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Experimental Studies on Durability Properties of Coconut Shell Concrete

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ABSTRACT
Abundant availability of natural resources has become a dream for present day engineering society due to large scale consumptions. The unaccountable population growth rate makes problem of availability of coarse aggregate for construction more severe. The rising cost of construction materials in developing countries has necessitated research into the use of alternative materials civil engineering construction. The properties of concrete using coconut shell (CS) as coarse aggregate were investigated in this experimental study. The cement was replaced with 10%, 20% and 30% of fly ash and optimum percentage was found. The crushed coconut shells were used as substitute for conventional coarse aggregate in proportions of 100%. For the selected mix, a comparison has been done for CS concrete with and without fly ash. Compressive strength, carbonation depth, alkalinity, sorptivity, water absorption test were investigated in the laboratory. The results showed that, density of the concretes decreases with increase in CS per cent. Workability decreased with increase in CS replacement. Compressive strength of CS concrete was lower than control concrete. absorption and sorption were higher for CS replaced concretes than control concrete. A potential exists for the use of coconut shells as
coarse aggregate and lightweight concrete construction. The use of coconut shells as full replacement for conventional aggregates should be encouraged as an environmental protection and construction cost reduction measure.
***Keywords*— Construction materials; Compressive strength; Coconut shells; Sorptivity; Water absorption; carbonation depth; alkalinity.**

I. INTRODUCTION

Structural LWC has a density of less than 2000 kg/m^3 and a compressive strength of more than 20 N/mm^2. Creating LWC is a problem because of the difficulty in reducing density while maintaining strength and avoiding an increase in cost. A popular method for reducing the density of concrete is to incorporate various types of lighter particles into the mix. When making LWC, the crushed stone and sand are typically swapped out for lightweight aggregate (LWA). Many countries throughout the world have been using LWC as a building material for many years now. It has become popular because of its low density and excellent thermal insulation characteristics.

By reducing the dead load, improving seismic structural response, and reducing foundation costs, structural LWC provides significant design freedom and substantial cost reductions. LWC pre-cast elements save transportation and installation costs. The uses span from lightweight partitions, walls, and subsidiary structural components to the most important structural elements. For the light partitions, the compressive strength ranges from 7 N/mm^2 to around 40 N/mm^2. Lightweight natural and artificial aggregates concrete and foamed-type concrete are some of the LWC.

Natural LWA are often derived from volcanic rocks such as pumice, which have a density of between 500 and 900 kg/m3. Recent innovations include the use of synthetic LWA derived from a variety of natural materials, including expanded clay, expanded shale, foamed slag, blast furnace slag, pulverised fuel ash, and perlite, to enable LWC and attain compressive strengths of up to 100 N/mm2. LWA is most notable for its high porosity, which results in a low specific gravity.Porous LWA with a low specific gravity can be utilised in place of crushed stone aggregate in the manufacturing of LWC. Though many experiments used commercially supplied LWA in place of crushed stone aggregates to create LWC, using waste materials as an aggregate may result in additional environmental and economic benefits. Given the rising environmental challenges, it is particularly desired to use aggregates made from by-products and/or solid waste materials from various sectors. The high cost of conventional building materials is a significant constraint on the delivery of construction in India. In developing nations with high levels of agricultural and industrial waste, these wastes can be employed as a prospective material or substitute material in the construction sector. This will have a dual benefit of lowering the cost of construction materials and also serving as a means of disposing of garbage. Thus, the preceding strategy is reasonable, deserving, and justifiable. As a result, this work attempted to utilise coconut shell (CS) as coarse aggregate in the creation of LWC.

CS has excellent durability characteristics, high toughness, and abrasion resistance; it is well suited for long-term use. CS is primarily used as an ornament, in the manufacture of decorative items and household utensils, as well as a source of activated carbon via its charcoal. Additionally, the powdered shell is used in the plastics, adhesives, and abrasive materials industries, as well as in the manufacture of insect repellent in the form of mosquito coils and agarbathis. The investigation of CS as a substitute for aggregates is another way to make use of the contributions made by a coconut tree. The goal of this research is to create a concrete that contains coarse aggregate made of CS. The entire structure might be referred to as coconut shell aggregate concrete (CSAC). After scraping out the coconut, the shell is typically discarded as waste. Given that the majority of this discarded CS resource is currently untapped commercially, its potential use as a building material, particularly in concrete, along the lines of other LWA is an intriguing subject for study. Not only will the study of CS result in the development of a new material for construction, but it will also aid in the preservation of the environment in addition to improving the economy by providing new use for the CS. Therefore, efforts have been made to use the CS as coarse aggregate and construct new structural LWCs. The strength and durability characteristics were studied.

