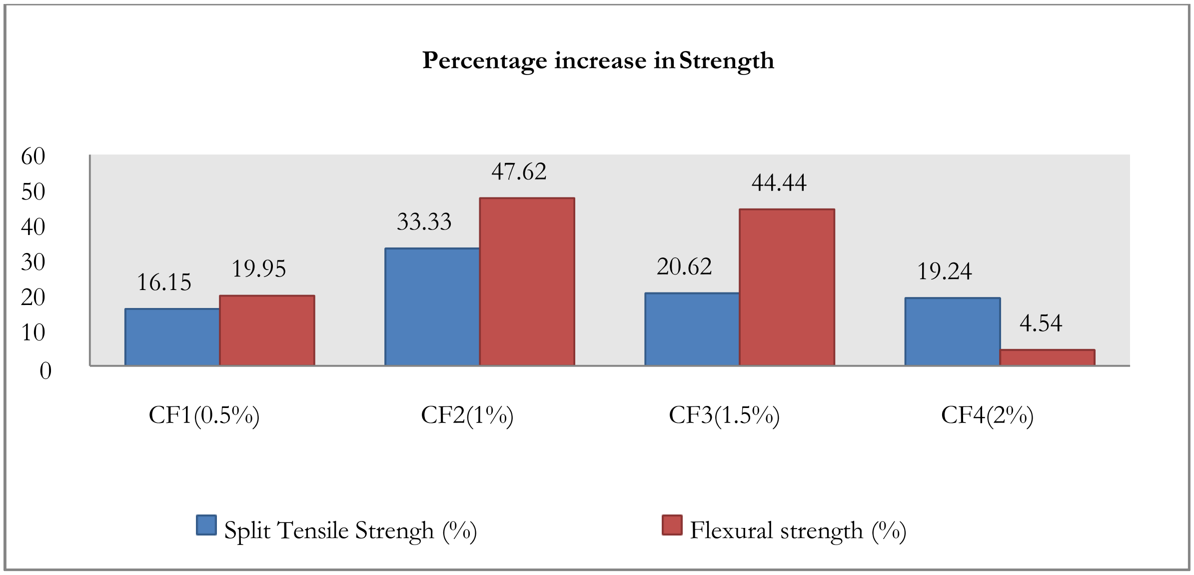

Fig.4 Percentage Increase in strength of CFRC

The reasons for the reduction in strength due to addition of fibre above optimum could be improper mixing of concrete due to a high fibre content leading to a non-homogeneous concrete mix. Another reason could be the reduction in the water content due to absorption of water by fibres, improper bonding and formation of voids by more coir fibre addition as it lead to nonuniform, random distribution within the matrix.

3.2 Coconut Shell Aggregate Concrete

Three different mixes of coconut shell aggregate concrete designated as CS1, CS2 and CS3 are cast incorporating 15%, 30% and 45% of coconut shell aggregate respectively and strength properties are determined. The strength properties for the mixes with varying percentages of coconut shell are presented in table 2.

Table 2 Mechanical Properties of Coconut Shell Aggregate Concrete

Mix	7 Day Compressive Strength (MPa)	28 Day compressive Strength (MPa)	Split Tensile Strength (MPa)	Flexural Strength (MPa)
CONTROL MIX (CM)	25.72	37.79	2.91	4.41
CS1	**25.69**	**36.86**	**2.88**	**4.40**
CS2	20.36	31.32	2.76	4.12
CS3	10.32	16.26	2.15	3.53

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The table 2 indicates that the 28 days compressive strength goes on decreasing with increase in coconut shell. The variation in compressive strength values is shown in figure 5. The percentage decrease in compressive strength of concrete with change in the coconut shell is shown in figure 6.

