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Behaviour of Fiber Reinforced Coconut Shell Concrete

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Abstract: **In recent days, the notable contribution of using waste materials in place of conventional coarse aggregate in concrete has gained significant attention to make the concrete sustainable building materials. Coconut Shell (CS) is one such agricultural solid waste material found in many countries around the globe including India. In India, more than 23904 million coconut nuts have been produced in 2016–2017 which is about 30 % of world coconut production followed by Indonesia. The large production of coconut shell simultaneously increases agricultural waste. When coconut shell is used as an alternative coarse aggregate in concrete production, numerous advantages such as reducing the environmental burden as well as the cost of concrete production can be gained. Past researches on CS revealed that CS could be considered as a suitable alternate for crushed stone aggregates for the production of sustainable eco-friendly lightweight concrete known as coconut shell concrete. However, the utilization of CS concrete in reinforced cement concrete element is not practiced due to its week durability characteristics and low tensile strength. The replacement of a significant portion of cement by fly ash and the addition of fiber has been effective measures to solve durability and tensile strength issue respectively. The initial task is to find out the optimum replacement of cement by class F fly ash. The next task in developing CS fiber reinforced concrete is the selection of suitable fibers. In this research, fibrillated polypropylene (PP) fibers and steel fibers were used in the CS concrete to explore the effects of fibers on the mechanical characteristics of fiber reinforced CS concrete and thus to choose the appropriate fiber. This would facilitate to investigate the effect of fibers addition on the mechanical characteristics and flexural behaviors of CS concrete. Among the two types of fiber reinforced CS concrete developed, the steel fiber on CS concrete performed well in terms of mechanical properties than polypropylene fibers. Hence, the flexural characteristic of steel fiber reinforced CS beams with 0.25, 0.50, 0.75 and 1.0% were investigated in this study. All the steel fiber reinforced CS concrete beams showed a typical flexural failure. The steel fibers addition increased the ultimate moment carrying capacity of the SFRCS concrete beams by 5-14% in CSF mix and 3-17% in CSP Mix. It can be concluded that fiber reinforced CS concrete with fly ash is suitable to be utilized as a sustainable eco-friendly construction material in the production of structural concrete**

Key Words: Coconut Shell (CS), durability and tensile strength, fly ash, crushed stone aggregates.

I. INTRODUCTION

Concrete is acknowledged to be the most widely used construction material in most parts of the globe. Concrete is also one of the most widely consumed materials by mankind in the modern world, second only to fresh water (Aitcin 2000). Its production involves large quantities of natural resources. The strength, durability and low maintenance cost of concrete make its usage inevitable in establishing the infrastructure of the construction industry. Simultaneously the growth of construction industry must aim at a sustainable construction that plans to meet present-day requirements.

1.2 ENVIRONMENTAL SUSTAINABILITY

Environmental sustainability is the key requirement of the construction industry. It may be interpreted as the ability to indefinitely retain the rates of renewable resource use and non-renewable resource depletion. For most nations, organisations and people who consider its importance, sustainability means the conservation of the earth and basic issues related to improvements, such as the productive utilisation of resources, stable economic growth, consistent social advance and poverty elimination. Ramezanianpour *et al.* (2013) reported that the current stage of the construction sector is unsustainable. To address this problem, recent researchers have been working on the use of recycled aggregate in concrete production (Guo *et al.* 2014; Richardson *et al.* 2011 and Thomas *et al.* 2014). Huge energy is required for crushing in processing recycled aggregate from demolition waste, and this process emits CO_2 into the atmosphere. Hence, present concrete production needs the use of alternate coarse aggregates, which should be a renewable source and eco-friendly. The use of agricultural solid waste might fulfil both criteria. Teo *et al.* (2007) have stated that this environmental sustainability can be achieved by using solid wastes and by-products of different industries as coarse aggregates. Cement and concrete production industries are also widely regarded as one of the major contributors to global warming, due to their energy intensive and high carbon dioxide (CO_2) footprint resulting their production. It is almost impossible to make concrete as a carbon-neutral material due to the high amount of cement used in its production. Each metre cube of concrete may contain between 200 to 1,200 kilograms of cement in its content. Cement production industry contributes not less than 5% of the anthropogenic emission of the total 25% of global CO_2 emission from the industrial sector. In addition, research has also shown that 85% of the CO_2 emission contributed through the life cycle of concrete structures comes directly from cement production (Lim *et al*. 2018 and Habert & Roussel 2009). An approach to reduce the reliance on cement inconcrete production is by introducing locally sourced by-products as supplementary cementitious material and other low carbon footprint materials in the production of concrete. Replacing conventional coarse aggregate and reducing the cement content in concrete help to minimise the usage of natural resources thereby aids to maintain the environmental sustainability.

1.3 LIGHTWEIGHT CONCRETE

Structural Light Weight Concrete (LWC) has a density of less than 2000 kg/m^3 and compressive strength of greater than 20 N/mm^2 (BS 8110-1997). Lightweight concrete is a versatile construction material, which contains scope for scientific, economic and eco-friendly advantages and is bound to turn into a prevalent construction material in the new millennium (Haque *et al.* 2004). The most popular method in LWC production uses lightweight coarse aggregate and normal weight sand for fine aggregate (Boyd *et al.* 2006). Aggregates having particle density not exceeding 2000 kg/m^3 and loose bulk density not exceeding 1200 kg/m^3 are defined as lightweight aggregate (EN 13055 Part1, 2002). According to ACI 213R (1987), aggregates with a dry loose density not exceeding 880 kg/m^3 is classified as lightweight aggregate (LWA). Aggregates having a particle density on a dry basis lesser than 2100 kg/m^3 and greater than 500 kg/m^3 is known as LWA as per IS 2758-Part 1 (1998). LWAC exhibits certain advantages over other types of concrete, such as lower dead weight, reduced seismic forces, lighter formwork, smaller size foundation, increased fire resistance, thermal insulation, better sound absorption, increased frost resistance, improved hydration and ease of transport. Structural lightweight concrete can be produced by replacing conventional aggregates with alternative lightweight aggregates, such as pumice, blast-furnace slag, vermiculite, expanded clay, clinker, foamed slag and OPS (Alengaram *et al.* 2013).

1.3.1 COCONUT SHELL

Coconut shells are available abundantly in many coconut growing countries around the globe, including India. Global production of coconut is 67 billion nuts from an area of 17 million hectares. According to the Ministry of Agriculture and Farmer‟s Welfare of India, more than 23904 million coconut nuts have been produced in India in 2016–2017 which is about 30 % of world coconut production followed by Indonesia (Coconut Development Board, 2018). Figure 1.1 shows the coconut nuts production around the world.

