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Experimental Analysis of the Use of Coconut Shell as Coarse Aggregate

B.Damodhara Reddy[1], S.Aruna Jyothy[2] , Fawaz Shaik[3]
[1]*Associate Professor, Department of Civil Engineering, Sri Venkateswara College of Engineering and Technology, Chittoor, Andhra Pradesh, India.*
[2] *Assistant Professor, Department of Civil Engineering, Sri Venkateswara University College of Engineering, Tirupati, ,Andhra Pradesh, India.*
[3] *PG Student, Department of Civil Engineering, Sri Venkateswara College of Engineering and Technology, Chittoor, Andhra Pradesh, India.*

Abstract: *The high cost of conventional building materials is a major factor affecting housing delivery in the world. This has necessitated research into alternative materials of construction. In this study, coconut shell is used as light weight aggregate in concrete. The properties of coconut shell and coconut shell aggregate concrete is examined and the use of coconut shell aggregate in construction is tested. The project paper aims at analyzing flexural and compressive strength characteristics of with partial replacement using M30 grade concrete. The project also aims to show that Coconut shell aggregate is a potential construction material and simultaneously reduces the environment problem of solid..Beams are casted, tested and their physical and mechanical properties are determined. The main objective is to encourage the use of these 'seemingly' waste products as construction materials in low-cost housing.*

Keywords: *Compressive strength, split tensile strength, flexural strength, Coconut shells, Portland pozzolana cement**(PPC).***

I. Introduction

Infrastructure development across the world created demand for construction materials. Concrete is the premier civil engineering construction material. Concrete manufacturing involve consumption of ingredients , aggregates, water and admixture(s). Among all the ingredients ,aggregates form the major part. Two billion tons of aggregate are produced each year the United States. Production is expected to increase to more than 2.5 billion tons per by the year 2020. Similarly,the consumption of the primary aggregate was 110 million tonnes in U.K in the year 1960 and reached nearly 275 million tonnes by 2006.Use of natural aggregate in such a rate leads to a question about the preservation of natural aggregates sources. In addition , operations associated with aggregate extraction and processing are the principal causes of environmental concerns. In light of this, in the contemporary civil engineering construction, using alternative materials in place of natural aggregate in concrete production makes concrete as sustainable and environmentally friendly construction material. Diffferent alternative waste materials and industrial byproducts such as fly ash, bottom ash, recycled aggregates, foundry sand, china clay sand, crumb rubber, glass were replaced with natural aggregate and investigated properties of the concretes. Apart from above mentioned waste materials and industrial byproducts, few studies identified that coconut shells, the agricultural by product can also be used as aggregate in concrete. According to a report, coconut is grown in more than 86 countries world wide, with a total production of 54 billion nuts per annum. India occupies the premier position in the world with an annual production of 13 billion nuts, followed by Indonesia and the Phillippines. Limited research has been conducted on mechanical properties of concrete with coconut shells as aggregate replacement. However, further research is needed for better understanding of the behaviour of coconut shells as aggregate in concrete. Furthermore, there is no study available in the literature on the transport properties which determine durability of the concrete. Thus, the aim of this work is to provide more data on the strengths coconut shell concretes at different coconuts shells (CS) replacements and study the transport properties of concrete with CS as coarse aggregate replacement. Furthermore, in this study, the effect of fly ash as cement replacement and aggregate replacement on properties of the CS replaced concrete was also investigated.

The high demand for concrete in the construction using normal weight aggregates such as gravel and granite drastically reduces the natural stone deposits and this has damaged the environment thereby causing ecological imbalance, there is a need to explore and to find out suitable replacement material to substitute the natural stone. In developed countries , many natural materials like Pumice ,Scoria and Volcanic debris and manmade materials like expanded blast-furnace slag, vermiculite and clinker are used in construction works as substitutes for natural stone aggregates. In India, commercial use of non-conventional aggregates in concrete construction has not yet started.