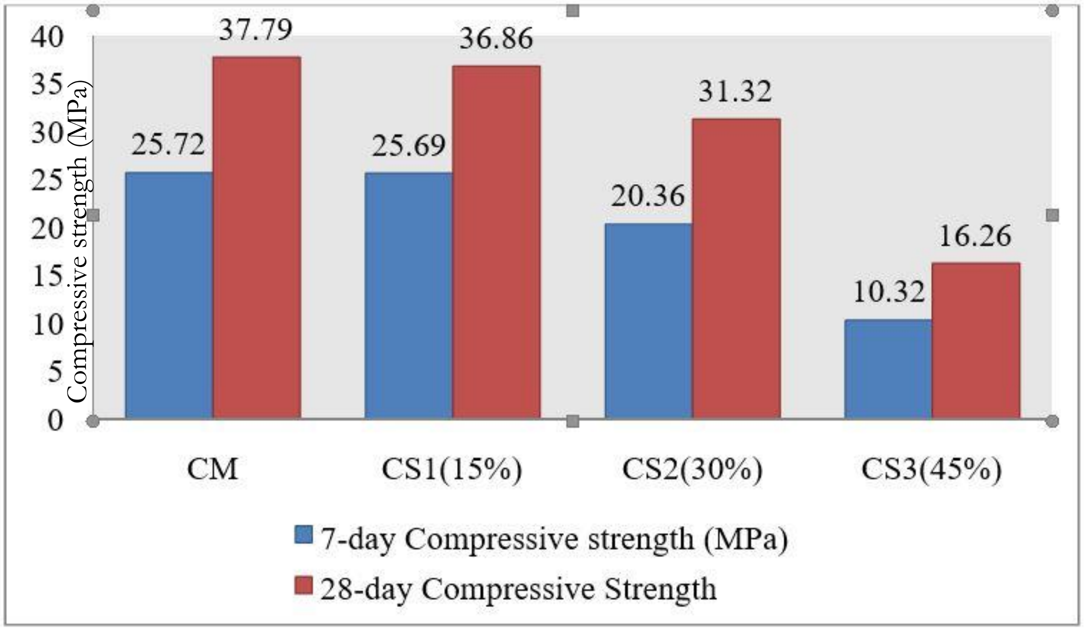

Fig. 5 Variation in Compressive Strength of Coconut Shell Aggregate Concrete

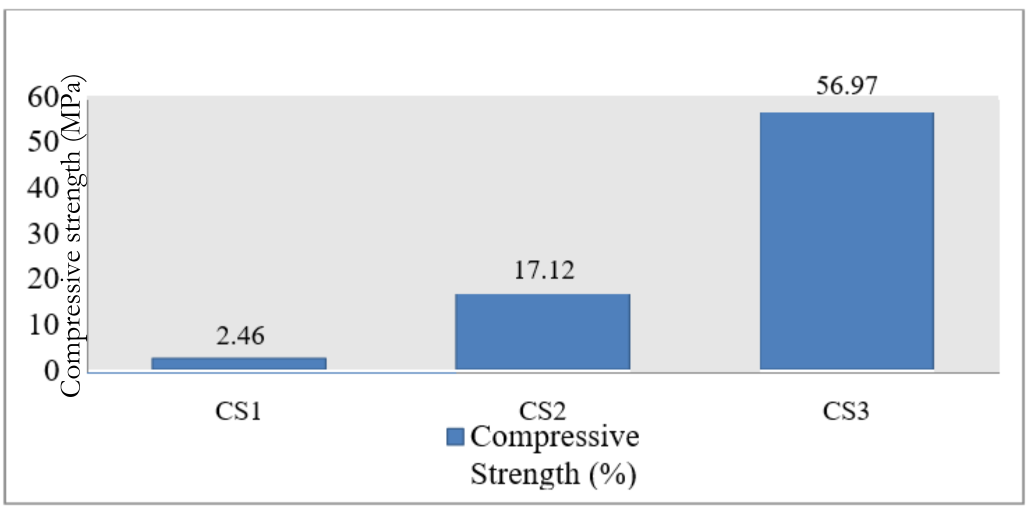

Fig. 6 Percentage Decrease in Compressive Strength of Coconut Shell Aggregate Concrete

From figure 5 and figure 6 it is found that compressive strength of concrete goes on decreasing with an increase in the shell content in the concrete mix. The percentage reduction in compressive strength compared to control mix is found to be minimal in case of mix CM1 with 15% coconut shell i.e., 2.46%. The split tensile strength and flexural strength also decreases similarly. Thus the optimum shell replacement percentage is obtained as 15%.

3.3 Coir Fibre Reinforced Concrete with Coconut Shell Aggregate

Concrete specimens incorporating coir fibre and coconut shell together in concrete matrix were casted by varying the percentages of coir fibre (0.5%, 1% and 1.5%) for fixed percentages of coconut shell aggregate (15% and 30%). Six different mixes designated as CS1CF1, CS1CF2, CS1CF3 with 15% shell and 0.5%, 1% and 1.5% fibre respectively and CS2CF1, CS2CF2 and CS2CF3 with 30% shell and 0.5%, 1% and 1.5% fibre respectively are cast and strength properties are determined. The improvement of strength properties for the proposed mixes CS1CF2 and CS2CF2 with respect to other mixes are presented in tables 3 and 4 respectively.