II. MATERIALS USED

A. Coconut Shell Aggregates (CSA)

This study relied on CS that had recently been collected from a local oil mill. In fig. 1, the shells of several species of CS are seen to have variable thicknesses ranging from 2–8 mm. A flaky and unevenly formed shell results from crushing. Manually crushing CS aggregates was used to prepare them. In order to gain suitable workability with the concrete, the longitudinal dimensions of CS are limited to a maximum of 12 mm (Fig. 1). The shell's concave and convex faces had different textures in terms of surface finish. The spiky edges of the smashed rock were noticeable. When using CS aggregates, it is important to mix at Saturated Surface Dry (SSD) in order to prevent water absorption by the concrete mix.

Fig.1 Coconut shell aggregate

B. Other concrete mix constituents

The binder is Ordinary Portland Cement (OPC) 43 Grade, which complies with Indian Standard IS 12269: 1987. As coarse aggregate, well-graded crushed quarry aggregate with a specific gravity of 2.75 was employed. The aggregate size limit was 12.0 mm. River sand was employed throughout the experiment as fine aggregate according to IS 383-1970 grading zone III with a specific gravity of 2.6 and a maximum particle size of 4.75 mm. This experiment makes use of class F fly ash from the Mettur thermal power plant. Fly ash has a specific gravity of 2.10. The University's potable water supply was used for mixing and curing.

III. DESIGN OF MIXTURE

The mix design for structural lightweight concrete is determined by the physical and mechanical qualities of the lightweight aggregate. There are no defined methodologies for the design of lightweight concrete mixes. Typically, the design of lightweight concrete mixes is created by trial mixes. ACI and Indian Standard techniques could not be used to develop concrete mixes using agricultural waste. For the production of coconut shell aggregate concrete (CSAC), sufficient trial mixes were prepared and established by weigh batches in order to optimise the mix ratio by considering the cement content, wood–cement ratio, and water–cement ratio. The mix ratio for CSAC has been determined to be 1:1.47:0.65:0.42 by weight of cement (Cement: Sand: CS: Water). This has a cement concentration of 510 kg/m^3 and also meets the ASTM C 330 standards for structural LWC. This predetermined mix ratio was used in this study. We discussed the physical and mechanical features of CS (Table 2).

The mix design for lightweight concrete used for structural purposes depends on the physical and mechanical properties of lightweight aggregate. No specific methods are available for the design of lightweight concrete mixes. Lightweight concrete mix design is usually established by trial mixes. ACI and Indian Standard methods could not be applied to the mix design of concrete with agro waste materials. For the production of coconut shell aggregate concrete (CSAC), enough trial mixes.

TABLE 1: PHYSICAL PROPERTIES OF COCONUT SHELL

Sl. No	Physical and mechanical properties	coconut shells
1	Maximum size (mm)	12.0
2	Moisture content (%)	4.10
3	Water absorption (24 h) (%)	25.00
4	Specific gravity	1.1–1.25
5	Impact value (%)	8.3
6	Crushing value (%)	2.6
7	Abrasion value (%)	1.8
8	Bulk density (kg/m3)	655
9	Fineness modulus	6.4
10	Shell thickness (mm)	3–7

III. METHODS

In this investigation, two proportions were to be employed. For the selected mix ratio, 60 Cubes 150mm X 150mm X 150mm, 30 Cylinders 150mm diameter and 300mm in length, and 4 Beams 1700 X 100mm X 150mm were tested. Various quantities of fly ash and coconut shell were used to cast the specimens.

IV. RESULTS AND DISCUSSION

Compressive Strength

According to Indian Standard specifications (IS:516 –1959), the compression test on cubes was conducted. Cubes of size 150mm x 150mm x 150mm (as per IS: 10086-1982) should be cast. The specimen should be given sufficient time for hardening (approx.24h) and then it should be cured for 7 and 28,56,90 days, it should be loaded in the compression testing machine and tested for maximum load.

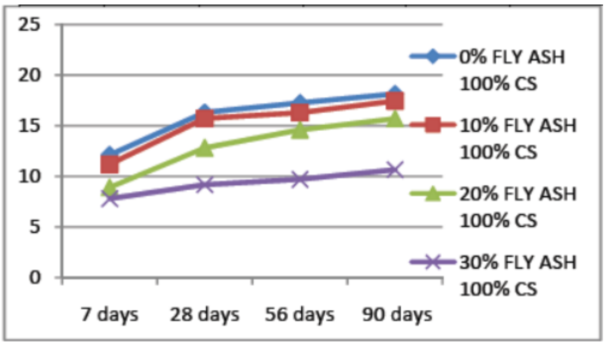


Figure 2. Compressive strength

From the above graph it is clear that the percentage of CSA is increases, it reduces the compressive strength of the cubes as compared to conventional concrete. Addition of fly ash in CSAC did not given any strength to the concrete and also the compressive strength get reduced here.