India is the third largest producer of coconut products in the world. Coconut trees are widely cultivated in the southern states of India, especially Kerala. Kerala got its name itself derived from a word, 'kera' meaning coconut tree. Kerala is densely populated state and most of its population uses coconut or it's byproducts in their daily activities. Coconut shells thus get accumulated in the mainland without being degraded for around 100 to 120 years. Disposal of these coconut shells is therefore a serious environmental issue. In thls juncture , the study on use of coconut shells as a substitute or replacement for coarse aggregates in concrete is gaining importance in terms of possible reduction of waste products in the environment and finding a sustainable alternative for non renewable natural stone aggregates.

II. Significance Of Study

In this study, coconut shell is used as light weight aggregate in concrete. The properties of coconut shell and coconut shell aggregate concrete is examined and the use of coconut shell aggregate in construction is tested. Moisture content and water absorption were 4.20% and 24% respectively and these values are more compared to conventional aggregate. Coconut shell exhibits more resistance against crushing, impact and abrasion compared to conventional aggregate. Density of coconut shell is in the range of 550-650 kg/m^3 and these are within the specified limits for light weight aggregate. There is no need to treat the coconut shell before use as an aggregate except for water absorption. The presence of sugar content in the coconut shell, as long as it is not in a free sugar form, does not affect the setting and strength of concrete. Hydration test on coconut shell fines with cement indicates that the inhibitory index for coconut shell fines with cement can be classified as low and no pre-treatment is required. Coconut shell-cement ratio has been optimized to satisfy the criteria of structural light weight concrete. Long-term investigation upto 365 days on compressive strength of coconut shell aggregate concrete for three different curing conditions, namely , laboratory curing(full water immersion W_1), simulation of the practical curing (Site curing W_2) and air-dry(no curing W_3) has been carried out. The increase in the pulse velocity and the compressive strength of coconut shell aggregate concrete is more in practical curing(W_2) followed by full water curing(W_1). Biological decay was not evident as the coconut shell aggregate concrete cubes gained strength even after 365 days. The continual increase in strength indicates that the coconut shell aggregate does not deteriorate once coconut shell aggregates are encapsulated into the concrete matrix. In a short term study, at 28days, properties of coconut shell aggregate concrete namely flexural strength, splitting tensile strength , impact resistance and elastic modulus were determined and a comparison made with control concrete. Long term investigation upto 365 days showed that the experimental bond strength of coconut shell aggregate concrete was much higher than the design bond strength as stipulated by IS 456 and BS 8110 under all types of curing conditions. The durability properties of coconut shell aggregate concrete are comparable to other conventional light weight concretes.

The flexural behavior of reinforced coconut shell aggregate concrete beams was comparable to control concrete and that of other light weight concretes. Beams with low reinforcement ratios satisfied all the serviceability VIII requirements as per IS 456 and BS 8110. Beams with shear links failed in flexure mode, while beams without shear links failed in diagonal shear modes. No horizontal cracks were observed at the level of the reinforcements, which indicates that there were no occurrences of bond failure. When coconut shell aggregate concrete is subjected to 100^{0}C for 4 Hrs and 200^{0}C for 2Hrs, its residual strengths are 18 N/mm^2, respectively. These values satisfy the criteria of structural light weight concrete strength as per ASTM C 330. Coconut shell aggregate concrete can offer 2 hours fire resistance and therefore it may be classified under type 3 constructions. Use of coconut shell aggregate concrete as structural light weight concrete is recommended. Coconut shell aggregate is a potential construction material and simultaneously reduces the environmental problem of solid.