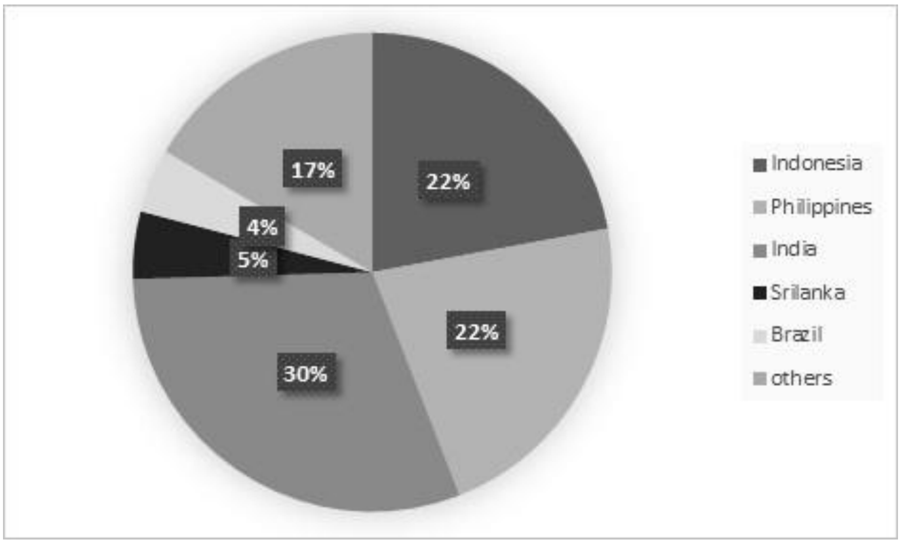


FIGURE 1.1 COCONUT SHELLS AVAILABILITY

This large production of coconut shell simultaneously increases agricultural waste. Figure 1.2 shows the discarded coconut shell. If coconut shell is used as an alternative coarse aggregate in concrete, it will provide numerous advantages such as reducing the environmental burden as well as the cost of concrete production. Olanipekun *et al.* (2006) have suggested that an approximate cost reduction of 30% can be achieved if the coconut shell is usedto replace gravel in concrete. Coconut shell concrete also contributes in terms of economy for low-income families (Gunasekaran *et al.* 2013a). Coconut shell reduces the reliance on natural resources for concrete making. Further, the recycling and disposal of coconut shell waste in concrete become easy and beneficial. Hence, it may be considered as an effective eco-friendly concrete material. According to Basri *et al.* (1999), the organic origin of wood-based material will not contaminate or leach to produce toxic substances once if they are incorporated into the concrete matrix. It has been observed that the bond between coconut shell aggregate and cement composite is compatible and no pretreatment is required, and it is low inhibitory. The durability properties of coconut shell concrete are comparable to that of other conventional lightweight concretes (Gunasekaran *et al.* 2015). The coconut shell concrete has exhibited better workability and impact resistance when compared with conventional concrete (Gunasekaran *et al.* 2011). As coconut shell is a lightweight aggregate, it reduces concrete density, thereby reducing the dead load of the structure. Lightweight concretes also result in reduced microcracks due to its lower stiffness and enhanced durability in the severe environment by the uniformdistribution of cracks at the micro level (Shafigh *et al.* 2014). Coconut shell coarse aggregate helps to enhance the sound absorption coefficient in lightweight concrete, compared with normal weight concrete (Umoh & Ekop 2013).

FIGURE 1.2 DISCARDED COCONUT SHELL

1.4 FLY ASH

In this study fly ash, an industrial waste generated during the combustion of coal in thermal power generation units is used as a partial replacement material for cement. Figure 1.3 shows the fly ash generated from the power plant. The environmental load contributed by fly ash and its disposal as industrial waste, have posed challenges to the power generation industry. The utilization of fly ash in concrete not only resolves its disposal challenges but alsoreduces greenhouse gases emission into the atmosphere. Replacement of a significant portion of the cement by fly ash can effectively reduce carbon emission associated with the cement and concrete manufacturing industry. As fly ash possesses suitable physical, chemical and mineralogical properties, it produces a promising performance in concrete. Further, the spherical nature of fly ash particles significantly aids to reduce the water-cement ratio of concrete. Evolving researches have shown that concrete having a high volume of class F fly ash indicates excellent mechanical and durability properties such as low permeability to chloride ion and other aggressive agents (Dinakar *et al.* 2008). Total replacement of cement with fly ash is not feasible for concrete production unless an activation agent is introduced in the mix. When fly ash is added partially, it reacts with calcium hydroxide, a compound released during hydration of cement in concrete. This reaction forms a cementitious binder phase which is responsible for the strength development of concrete (Mehta 2004). Hence, for high-strength concrete it is suggested that the fly ash replacement level will be in the range of 15%–25% (ACI Committee 211.4R-08, 2008). The pozzolnic quality and low CaO consistence of fly ash result in better workability, permeability, cohesiveness and finishing strength in concrete.

FIGURE 1.3 FLY ASH

1.4.1 Class F Fly Ash

Burning of harder, older anthracite and bituminous coal typicallyproduces Class F fly ash. This fly ash is pozzolnic in nature and contains less than 10% lime (CaO). Possessing pozzolnic properties, the glassy silica and alumina of class F fly ash requires a cementing agent, such as Portland cement, quicklime or hydrated lime, with the presence of water in order to react and produce cementitious compounds. Alternatively, the additions of a chemicalactivator such as sodium silicate (water glass) to a Class F ash can lead to the formation of a geopolymer

1.4.2 CLASS C FLY ASH

Fly ash produced from the burning of younger lignite or sub- bituminous coal, in addition to having pozzolnic properties, also have some self-cementing properties. In the presence of water, class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime in the form of (CaO). Unlike Class F fly ash self-cementing class C fly ash does not require an activator. Alkali and sulphate (SO_4) contents are generally higher in class C fly ashes.

1.5 FIBERS AS SECONDARY REINFORCEMENT IN CONCRETE

The concept of adding fibers to improve brittle material behavior is ancient. For example, Mesopotamians used the straw to reinforce unbaked bricks. This ancient technology is still used to improve concrete characteristics. Though cement concrete has many advantages such as good compressive strength, stiffness, low thermal conductivity, low combustibility and toxicity, thedisadvantages which limit its usage due to its brittle nature and poor tensile strength. However, these shortcomings are overcome due to the developments of Fiber Reinforced Concrete. Concrete reinforced with natural or artificial fibers was known as fibro concrete. The shrinkage and heat of hydration developed in the concrete lead to breaking and cracking during setting and hardening periods. The shrinkage cracks in concrete cannot be completely avoided but by using fibers of high tensile strength, it can be substantially reduced and it improves the strength of the concrete also. The effect of fibers ceases after a time when the increasing value of modulus of elasticity concrete exceeds the modulus of elasticity of fibers. In the case of simultaneous use of two different hybrid fiber reinforcements, the synergy between the two fibers enhances the characteristics of concrete further. Nowadays, fibers are produced from different materials such as steel, glass, carbon, and synthetic material.