Carbonation depth

Cement paste has a pH of about 13 which provides a protective layer (passive coating) to the steel reinforcement against corrosion. Loss of passivity occurs at about pH 11. Carbonation of the concrete, caused by carbon dioxide in the atmosphere, has the effect of reducing the pH.

Carbonation depth is assessed using a solution of phenolphthalein indicator that appears pink in contact with alkaline concrete with pH values in excess of 9 and colourless at lower levels of pH.

Carbonation is the result of the dissolution of CO2 in the concrete pore fluid and this reacts with calcium from calcium hydroxide and calcium silicate hydrate to form calcite (CaCO3). Aragonite may form in hot conditions.

The 1% phenolphthalein solution is made by dissolving 1gm of phenolphthalein in 90 cc of ethanol. The solution is then made up to 100 cc by adding distilled water. On freshly extracted cores the core is sprayed with phenolphthalein solution, the depth of the uncoloured layer (the carbonated layer) from the external surface is measured to the nearest mm at 4 or 8 positions, and the average taken. If the test is to be done in a drilled hole, the dust is first removed from the hole using an air brush and again the depth of the uncoloured layer measured at 4 or 8 positions and the average taken. If the concrete still retains its alkaline characteristic the colour of the concrete will change to purple. If carbonation has taken place the pH will have changed to 7 (i.e. neutral condition) and there will be no colour change.

The concrete still retains its alkaline characteristic the color of the concrete will change to purple. There is no carbonation takes place in the coconut shell aggregate concrete at the age of 28 days and 56,90 days.

Figure 3. Carbonation depth

Alkalinity

Tests are carried out on specimens of 28 days, 56 days & 90 days water curing. The broken pieces of tested specimen are again broken into small pieces using hammer and ball mill and then powdered. Each of the powder samples (say 20gms) is put into 100ml distilled water. The aqueous solution is allowed to stand for 72 hours & more. To enable more of free lime of hydrated cement paste to get dissolved in water. The pH of the aqueous solution is measured by pH meter.

Fig 4.Testing of PH value

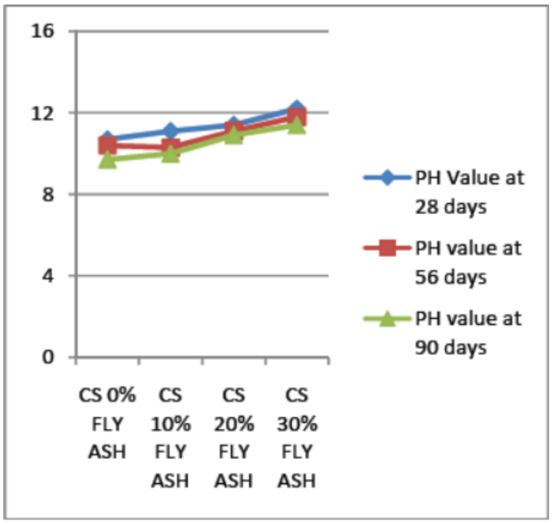


Figure 5. Alklalinity

The alkalinity test results gives the maximum value of PH at 30% replacement of Fly ash 100%replacement of coconut shell as coarse aggregate compare to the control concrete at 28 days and 56,90 days. The PH was low for the control concrete for both 28 days and56, 90 days. With the addition of fly ash the PH was increased gradually.

Rapid chloride penetration

Corrosion is mainly caused by the ingress of chloride ion into concrete annulling the original passivity present. Rapid chloride penetration test (RCPT) has been developed as a quick test able to measure the rate of transport of Chloride ions in concrete. Concrete disc specimens of size 100mm diameter and 50mm thick are cast using, with coconut shell aggregate. After 24 hours, the disc specimens were removed from the mould and subjected to curing for 28 and 56 days in chloride free distilled water.