Table 3 Mechanical Properties of CFRC with Coconut Shell Aggregate 15%

Mix	7 Day compressive Strength (MPa)	28 Day Compressive Strength (MPa)	Split Tensile Strength (MPa)	Flexural Strength (MPa)
CONTROL MIX (CM)	25.72	37.79	2.91	4.41
CS1	25.69	36.86	2.88	4.40
CS1CF1	25.14	36.91	3.29	5.49
CS1CF2	**25.72**	**37.15**	**3.34**	**6.84**
CS1CF3	25.80	36.88	3.15	4.94

Table 4 Mechanical Properties of CFRC with Coconut Shell Aggregate 30%

Mix	7 Day Compressive Strength (MPa)	28 Day Compressive Strength (MPa)	Split Tensile Strength (MPa)	Flexural Strength (MPa)
CONTROL MIX (CM)	25.72	37.79	2.91	4.41
CS2	20.36	31.32	2.76	4.12
CS2CF1	19.26	27.87	2.97	4.70
CS2CF2	**20.78**	**32.41**	**3.01**	**5.09**
CS2CF3	24.20	30.81	2.82	3.92

From the test results the addition of coconut shell aggregate reduces the compressive strength, split tensile strength and flexural strength of concrete mix. But the mechanical properties of coconut shell aggregate concrete are improved upon the addition of coconut fibre. The variation in properties of different mixes is presented in figures 7 and 8 below.