Lightweight aggregate concrete (LWAC) is an important and versatile material in modern construction. It has gained popularity due to its lower density and superior thermal insulation properties. Many architects, engineers, and contractors recognize the inherent economies and advantages offered by this material, as evidenced by the many impressive lightweight concrete (LWC) structures found throughout the world. Lightweight concrete has strengths comparable to normal concrete; yet is typically 25-35% lighter. Structural LWC offers design flexibility and cost savings due to self-weight reduction, improved seismic structural response, and lower foundation costs. Lightweight concrete pre-cast elements offer reduced transportation and placement costs. The main characteristic of lightweight aggregate is its high porosity, which results in a low specific gravity. Although commercially available lightweight aggregate has been used widely for manufacture of LWC, more environmental and economical benefits can be achieved if waste materials can be used as lightweight aggregates in concrete. In view of the escalating environmental problems, the use of aggregates from by-products and/0r solid waste materials from different industries is highly desirable. In recent years, researchers have also paid more attention to some agriculture wastes for use as building material in construction.

III. A Glance To A Few Of Such Studies Is Added Below:

A study was made on possibility of using periwinkle shells as substitute for coarse aggregate in concrete. Compressive strength tests showed that 35.4% and 42.5% of the periwinkle shells in replacement for granite was quite satisfactory with no compromise in compressive strength requirements for concrete mix ratios 1:2:4 and 1:3:6 respectively. The corresponds to savings of 14.8% and 17.5% for 1:2:4 and 1:3:6 concrete mixes, respectively.

Agricultural industrial wastes produced after extracting palm oil from palm fruits known as palm kernel shell (PKS) are available in large quantities in Indonesia, Malaysia, Nigeria and other tropical countries. The concrete produced using PKS referred to here after as palm kernel shell concrete (PKSC) and its properties were compared with properties of normal weight concrete (NWC) of grade 30 produced using crushed granite aggregates. The fresh and hardened concrete properties such as density, workability, compressive strength of PKSC and NWC were compared. Further, structural behavior through flexural test was investigated. It has been found that PKSC has produced workable concrete and compressive strength of about 35MPa was obtained within 90 days. The addition of 10% silica fume has effect on both workability and strength. The as-cured density of PKSC was found 22% lower than the NWC. Further, the moment capacity of PKSC beams was found higher than NWC beams. In addition, the mode of failure observed in PKSC was ductile compared to the brittle failure of NWC beams.

("*Development of lightweight concrete using industrial waste material, palm kernel shell as lightweight aggregate and its properties", Alengaram, U.J.Dept. of Civil Eng., Univ. of Malaya, Kuala Lampur, Malaysia)*

- An investigation carried out on the comparative cost analysis and strength characteristics of concrete produced using crushed ,granular coconut and palm kernel shells as substitutes for conventional coarse aggregate. The results of the tests showed that the compressive strength of the concrete decreased as the percentage of the shells increased. However, concrete obtained from coconut shells exhibited a higher compressive strength than palm kernel shell concrete in the two mix proportions. The results also indicated cost reduction of 30% and 42% for concrete produced from coconut shells and palm kernel shells, respectively. Considering the strength/economy ratio, it was concluded that coconut shells were more suitable than palm kernel shells when used as substitute for conventional aggregates in concrete production.

("Comparative study of concrete properties using coconut shell and kernel shell as coarse aggregates")

- The properties of concrete using coconut shell as coarse aggregate were investigated in an experimental study. Compressive , flexural , splitting tensile strengths , impact resistance and bond strength were measured and compared with the theoretical values as recommended by the standards. For the selected mix , two different water-cement ratio's have been considered to study the effect on the flexural and splitting tensile strengths and impact resistance of coconut shell concrete.
- The bond properties were determined through pull-out test. The results showed that coconut shell concrete can be classified under structural lightweight concrete.

("*Mechanical and bond properties of coconut shell concrete"*,
K. Gunasekaran P.S Kumar, M. Lakshmipathy, Department of Civil Engineering, Faculty of Engineering and Technology, University, Kattankulathur, TamilNadu,India).

- Coconut shell as aggregate and grained palm kernel as fine aggregate will be employed to replace the conventional aggregates in concrete. The parameters tested were flexural strength , compressive strength ,tensile strength ,modulus of Elasticity, durability and deflection crack behavior. The effect of using different length of natural material aggregate was also investigated. The effect of aggregate content to workability was also examined. The outcome of the study showed that the combination of coconut shell and palm kernel has potential as lightweight aggregate in concrete.