1.5.1 POLYPROPYLENE FIBERS

Due to the high modulus of elasticity, high strength, excellent ductility, excellent durability and low price, polypropylene fiber is often used in cement and concrete to improve the ductility and anti-cracking performance of the matrix concrete. Past researches conclude that polypropylene fibers have a significant improvement on mechanical properties of concrete. Concrete reinforced with polypropylene fibers shows smaller absorption and permeability, increased frost and abrasion resistance as well as good durability under dynamic load. Kakooei *et al*. (2012) reported that the compressive strength of concrete improved proportionately for the increase in the volume of polypropylene fibres. Zhang & Li (2013) stated that the addition of polypropylene fiber decreases the length of water permeability, drying shrinkage, carbonation depth of concrete with the increase of volume fraction. It also increases the freeze and thawresistance of concrete. Yew *et al*. (2015) showed that the inclusion of polypropylene fibers improved the post-failure toughness of concrete.

1.5.2 STEEL FIBERS

The incorporation of steel fibers in concrete is known to substantially increase the ductility of concrete, especially under tensile loading. The use of fibers on the improvement of flexural toughness, impact resistance and related parameters is well established. The application of steel fibers in different types of concrete, such as normal weight concrete, lightweight concrete, high strength concrete, ultra-high performance concrete and self-compacting concrete has altered the design philosophy of reinforced cement concrete. Past researches stated the influence of steel fibers on the improvement of the properties, such as mechanical properties, shrinkage, freeze-thaw resistance, modulus of rupture, deflection capacity, energy absorption, fatigue strength, toughness, shear strength, torsion strength, impact resistance, and fire resistance. Further, studies on the influence of steel fibers in lightweight concrete using lightweight aggregates such as expanded clay aggregate, sintered fly ash aggregate, natural pumice and oil palm shell were reported.

1.6 RESEARCH OBJECTIVES

- To study the effects of fly ash as partial cement replacement for cement on the mechanical and durability characteristics of CS concrete.
- To investigate the effect of polypropylene fibres on fresh and mechanical properties of CS concrete.
- To study the influence of incorporation of steel fibres on fresh and mechanical properties of CS concrete.

- To evaluate the flexural behaviour of steel fibre reinforced CS concrete and to compare with the CS concrete without fibre.

2.0 MECHANICAL AND DURABILITY CHARACTERISTICS OFCOCONUT SHELL CONCRETE

2.1.1 **Preparation of coconut shell aggregate**

After removing the copra from the coconut, the coconut shells become a waste and discarded section. This discarded waste coconut shell is collected from local copra preparation drying yard (Figure 3.1a) and washed thoroughly to remove the iron content from the surface of the coconut shell. The concave part of coconut shell is smooth but the convex part is rough due to the presence of coconut fiber and husks. Hence for better workability, the fibers and husks in the convex side of coconut shell are removed before crushing. This is similar to the practice by Gunasekaran *et al.* (2012). Since different species of coconut shells are processed together, the shells are found to have varyingthicknesses, in the range of 2 – 5 mm (Figure 3.1 b). Due to high water absorption of CS, it is necessary to mix at saturated surface dry (SSD) condition based on 24 hours' submersion in potable water. No pre-treatment is required for the shells except this water submersion process.


(a) (b)

Figure 3.1 (a) Coconut shell and (b) Coconut shell aggregate

2.1.2 PHYSICAL AND MECHANICAL PROPERTIES

As per the Bureau of Indian standards, the necessary tests on coconut shell (CS) and on conventional aggregates were conducted and the results are given in Table 3.1. The size of coconut shell aggregate in the range of 4.75 mm to 12.5 mm attributes to best packing density (Jayaprithika & Sekar 2016). The gradation of coconut shell aggregate covers 4.75 mm to 12 mm in order to get maximum packing density. The length of coconut shell aggregate is restricted to 12 mm due to its flaky nature. The normal moisture content and absorption of water for the CS are 4.5% and 25% respectively. It is well known that LWA is permeable and therefore have excessive water retention. The water absorption is generally in the range of 3 - 15% for most LWA such as manufactured aggregates, (Newman 1993). OPS have a water absorption value of around 23.32% (ASTM C78-84). CS has water absorption about 25%. Other LWA having similar water absorption values include cold-bonded pelletized LWA, which have an absorption value of 20.8 - 34.4% (Chi *et al.* 2003) and volcanic pumice, which have values of around 37% (Hossain 2004).

Physical and mechanical properties		**CS**	**Crushed granite**	**River sand**
Maximum size (mm)		12.5	12.5	-
Moisture content (%)		4.5	-	-
Water absorption (24 hrs.) (%)		25	0.20	-
Specific gravity	SSD*	1.06 -1.18	2.82	2.5
	Apparent	1.30 -1.45	2.8	-
Impact value (%)		8.2	13.40	-
Crushing value (%)		2.2	18.80	-
Abrasion value (%)		1.6	15.8	-
Bulk Density (kg / m^3)	Compacted	650	1650	590
	Loose	550	1450	-
Voids (%)	Compacted	38.1	41.5	-
	Loose	47.7	48.6	-
Fineness modulus		6.32	6.76	2.76
Shell thickness (mm)		2 - 8	-	-

TABLE 2.1 PROPERTIES OF CS, CRUSHED GRANITE, AND RIVER SAND

2.1.3 CHEMICAL PROPERTIES

The chemical properties of CS fine particles passed through IS sieves 9, 15 and 30 were studied by Gunasekaran *et al*. (2012) and presented in this section. The results reported that in all the sizes of CS fines, only very few variations were found in almost all the parameters as shown in Table 3.2. As CS fines particles does not have much impact on the chemical properties, CS fines passed through IS sieve 15 were taken for the study on chemical properties ofCS with different treatment of soaking periods such as 30 min, 1 h, 2 h, 24 h, 48 h and hot water soaking for 2 h respectively. It is found that in every one of the treatments of CS fines, there is not much variation in the results of almost all the parameters as shown in Table 3.3. The results of treatment with various soaking periods show that there is not much variation from samples without treatment also. No variations in results are noticed in all the parameters in both treated and untreated CS fines. This exhibits that the sugar present in CS is not active in reacting with other ingredients of concrete, to alter the setting action. Therefore, it is concluded that no pretreatment of CS is required for using as an aggregate inconcrete.