After curing, the specimens are tested for chloride permeability. All the specimens are dried free of moisture before testing. The test set up is called rapid chloride permeability test (RCPT) assembly. This is a two-component cell assembly checked for air and watertight. The cathode compartment is filled with 3%NaCl solution and anode compartment is filled with 0.3 NaOH solutions. Then the concrete specimens were subjected to RCPT by impressing a 60V from a DC power source between the anode and cathode. Current is monitored up to 6 hours at an interval of 30 minutes. From the current values, the chloride permeability is calculated in terms of coulombs at the end of 6 hours by using the formula.

$Q= 900 (I_0 + 2I_{30} + 2I_{60} + 2I_{90} + \ldots\ldots\ldots\ldots + 2I_{300} + 2I_{330} + 2I_{360})$

Where,

Q = Charge passed (Coulombs)

I_0 = Current (amperes) immediately after voltage is applied

I_t = Current (amperes) at t min. after voltage is applied

Figure 6. Specimens for RCPT

Table 2. Ratings of RCPT (as per ASTM C1202)

Charge Passed (coulombs)	Chloride ion penetrability
< 100	Negligible
100 to 1,000	Very Low
1,000 to 2,000	Low
2,000 to 4,000	Moderate
> 4,000	High

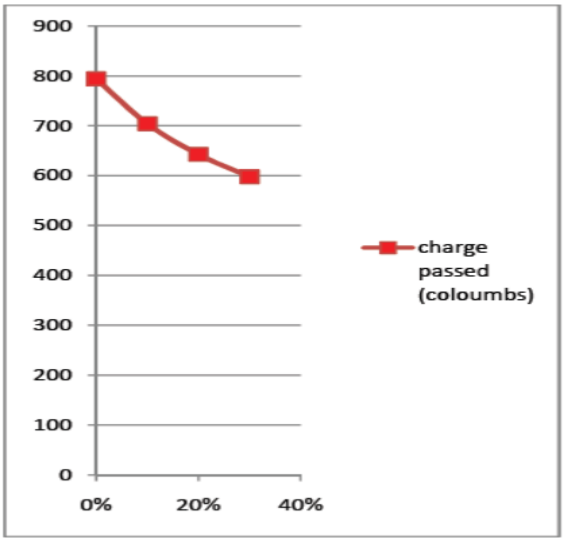


Figure 7. RCPT Test result

From the results of RCPT it is observed that the maximum value of penetration was achieved at 0% replacement of fly ash with 100% replacement of coconut shell as coarse aggregate which the value is 793.8 at 28 days. This value falls under the “very low” category as per ASTM C1202. The minimum value of attained for the control mix at 28 days. The rate of chloride ion penetration is minimum for each 30% addition of fly ash.

Sorptivity

Ovens dry at 50 degree for 7 days, after cooling take initial weight. Immerse at 2 to5 mm depth in water after sealing sides. Take out and weigh at 1,2, 3, 4, 5, 9, 12, 16, 20, 25 minutes and at every 30 min for two hrs.

The maximum sorption rate of concrete is 29.033at 120minutes at 28 days. The minimum sorption rate of concrete is 19 at 30 minutes at 90 days. The proportions of coconut shell 100% and 0% fly ash replacement for cement show lower sorption rate compared to 30% fly ash replacement of cement at 28 days and 90 days.

Table 3. Sorptivity result at 28 days

SPECIMEN	30 Min	60 Min	90 Min	120 Min
100%CS 0%FLY ASH	22.0333	23.667	25.3	26.4
100%CS 10%FLY ASH	23.4	24.8	25.833	26.866
100%CS 20%FLY ASH	24.133	25.366	27.033	27.866
100%CS 30%FLY ASH	23.866	25.833	28.3166	29.033

Table 4. Sorptivity result at 90 days

SPECIMEN	30 Min	60 Min	90 Min	120 Min
100%CS 0%FLY ASH	19	19.7	21.1	21.4
100%CS 10%FLY ASH	19.3	19.8	21.3	22.1
100%CS 20%FLY ASH	19.9	21.6	21.6	22.9
100%CS 30%FLY ASH	21.7	22.1	22.3	24.6

Saturated water absorption result

According to ASTM C 642-06, water absorption test was performed on fly ash with Coconut shell aggregate concrete. Cubes of size 100×100×100 mm were tested after 28,90 days of curing. The specimens were taken out and dried in an oven at a temperature of 100 to 110C for not less than 24hours. Each specimen removed from the oven was allowed to cool in dry air to a temperature of 20 to 25C and the dry weight was determined. Then the specimens were immersed in water. The wet weights were recorded for every ½ hour for 2½ hours, every 1 hour for 4 hours, 24 hr and 72 hr. The percentage of water absorption was calculated as follows.