("Investigate the combination of coconut shell and grained palm kernel to replace aggregate in concrete: A technical review".
Siti Aminah BtTukiman and Sabarudin Bin Mohammed, Faculty of Civil Engineering and Earth Resources, University Malasiya Pahang*)*

From the research works reviewed above, we can understand that coconut shells can be successively used as a substitute for coarse aggregate in concrete. We focused our study on finding out the optimum range of replacement of coarse aggregate based on its strength properties. We also planned to extent our work in terms of cost efficiency of commercially produced coconut shell concrete.

IV. Materials and Methods

The constituent materials used in this investigation were produced from local sources. Portland Pozzolana cement of PPC 53 grade conforming to both the requirements of IS: 12269 and ASTM C 642-82 type I was used . Fly ash used in this investigation was procured from local suppliers. Chemical composition of the materials is presented in the table 1 along with specific gravities of the materials. Normal aggregate, that is ,crushed blue granite of maximum size 20mm was used as coarse aggregate. Well graded river sand passing through 4.75mm was used as fine aggregate. The specific gravities of coarse and fine aggregates were 2.65 and 2.63 respectively. The freshly discarded Coconut shells were collected from a local oil mill. The coconut shells were crushed using concrete hammers to a size such that it passes through a 20mm sieve and retained on 4.75mm sieve. Crushed shells were washed to remove fibres, mud,etc from them. The washed shells were dried in sunlight for 2 days. The crushed edges were rough and spiky. The surface texture of the shell was fairly smooth on concave and rough on convex faces. Coconut shell aggregates used were in saturated surface dry(SSD) condition. Further broken the shells into small chips manually using hammer and sieved through 12mm sieve. The material passed through 12mm sieve was used to replace coarse aggregate with coconut shells. Water absorption of the coconut shells was 8% and specific gravity at saturated surface dry condition of the material was found as 1.33.

The six mixes were employed in order to investigate the properties of concrete shell concretes. Control mix(M1) that is ,without CS was made. Coarse aggregate was then replaced with CS in 10(M2), 15(M3), 20(M4) percentages to study the effect of replacement. Furthermore, a mix with both CS and fly ash (M5) was also employed , in which ,20% of CS was replaced with aggregate and 25% of fly ash was replaced with cement. M6 mix contained 20% of coconut shells and 5% of fly ash both replaced with aggregate. Free water to cement ratio was maintained constant at 0.6 for all concrete mixes. Extra water was added in the mixes depending on the CS replacement to compensate water absorption of the CS particles. The various tests such as workability test, compressive strength test, flexural strength test and split tensile strength tests were conducted.
A nominal mix of 1:2:4 was used and four different mixes were made with 0%,25%,50%,100% replacement of coarse aggregate with coconut shells.

V. Results And Discussions

Properties of fresh concrete

Visual observations during mixing and compaction of all the concretes suggested that the concretes were homogenous ; there was no segregation and bleeding , the mixes were compactable. The fresh state performance of the CS concretes was comparable with control concrete. The concretes had low slump ,the slump values of the concretes were between 20-26 mm. The slump decreased with increase in CS percentage. However, for M5 mix, in which ,the cement content was replaced with 5% fly ash and had 25% CS shown little better performance over M4. Furthermore , for M6 mix, in which , the total aggregate was replaced with 5% of fly ash and had 25% CS shown highest slump value. This observation suggests that addition of CS decreases workability and addition of fly ash either as cement replacement or aggregate replacement increases workability in CS concrete. The decreased workability of CS concretes may be due to CS particle shape. Flat shaped CS particles could have restricted overall movement of the aggregate particles and thus reduced workability. The workability was found to be increasing with increase in the replacement percentage of aggregates with coconut shell. Coconut shell concrete probably has better workability due to the smooth surface on one side of the shells and also due to the smaller size of coconut shells compared to conventional aggregates.