Parameter	**IS sieve No 30 size sample**	**IS sieve No 15 size sample**	**IS sieve No 9 size sample**
Glucose (%)	1.92	1.94	2.01
Fructose (%)	2.85	2.89	2.91
Sucrose (%)	14.82-16.62	14.81	16.62
Reducing sugar (%)	7.55	7.55	7.55
Total phenols (%)	5.88	6.68	8.18
Ash (%)	0.60-0.70	0.60-0.70	0.60-0.70
Cellulose (%)	32.44	32.58	32.88
pH	6.00-6.50	6.00-6.50	6.00-6.50

Table 2.2 Chemical analysis of CS without treatment (Gunasekaran 2012

Time in hours	**Hydration Temp in °C of cement**	**Hydration Temp in °C of cement with CS fines**	**Time in hours**	**Hydration Temp in °C of cement**	**Hydration Temp in °C of cement with CS fines**
0	88	76	12.5	51	49
0.5	33	33	13	51	44
1	38	36	13.5	51	44
1.5	38	36	14	51	44
2	39	37	14.5	49	42
2.5	39	37	15	49	42
3	46	37	15.5	49	41
3.5	46	37	16	47	42
4	48	40	16.5	47	39
4.5	48	45	17	42	38
5	51	45	17.5	42	38
5.5	51	46	18	42	38
6	65	49	18.5	42	36
6.5	69	49	19	42	36
7	73	55	19.5	40	37
7.5	72	56	20	40	37
8	69	56	20.5	40	36
8.5	69	56	21	38	36

9	69	58	21.5	37	35
9.5	65	60	22	37	35
10	65	63	22.5	37	32
10.5	65	62	23	35	32
11	62	60	23.5	35	30
11.5	58	52	24	33	30
12	58	51			

Table 2.3 Hydration test results

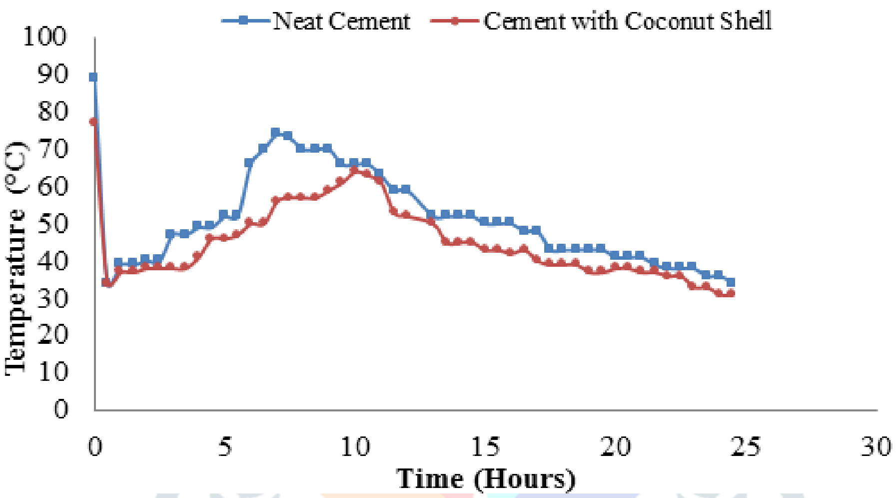


Figure 2.1 Hydration temperature vs time

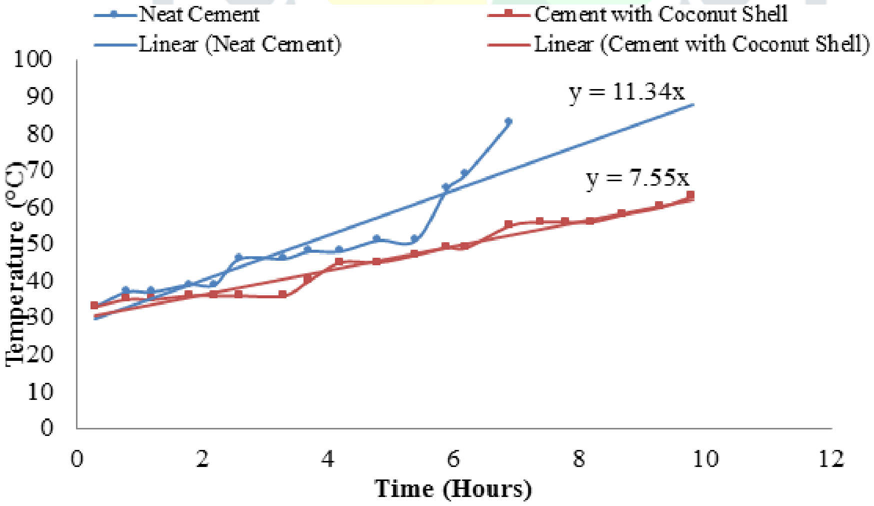


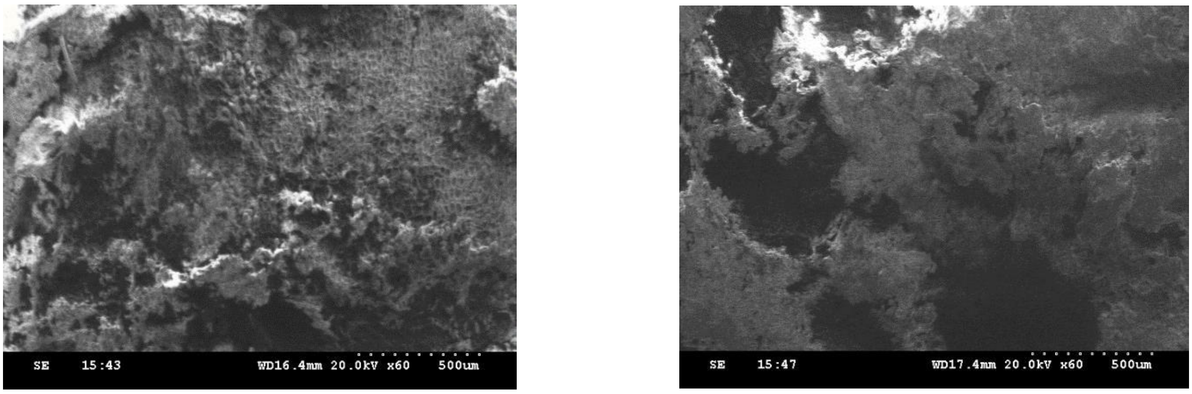
Figure 2.2 Maximum slope of hydration temperature

Parameters	Cement	Cement with CS fines	Normal range
Normal consistency (%)	31	38	26 - 33
Setting Time			
(i) Initial setting time (min)	76	88	Not less than 30
(ii) Final setting time	7 h10 min	9 h 50 min	Not more than 10 h
Compressive strength (N/mm^2)			
(i) 3 days	28.12	22.89	27.00
(ii) 7 days	38.26	28.78	37.00
Hydration test			
(i) Maximum hydration temperature (°C)	73	63	Greater than 60
(ii) Maximum slope (°C/ h)	11.35	7.55	-----
Inhibitory index (I) %	2.59	I < 10 Low I = 10-50 Moderate I = 50-100 High I >100 Extreme (Pablo *et al.* 1994)	Inhibitory index (I) %