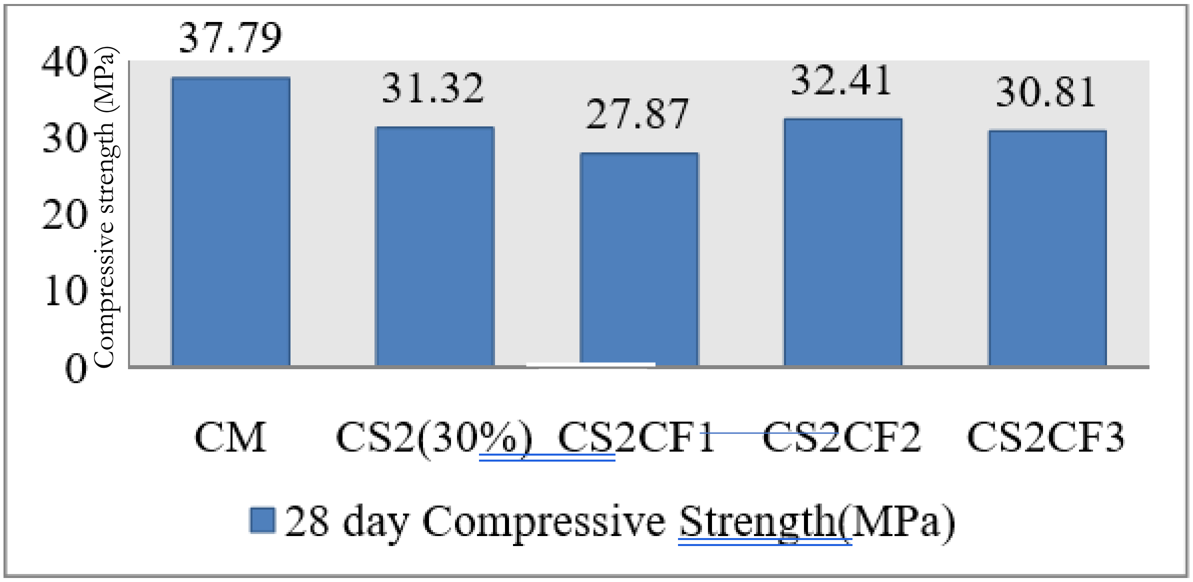

Fig. 7 Variation in Compressive Strength of CFRC with Coconut Shell 30%

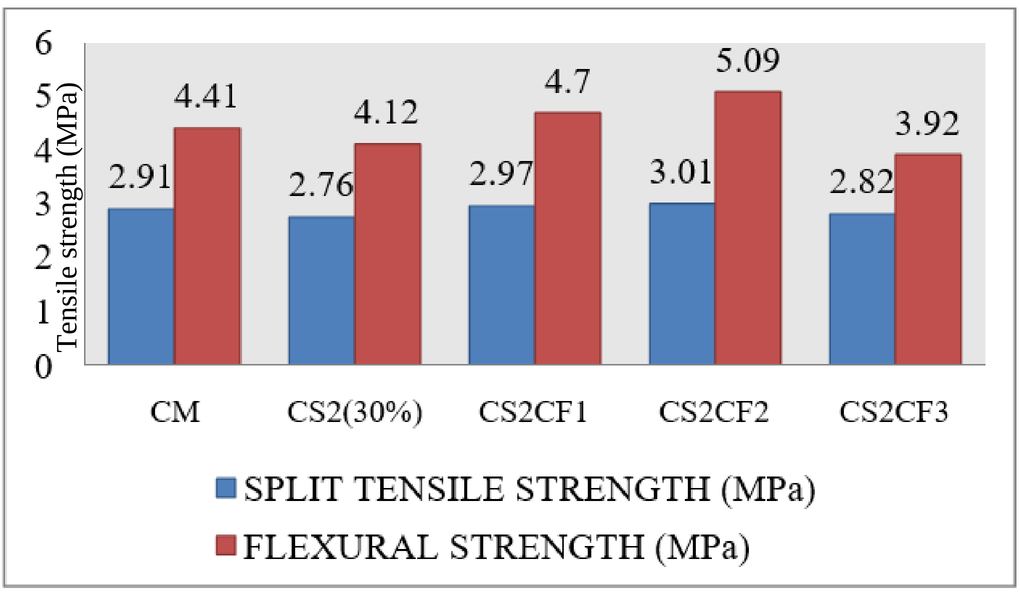

Fig. 8 Variation in Split Tensile and Flexural Strength of CFRC with Coconut Shell 30%

The compressive strength of CFRC with coconut shell 15% is comparable with that of mix CS1 and CM and is increasing slightly with increase in coir fibre content up to 1% of fibre (CS1CF2). And its split tensile and flexural strength are more than that of mix CS1 and CM and is increasing gradually with increase in coir fibre content up to 1% of fibre and further it reduces. But the strength values for CS1CF3 are higher than that of CM and CS1 as shown in figure above

Similar trend in variation of strength can be shown for CFRC with coconut Shell 30% in figures 4.7 and 4.8. The compressive strength is low compared to that of CM and is more than that of CS2 and is increasing with increase in coir fibre content up to 1% of fibre (CS2CF2). Its split tensile and flexural strength are more than that of mix CS2 and CM and is increasing gradually with increase in coir fibre content up to 1% of fibre and further it reduces. But the strength values for CS2CF3 are higher than that of CM and CS2 as shown in figures 7 and 8 above. And it is found that CFRC with 15% coconut shell has good flexural and split tensile strength compared to CFRC with 30% coconut shell. CFRC with 15% coconut shell and 1% coir fibre has improved mechanical properties compared to control mix.

3.4 Workability

Table 5 workability results of various mix

Mix	Workability(mm)
CM	**135**
CS1	**132**
CS2	**129**
CS3	**125**
CF1	**136**
CF2	**140**
CF3	**137**
CF4	**136**
CS1CF1	**133**
CS1CF2	**136**
CS1CF3	**132**
CS2CF1	**137**
CS2CF2	**133**
CS2CF3	**132**

4 Summary

The present work explores the feasibility of utilization of coir fibre and coconut shell as additional materials in concrete to improve its strength, ductility and load carrying capacity. The present investigation was also taken up in view of disposal problem of coconut by products and scarcity of conventional coarse aggregate used for concrete. Various experiments have been performed and the results for compressive strength, tensile strength and flexural strength are reported. The present work explores the feasibility of utilization of coir fibre and coconut shell as additional materials in concrete to improve its strength, ductility and load carrying capacity. The present investigation was also taken up in view of disposal problem of coconut by products and scarcity of conventional coarse aggregate used for concrete. Various experiments have been performed and the results for compressive strength, tensile strength and flexural strength are reported.

5 Conclusions of Study

1. The peak increase in tensile and flexural strength of concrete was achieved for the addition of coir of 1% by the weight of cement which was found to be the optimum percentage.
2. The tensile strength of CFRC is nearly 33% more than the PCC. The flexural strength of CFRC is 47% more than that of PCC which is a significant increment.

3. Replacement of conventional aggregate by coconut shell results into a decrease in compressive strength. 15% replacement resulted in minimum reduction in the compressive strength (2.46%) which was found to be optimum percentage of shell.
4. Mechanical properties of coconut shell aggregate concrete are improved upon the addition of coconut fibre.
5. CFRC with 15% coconut shell and 1% coir fibre has improved mechanical properties compared to PCC and can be used as an alternative for conventional concrete.
6. Coconut fibre and coconut shell being low in density reduces the overall weight of the concrete thus it can be used as a structural light weight concrete.
7. Sustainable concrete can be made by using green materials like coconut shell and coconut fibre.

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