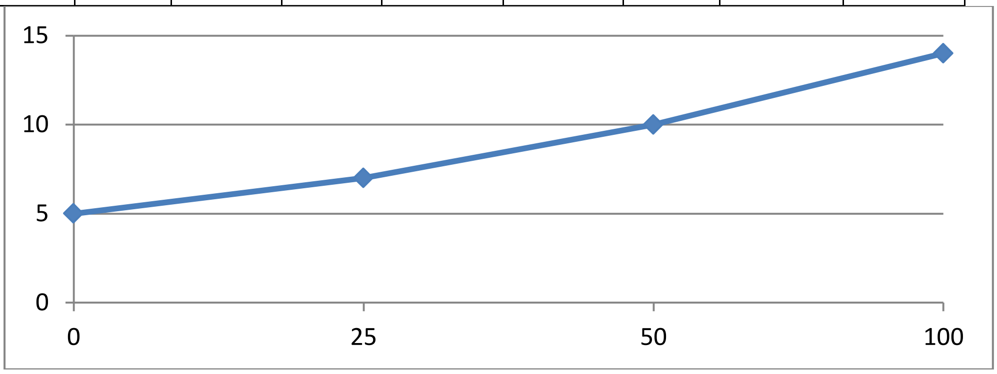
The 25% replacement mix got an average compressive strength of 22.62 MPa which is about 94.25% strength of normal concrete(24MPa). Likewise ,we got a compressive strength of 14.93 MPa and 5.48 MPa for 50% and 100% replacement respectively. The result shows that coconut shell concrete can be even used in high strength applications with replacements within or around 25%. Further we can use higher percentage replacement for non load bearing structures. An examination of the failure surfaces showed the breakage of the Coconut shell aggregate, indicating shell strength had a strong influence on the resultant concrete strength. The flexural strength was found to be 80.6% (4.32 MPa) and 44.8%(2.40MPa) of normal concrete flexural strength (5.36MPa) for 25% and 50% replacementmixes respectively. The 100% replacement concrete mix showed negligible flexural strength. The beam cast with 100% replacement concrete mix showed negligible flexural strength. The beam cast with 100% coarse aggregate replaced with coconut shells broke under its self weight itself. The flexural strength percentages are slightly lower than compressive strength percentages. In concrete with conventional aggregates, the failure in tension occurs as result of breaking of bond between the matrix and the surface of the aggregate used or by fracture of the concrete matrix itself. Thus the surface properties of coconut shells also pay an important role in determining the flexural properties of concrete. The 25% replacement mix got an splitting tensile strength of 2.22MPa which is about 89.5% strength of normal concrete (2.48MPa). Likewise we got a splitting tensile strength of 1.27 MPa and 0.495 MPa for 50% and 100% replacement respectively. The reduction in self weight was found to be 9.56%,19.16%,38.32% when 25%,50% and 100% of coarse aggregate was replaced by coconut shell respectively.

Coconut shells were used as a source of fuel for burning in olden days. In this modern era where olden burning procedures are replaced by cooking gas, electrical furnaces, etc. Hence, coconut shells are available practically of no cost. Moreover the availability of coconut shell on a local basis is in abundance. So we can produce concrete with more than 90% strength of conventional concrete with lower cost of production. A reduction in cost of 4.45%, 8.90% and 17.81% was found when 25%, 50%and 100% of coarse aggregate was replaced was replaced by coconut shell.

There may be a possibility to increase of CS replaced concrete. The coconut shells need to be cleaned thoroughly and make them free from fiber and husk on the surface. Size of the CS particles should be nearly equal to the thickness of the CS particle, that is, the ratio between the lateral dimensions of CS particle and thickness should be nearly equal to one. The particles with decreased size may avoid problems associated with shape and thus improve bonding between the aggregate particles and cement paste. Increased bond between the particles may increase surface area and may lead to increased water demand and may cause strength reduction. In the present investigation the free water to cementitious ratio was 0.6. However, with the help of water reducing admixtures, if water to cementitious materials ratio can be reduced, then, it may be possible to increase strength of CS replaced concretes. Further investigation is clearly needed to assess particle size effect and effect of water to cementitious ratio on CS concretes.