TABLE 2.4 TEST RESULTS ON CEMENT WITH AND WITHOUT CS FINES

2.2 Microstructure of coconut shell

The Scanning Electron Microscope (SEM) images of coconut shell in Saturated Surface Dry (SSD) state and in air dried state for both convex and concave surfaces are shown in Figures 3.4 and 3.5, respectively. Due to the rough convex texture of coconut shell, the coconut shell concrete possesses good bond strength. The texture of the convex face of 24 hours soaked coconut shell shows rougher surface than air dried coconut shell, which in turn will improve the bonding between the coconut shell and the binder's matrix. The smooth concave texture of coconut shell enhances the workability of concrete. Figure. 6 shows the findings of Energy Dispersive X-ray (EDX) spectroscopy analysis of air dried coconut shell and soaked coconut shell. In air dried coconut shell,traces of Fe that cause the staining on the aggregate, are found on the surface, whereas Fe is not found in the soaked coconut shell



(a) **(b)**

Figure 2.1 SEM images on the convex side of the coconut shell (a) Soakedcoconut shell and (b) Air dried coconut shell

Sieve size (mm)	**Weight retained in (g)**	**Cumulative weight retained (g)**	**Cumulative percentage retained (%)**	**Percentage passing (%)**	**Grading for zone – II as per IS:383 (1970)**
4.75	0	0	0	100	90-100
2.36	50	50	5	95	75-100
1.18	173	223	22.3	77.7	55-90
0.6	401	624	62.4	37.6	35-39
0.3	275	899	89.9	10.1	8-30
0.15	101	899	89.9	10.1	0-20

TABLE 2.5 PARTICLE SIZE DISTRIBUTION OF FINE AGGREGATE

Properties	**Value**
Bulk density	16 kN/m^3
Specific gravity	2.6
Water absorption	1.1%
Void ratio	0.468
Fineness modulus	2.78

Table 2.6 Properties of fine aggregate

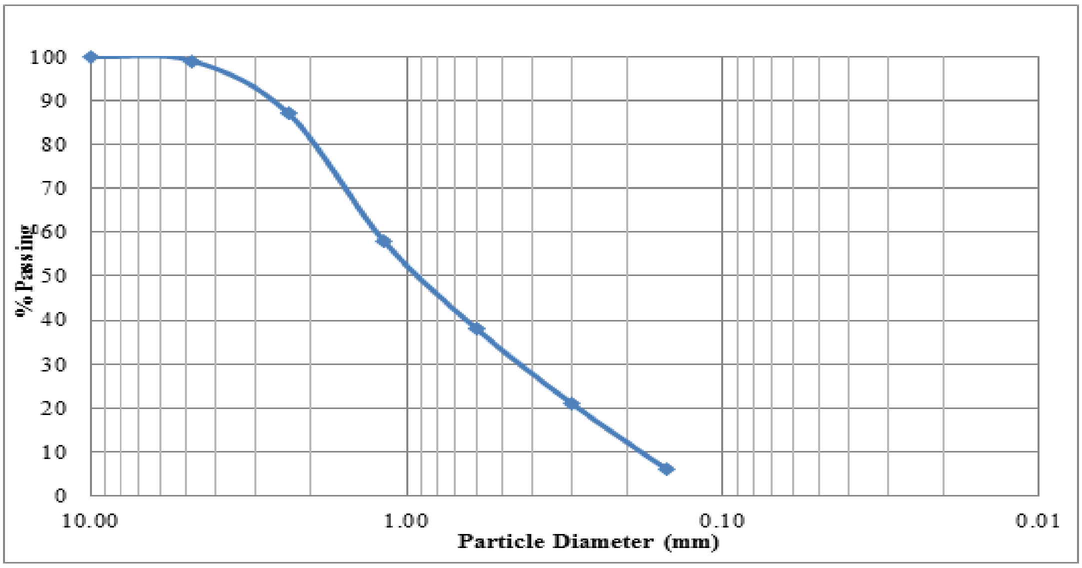


Figure 2.2 Gradation curve of river sand

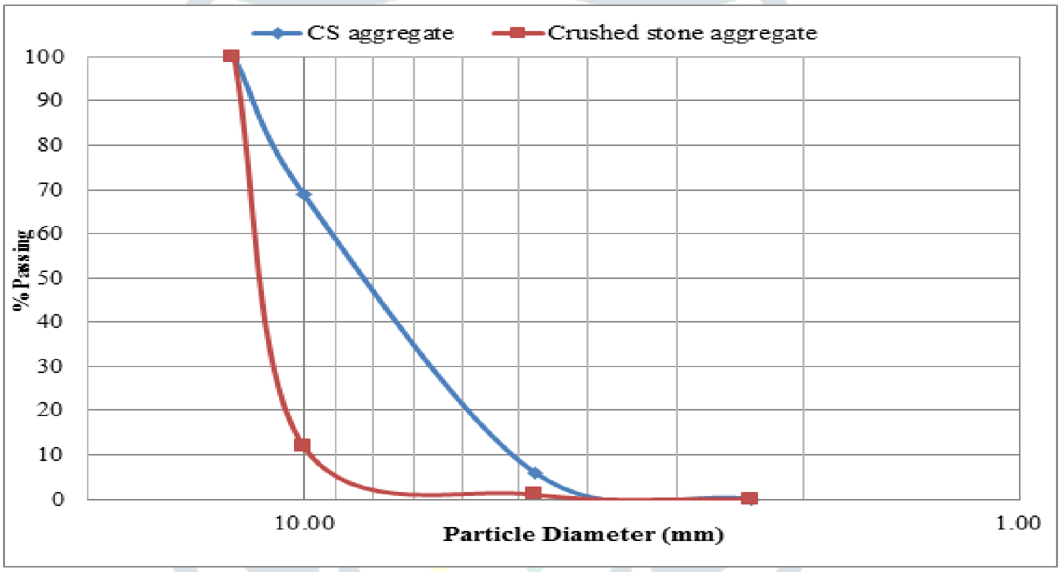


FIGURE 2.3 GRADATION CURVES OF COARSE AGGREGATES

Description	**Test results**	**Requirements of IS 12269: 2013**
Fineness – Specific surface	305 m^2/g	Not less than 225
Specific gravity	3.15	-
Consistency	33 %	-
Initial setting time	76 minutes	Not less than 30
Final setting time	430 minutes	Not more than 600
Soundness (Le Chatelier method)	0.4 mm	Not more than 10

TABLE 2.7 PHYSICAL PROPERTIES OF CEMENT

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI
Fly Ash	53.68	23.07	10.03	2.98	2.16	0.12	0.48	2.1	2.98
Cement	20.90	4.70	3.4	65.4	1.2	0.2	0.3	2.7	0.9

TABLE 2.8 CHEMICAL COMPOSITION OF FLY ASH AND OPC

Parameters	**Value**	**Permissible value as per IS 456 – 2000**
pH value	8.2	Not less than 6.0
Chloride content (mg/l)	112.5	500 mg/l
Total hardness (mg/l)	105	200 mg/l
Total Dissolved Solids (mg/l)	150	-