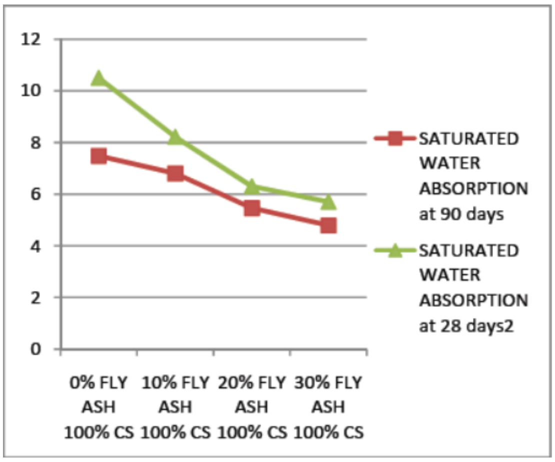
SWA= $[(W_s-W_d) / W_d] \times 100$

Where,

SWA - Saturated Water Absorption in percentages

W_s - Weight of the specimen at fully saturated condition in kg,

W_d - Weight of oven dried specimens in kg.



From that graph was observed that the 30% fly ash replaced cement in coconut shell aggregate concrete showed lower water absorption than 0 % fly ash replaced cement in coconut shell concrete. The maximum water absorption = 10.5 % (28 days and CS 0% fly ash). The minimum water absorption = 5.7% (28 days and CS 30% fly ash).

Porosity results at 28 days and 90 days

According to ASTM C 642-06, porosity test was performed on fly ash with Coconut shell aggregate concrete. Cubes of size 100×100×100 mm were tested after 28,56, 90 days of curing. The specimens were taken out and dried in an oven at a temperature of 100 to 110C for not less than 24hours. Each specimen removed from the oven was allowed to cool in dry air to a temperature of 20 to 25C and the dry weight was determined. Then the specimens were immersed in water. The wet weights were recorded for every ½ hour for 2½ hours, every 1 hour for 4 hours, 24 hr and 72 hr. The porosity was calculated as follows.

n = $(W_s-W_d)/(Ws-Wsub) \times 100$

Where,

n- Porosity, Ws - Weight of the specimen at fully saturated condition in kg,

Wd - Weight of oven dried specimens in kg,

Wsub -Weight of the submerged condition in kg

Table 5. Porosity

SPECIMEN	Porosity at 28 days	Porosity at 90 days
100%CS 0%FLY ASH	20.83	14.66
100%CS 10%FLY ASH	15.06	13.33
100%CS 20%FLY ASH	13.66	10
100%CS 30%FLY ASH	10	8.66

From the above Table the porosity (n) of the proportions of fly ash 30% replacement for cement show lower porosity rate compared to 0% replacement Maximum porosity = 20.83 % (at 28 days and 0% fly ash) Minimum porosity = 8.66 % (at 90 days and 30% fly ash)

V. CONCLUSION

Based on the works carried out so far, the followings conclusion has been made, From the graph the compressive strength decreases for increase in the proportion of fly ash content Increasing the fly ash content with coconut shell aggregate decreases the compressive strength. In the content, the strength increases for 100 % of CSA compare to the other proportions.

There are no carbonation takes place in the coconut shell aggregate concrete. The alkalinity test results give the maximum value of PH at 30% replacement of Fly ash with 100%replacement of coconut shell as coarse aggregate compare to the control concrete at 28 days and 56,90 days.

The proportions of coconut shell for 100% and 30% fly ash replacement for cement showed lower sorption rate compared to 0% fly ash replacement of cement at 28 days and 90 days.

The minimum value of RCPT had attained for the control mix at 28 days. The rate of chloride ion penetration is minimum for each 30% addition of fly ash.

The maximum saturated water absorption was observed for control mix at 28 days. The rate of saturated water absorption is decreased at 90 days. The proportions of coconut shell for 100% and 0% fly ash replacement for cement showed higher water absorption compared to 30% fly ash replacement of cement at 28 days and 90 days.

The maximum porosity was observed for control mix at 28 days. The minimum porosity was observed at 90 days. The proportions of coconut shell for 100% and 0% fly ash replacement for cement showed higher porosity rate compared to 30% fly ash replacement of cement at 28 days and 90 days.

From the literature review, the selected and established mix ratio for CSAC is 1:1.47:0.65:0.42 by weight of cement (Cement: Sand: CSA: Water) in which cement content was set 510 kg/m3 and this mix also satisfies the criteria of structural LWC as per ASTM C330. This established mix ratio was taken for this study.

The utilization of coconut shell in concrete is a productive way of disposal of natural waste.

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