Table: 1. Properties of Concrete with Coconut Shells as Aggregate Replacement

Mix name	Slump mm	Density Kg/m^3	Compressive strength MPa			Split Tensile Strength MPa		
			1 day	7 day	28 day	1 day	7 day	28 day
M1	25	2365	6.84	11.11	22.33	0.38	0.76	2.39
M2	23	2186	3.2	5.16	13.56	0.19	0.95	1.51
M3	22	2117	3.56	7.29	12.56	0.45	0.45	1.35
M4	20	2061	3.91	7.82	9.33	0.25	0.25	1.15
M5	23	2027	2.22	3.17	7.22	0.19	0.19	0.8
M6	26	2023	3.40	5.56	9.67	0.32	0.32	1.08

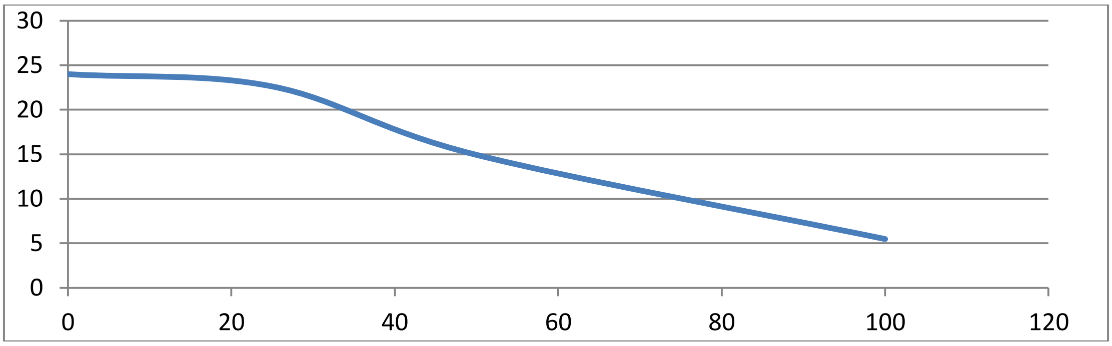


% Replacement of coarse aggregates

Fig.1Variation of Workability (slump in mm)with increase in replacement percentage

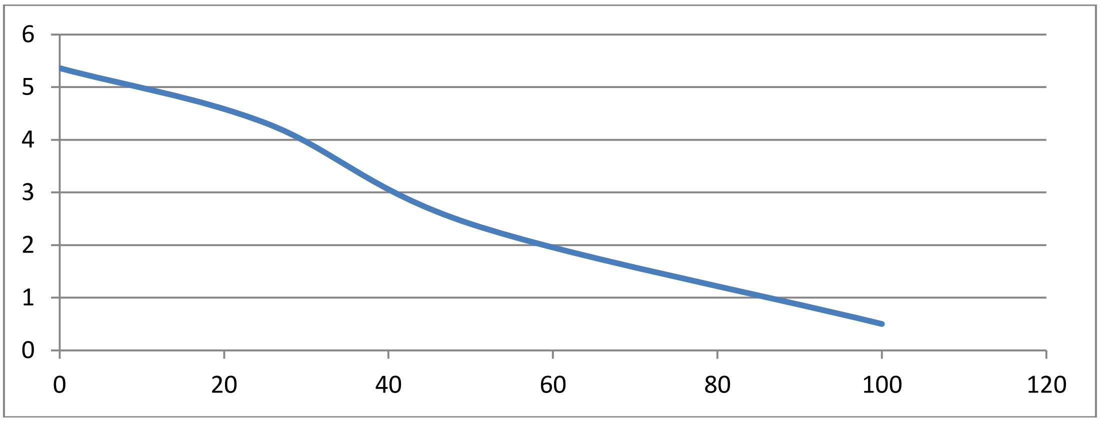
Table: 2. Compressive strength of CSc cube samples