TABLE 2.9 PROPERTIES OF WATER

PROPERTIES	**VALUES**
Appearance	Brown liquid
Specific gravity	1.18 @ 22°C ± 2°C
Chloride content	Nil
Air entrainment (%)	Less than 2
Alkali content (g/l)	Less than 55

TABLE 2.10 PROPERTIES OF SUPER PLASTICIZER

Figure 2.4 Superplasticizer

Mix Series	Mix ID	Fly ash (%)	Cement (kg/m^3)	Sand (kg/m^3)	Coarse Aggregate		w/b	Superplasticizer % (by weight of binder)
					Coconut Shell Aggregate (kg/m^3)	Crushed stone aggregate (kg/m^3)		
CSF	CSF0	0	510	750	332	0	0.33	1.2
	CSF10	10	459	750	332	0	0.33	1.2
	CSF20	20	408	750	332	0	0.33	1.2
	CSF30	30	357	750	332	0	0.33	1.2
CSP	CSP0	0	510	750	165	428	0.33	1.2
	CSP10	10	459	750	165	428	0.33	1.2
	CSP20	20	408	750	165	428	0.33	1.2
	CSP30	30	357	750	165	428	0.33	1.2

TABLE 2.11 MIX PROPORTIONS OF CS CONCRETE WITH FLY ASH

Mix ID	Slump (mm)	Mix ID	Slump (mm)
CSF0	55	CSP	50
CSF10	60	CSP10	55
CSF20	65	CSP20	60
CSF30	65	CSP30	60

Table 2.12 Slump of CS concrete

Mix ID	Density (kg/m^3)	Mix ID	Density (kg/m^3)
CSF0	1940	CSP0	2125
CSF10	1925	CSP10	2105
CSF20	1905	CSP20	2085
CSF30	1885	CSP30	2065

TABLE 2.13 DENSITY OF THE HARDENED CONCRETE MIXES

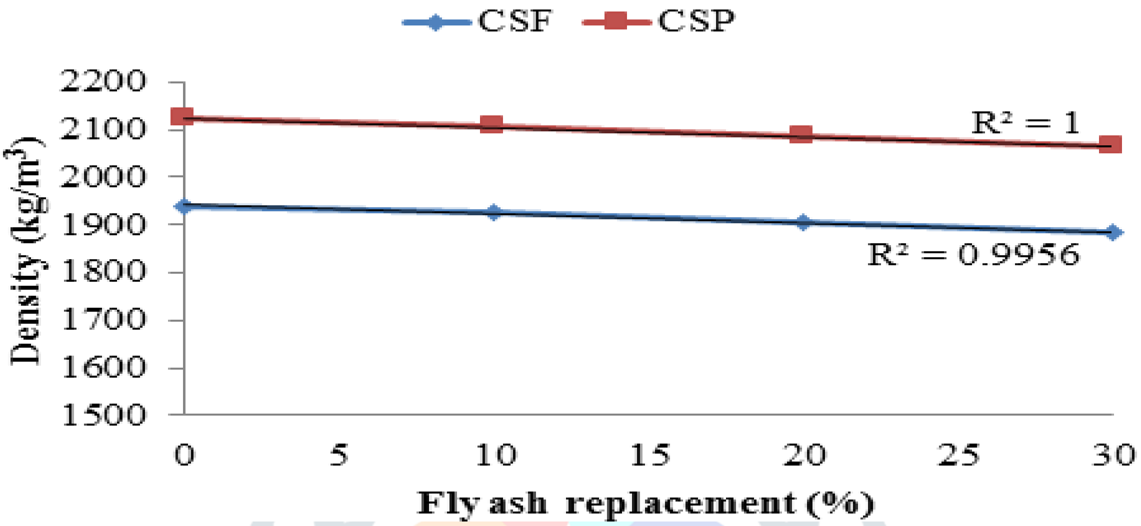


Figure 2.5 Density variation of CS concrete

Mix ID	UPV 28 days	Compressive strength 28 days
CSF0	3.85	30.7
CSF10	3.95	35.6
CSF20	3.72	27.6
CSF30	3.52	26.4
CSP0	4.01	33.7
CSP10	4.10	38.8
CSP20	3.78	30.0
CSP30	3.66	28.7

Table 2.14 UPV of CS Concrete

Figure 2.5 UPV test on CS concrete specimen

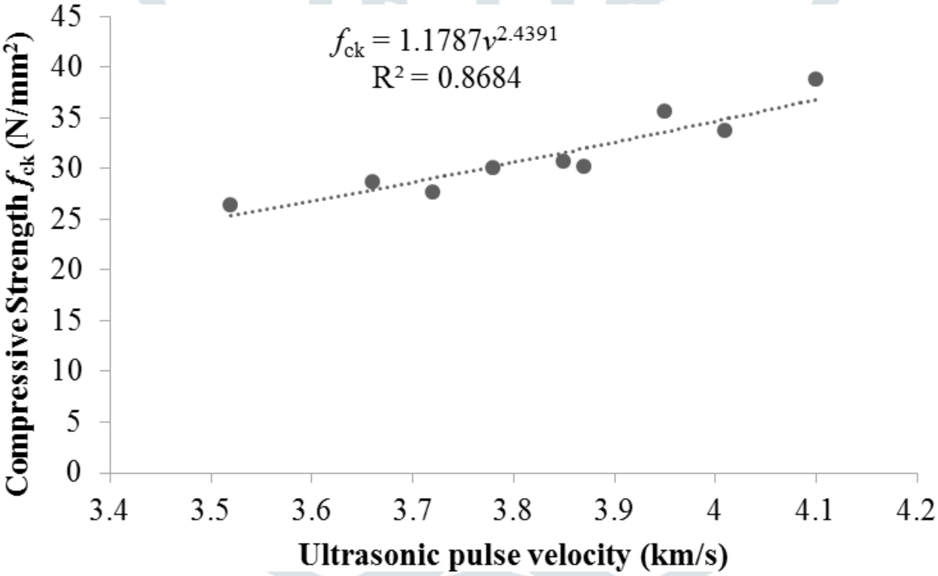


FIGURE 2.6 RELATION BETWEEN COMPRESSIVE STRENGTH AND UPV

Mix ID	**Compressive strength (MPa)**		
	7 days	**28 days**	**56 days**
CSF0	23.0 (75%)	30.7	31.3 (102%)
CSF10	27.7 (78%)	35.6	41.2 (116%)
CSF20	19.2 (72%)	27.6	38.3 (139%)
CSF30	16.7 (68%)	26.4	40.3 (153%)
CSP0	25.3 (79%)	33.7	34.7 (103%)
CSP10	30.2 (78%)	38.8	43.4 (112%)
CSP20	21.6 (72%)	30.0	41.8 (138%)
CSP30	18.6 (65%)	28.7	43.3 (151%)