% Replacement of aggregates	Trial No.	Load(KN)	Compressive strength(Mpa)	Average Compressive strength(Mpa)
0	1	513	22.80	24.00
	2	531	23.60	
	3	576	25.60	
25	1	548	24.35	22.62
	2	490	21.78	
	3	489	21.74	
50	1	365	16.22	1493
	2	330	14.80	
	3	310	13.78	
100	1	105	4.67	5.48
	2	130	5.78	
	3	135	6.00	



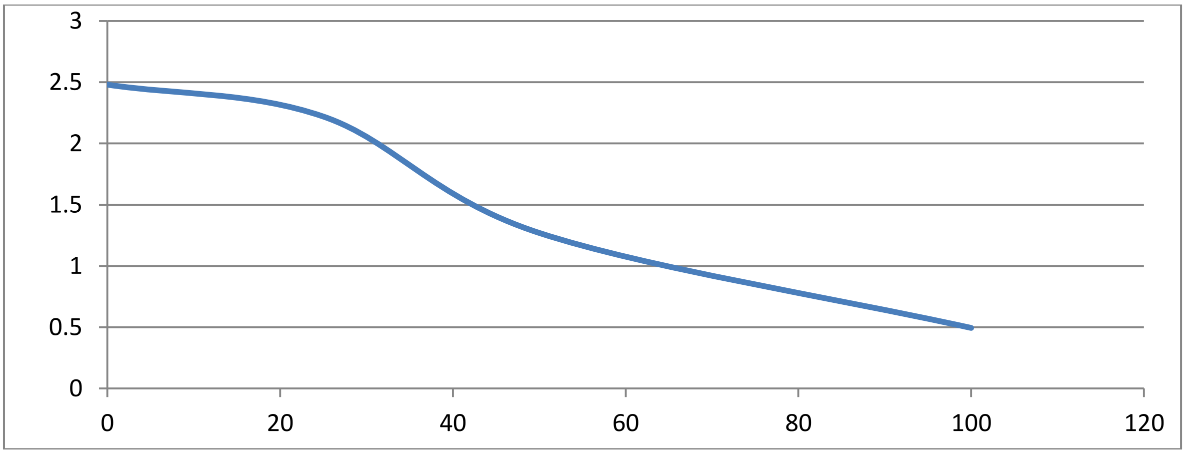
% Replacement of coarse aggregates

Fig.2 Variation of Compressive Strength with respect to % replacement of coarse aggregate



%Replacement of coarse aggregates

Fig. 3 Variation of Flexural Strength with respect to % replacement of coarse aggregate



% Replacement of coarse aggregates

Fig.4 Variation of Split Tensile Strength with respect to % replacement of coarse aggregate

Cost Efficiency

% replacement of coarse aggregate	Cost of components in concrete of 1m^3 volume in KN (mix 1:2:4)				Cost of 1m^3 of concrete (INR)	% reduction in cost
	Cement	Fine aggregate	Coarse aggregate (normal)	Coarse aggregate (coconut shell)		
0	2142.00	1713.60	835.70	0.00	4691.30	-
25	2142.00	1713.60	626.84	0.00	4482.44	4.45
50	2142.00	1713.60	418.08	0.00	4273.68	8.90
100	2142.00	1713.60	0.00	0.00	3855.60	17.81