Table 2.15 Compressive strength of CS concrete

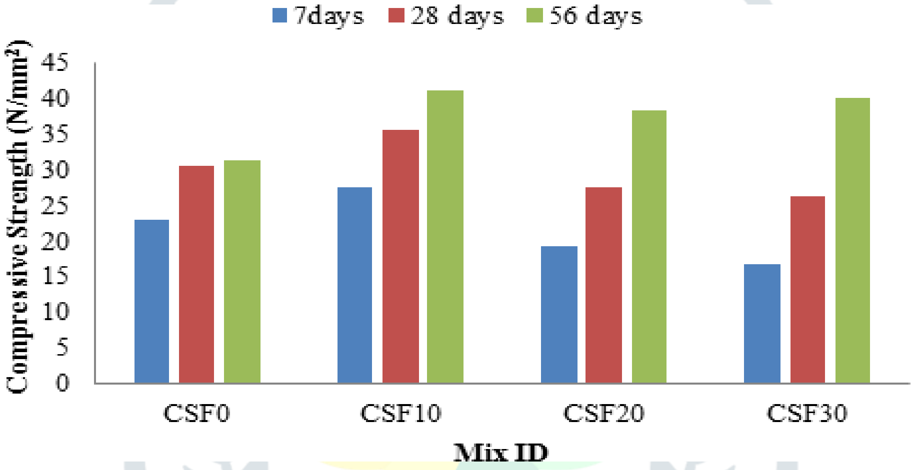


FIGURE 2.7 COMPRESSIVE STRENGTH OF CSF MIX

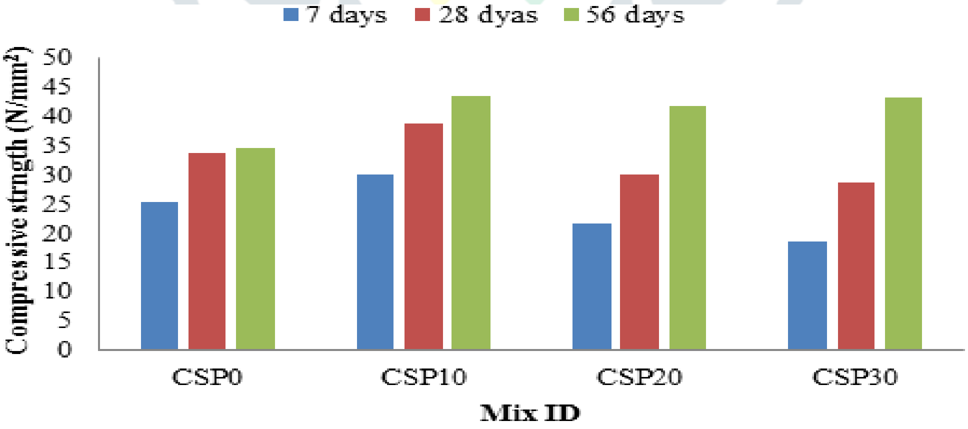


Figure 2.8 Compressive strength of CSP mix

Mix ID	Split tensile strength (MPa)		% variation of 28 days split tensile strength over control concrete	% variation of 56 days split tensile strength over control concrete
	28 days	56 days		
CSF0	3.1 (10%)	3.1	-	-
CSF10	3.7 (10%)	4.0	+19.3	+29.0
CSF20	2.6 (9%)	3.7	-16.1	+19.3
CSF30	2.7 (10%)	3.9	-12.9	+25.8
CSP0	3.3 (10%)	3.3	-	-
CSP10	3.8 (10%)	4.1	+15.1	+24.2
CSP20	2.9 (10%)	4.0	-12.1	+21.2
CSP30	2.7 (9%)	4.2	-18.2	+27.3

Table 2.16 Split tensile strength of CS concrete

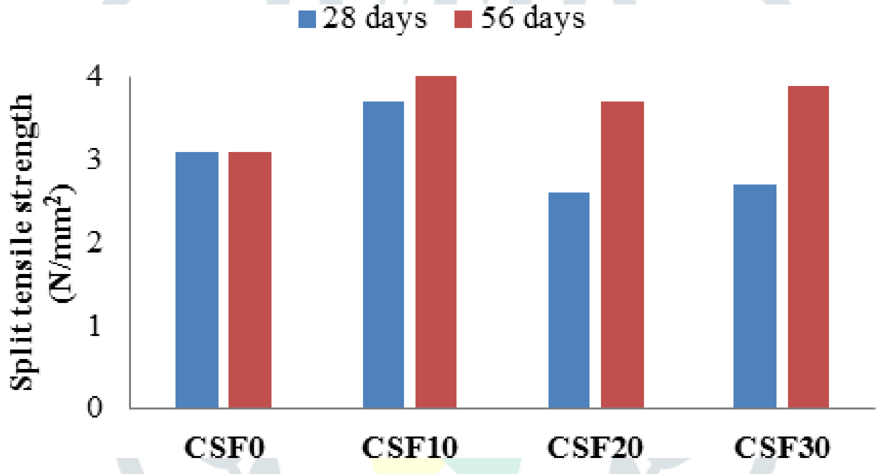


FIGURE 2.9 SPLIT TENSILE STRENGTH (CSF MIX)

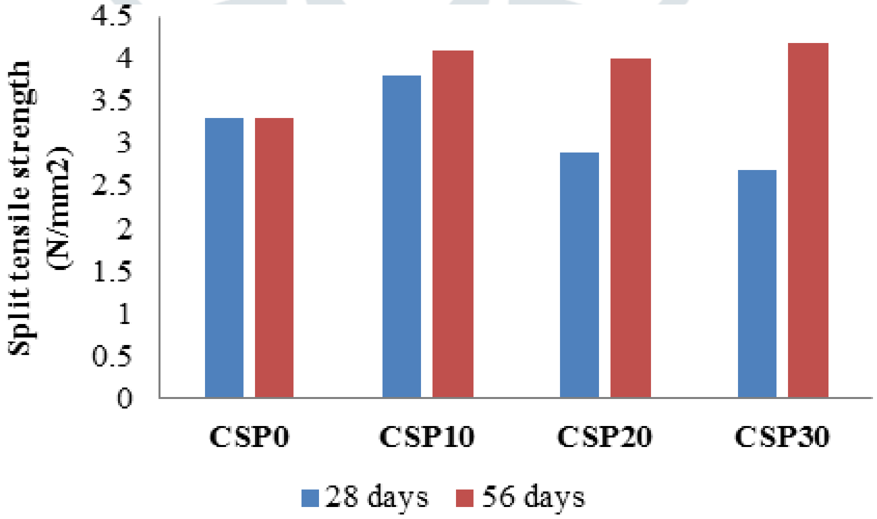


Figure 2.10 Split tensile strength (CSP mix)

Mix ID	**Flexural strength experimental (MPa)**	**Flexural strength as per IS 456:2000 $0.7\sqrt{fck}$ (MPa)**	**Percentage increase over theoretical flexural strength (%)**
	28 days	**28 days**	**28 days**
CSF0	4.33	3.88	11.6
CSF10	4.6	4.18	10
CSF20	4.1	3.68	11.4
CSF30	3.82	3.60	6.1
CSP0	4.62	4.06	13.8
CSP10	5.2	4.36	19.3
CSP20	4.42	3.83	15.4
CSP30	4.02	3.75	7.2