VI. Conclusion

In our study, we replaced coarse aggregate with coconut shell, by volume. Specimens were cast by replacing 25%,50%,75% and 100% of coarse aggregate with coconut shells. Tests were conducted on the cast specimens after 28 days as mentioned in the IS code. Tests for workability, flexure, compression and split tensile strength were conducted and results were obtained. Coconut shell concrete has better workability because of the smooth surface on one side of the shells and the smaller size of coconut shells. So we could possibly use coconut shell concrete in concretes where high workability is desirable. The flexural strength of CSC is approximately 5.36N/mm^2, 4.32N/mm^2, and 2.4N/mm^2 for specimens replacing 25%,50%,100%, of coarse aggregate respectively. But in case of 100% replacement of coarse aggregate flexural strength was not obtained as the specimen failed under its self weight. Its corresponding compressive strengths were obtained as 24N/mm^2,22.62N/mm^2,14.93N/mm^2 and 5.48N/mm^2. The splitting tensile strength of CSC was obtained as 2.48N/mm^{2}2.22N/mm^2,1.27N/mm^2 and 0.495N/mm^2 respectively. From the above results we can see that in CSC where 25% of the coarse aggregate is replaced, shows properties similar to the nominal mix and 50% replaced CSC shows properties similar to light weight concrete which can be used as filler materials in framed structures, flooring tiles, thermal insulating concrete etc.

The main points of this study are:

1. Addition of CS decrease workability and addition of fly ash either as cement replacement or aggregate replacement increases workability of CS concrete. Increase in CS percentage decreased densities of the concretes.
2. With CS percentage increase the 7 day strength gain also increased with corresponding 28 day curing strength. However, the overall strength decreased with CS replacement when compared to control concrete. Furthermore, fly ash as cement replacement had negative influence when compared to corresponding CS concrete and fly ash as aggregate replacement had similar performance as that of corresponding CS replaced concrete.
3. Similar to compressive strength, the split tensile strength also decreased with increase in CS replacement. Furthermore, for 28 days of curing addition of fly ash as cement replacement reduced overall split tensile strength of CS concrete and fly ash addition as aggregate replacement showed no major difference with corresponding CS replaced concrete(M4).
4. The results demonstrated that, irrespective of CS percentage replacement there was good relationship between compressive strength and split tensile strength. The equation proposed by Raphael, 1984[19] for normal concrete was over predicting at lower strengths for CS concretes.
5. Increase in CS replacement permeable voids also increased. With 10% CS replacement the permeable were 30 percent higher than control concrete. Similarly, the permeable were 30 percent higher than control concrete. Similarly, the permeable voids were 88 percent higher than control concrete for20% CS replacement. Addition of fly ash as cement replacement increased permeable voids with corresponding CS concrete (M4). However, addition of fly ash as aggregate replacement reduced permeable voids.
6. The absorption characteristics show that the initial 30 min absorption values for all the concretes were lower than limits commonly associated with good quality concrete [21]. The maximum absorption was 2.3% for the concrete having 20% CS and 25% fly ash as cement replacement. Fly ash as cement replacement increased water absorption and fly ash as aggregate replacement did not show any marked difference with corresponding CS replaced concrete.
7. Sorptivity of the concretes was higher than control concrete for all CS concrete. The maximum sorption was 0.18mm/s0.5 for the concrete having20% CS and 25% fly ash as cement replacement. Similar to absorption, fly ash as cement replacement increased sorption and fly ash as aggregate replacement did not show any marked difference with corresponding CS replaced concrete.

Future scope of the project : Our study had many limitations, of which the time was a major concern. The durability properties of coconut shell concrete are to be rested before practically applying our project. Durability tests on CSC which may take around a year to complete can be conducted as a future work. The strength properties of CSC depend on the aggregate properties of coconut shells and its individual strength characteristics. Experiments on impact value, crushing value etc can be done in order to analyze the strength properties of coconut shells. When CSC is used along with reinforcement , the surface bonding between coconut shell aggregates and steel comes into play. Therefore study about bond properties of these can be useful. Furthermore the action of coconut shell aggregates in cement matrix is also an area requiring future research. We can also study about the use of coconut shell aggregates along with other non-conventional aggregates like palm kernel shells, coir pith, volcanic debris,etc.

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