TABLE 2.17 FLEXURAL STRENGTH OF CS CONCRETE

Mix ID	**Modulus of Elasticity (GPa)**	**Modulus of elasticity as per IS 456:2000 $5.0\sqrt{fck}$ (GPa)**	**% variation of Exp. Modulus of elasticity over Theo. as per IS 456 (2000)**
CSF0	12.50	26.0	-54.9
CSF10	14.32	28.0	-52.0
CSF20	13.5	24.7	-48.6
CSF30	11.1	24.1	-56.8
CSP	17.50	27.3	-39.7
CSP10	20.25	29.3	-35.0
CSP20	17.20	25.7	-37.2
CSP30	14.21	25.2	-47.0

TABLE 2.18 MODULUS OF ELASTICITY OF CS CONCRETE

Mix ID	3 days	7 days	28 days	56 days	90 days
CSF0	12	12.2	10.5	9.1	7.5
CSF10	10.1	9.9	8.2	7.6	6.8
CSF20	9.1	8.8	6.3	5.9	5.5
CSF30	8.2	8.1	5.7	5.2	4.8
CSP0	6.2	6.0	4.8	4.2	3.8
CSP10	5.7	5.6	4.1	3.7	3.2
CSP20	5.2	5.0	3.8	3.4	2.9
CSP30	4.9	4.9	3.5	3.2	2.7

Table 2.19 Water absorption

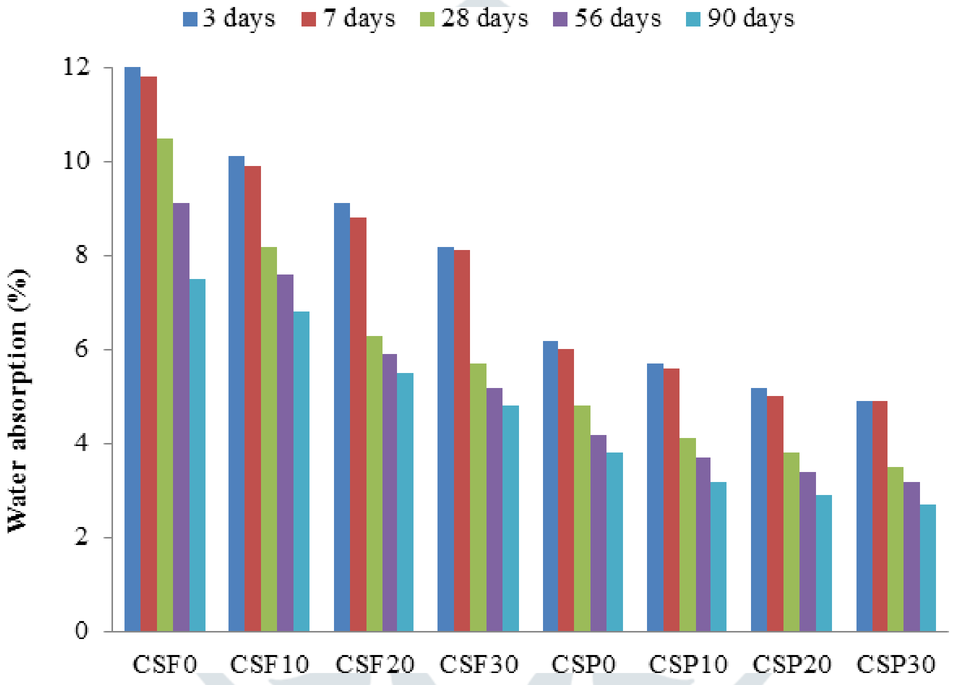


FIGURE 2.11 WATER ABSORPTION OF CS CONCRETE

3.0 CONCLUSIONS

- The density of hardened concrete is reduced when coconut shell is used as coarse aggregate in mixes, and the addition of fly ash further reduces the density of coconut shell concrete.
- The density is also decreased with increasing content of fly ash. This study has established that an eco-friendly lightweight concrete can be produced using coconut shell aggregate and the strength can also be increased significantly by incorporating a reasonable amount of fly ash as binder material. Compressive strength of 35.6 MPa is achieved for coconut shell concrete (CSF10) and 38.8 MPa is recorded for partial coconut shell (CSP10) respectively when compared to the corresponding mixes without fly ash.
- The minimum and maximum split tensile strength at 28 days are 2.6 MPa and 3.8 MPa respectively. It satisfies well with the requirement of structural grade

lightweight aggregate concrete as per ASTM C330(2014).

- Polypropylene fibres addition into CS concrete decreases the slump value up to 60%.
- The incorporation of polypropylene fibres results in a marginal reduction in the density of CS concrete, and subsequently, overall deadweight is reduced. Hence, the costs of foundation, erection and installation can be decreased.
- Polypropylene fibre slightly increases the compressive strength of CS concrete whereas it improves the tensile strength, flexural strength and modulus of elasticity considerably.
- The addition of steel fibre into CS concrete substantially decreased the slump value.
- Although steel fibre addition increased the density of CS concrete, the increase was insignificant up to 1% fibre.
- A significant increment in the compressive strength was obtained for1% steel fibre addition in both CSF and CSP mixes.
- Modulus of elasticity value of up to 17% was obtained in both CSFand CSP mixes.
- A remarkable improvement in split tensile strength and flexuralstrength was achieved for steel fibre addition in CSF and CSP mixes.
- A significant reduction in brittleness ratio was achieved byincorporating steel fibre in CS concrete.
- All the CS concrete and steel fibre reinforced CS concrete beams exhibited a typical flexural failure. As the fibre volume increases, a reduced concrete wedge and the deeper flexural crack are developed.
- The steel fibres addition increased the ultimate moment carrying capacity of CS concrete beams upto14% in CSF mix and 17% in CSP Mix.
- The steel fibre addition into CSF and CSP beams reduced its ductility due to strain localization phenomenon.
- The steel fibre addition increased the flexural toughness of CS concrete significantly.
- Ultimate load carrying capacities of the beams in flexure were determined using IS456 code. Since the equations stated by codes such as IS, ACI, BS and Eurocode are not meant for fibre reinforced concrete elements, the observed moment capacity and displacements of steel fibre reinforced CS concrete beams either overestimate or underestimate the theoretical values.

- The modified Branson‟s deflection equation holds good for the correlation between theoretical and experimental deflection.
- The behaviour of beams in load-deflection characteristics of finite element modeling showed good agreement with the experimental value.
- The ratio of ultimate loads (ANSYS/Experimental) is found within the range of 0.967 to 1.009.
- The ratio of total deflection (ANSYS/Experimental) is found within the range of 0.777 to 1.022.

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