EFFECTIVE UTILIZATION OF HERBOCRETE AND PARTIAL REPLACEMENT OF CEMENT USING EGG SHELL POWDER

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ABSTRACT

Cement is an inevitable constituent used in the production of concrete. Cement production results in the emission of an equal amount of carbon-dioxide into the atmosphere which may be serious threat to the environment in various forms. Admixtures have also been recognized as important components of concrete used to improve its performance. Most of the admixtures are available in market in the form of chemical composition. These chemical admixtures are very expensive and severely pollute the surrounding environment. This paper aims at the development of a sustainable concrete by replacing cement with natural egg shell powder and using Terminalia Chebula (Kadukkai) as a natural admixture. The concrete design mix considered is M30. The specimens were cast and compressive strength of 7th,14th and 28th day are determined. From the results, optimum mix percentage was obtained, on which split tensile strength, flexural strength test and rapid chlorine permeability test were conducted and their performance were analysed. This study proves that eggshell powder along with Terminalia Chebula is a good natural replacement for both cement and chemical admixture.

Keywords – Sustainable Concrete, Herbocrete, Terminalia Chebula, Egg Shell, Kaukkai, RCPT, Cement Replacement.

1. INTRODUCTION

Over the last twenty years remarkable advances have taken place in the research of concrete. Concrete exhibits excellent rheological behavior that includes workability, improved mechanical and durability performance with high compressive strength, and non-brittleness behavior. Cement is an inevitable constituent used in the production of concrete and also posses the problem of acute shortage in many areas, which posses serious problems on its availability, cost, and environmental impact. Construction industry depends heavily on conventional materials such as cement, granite, and sand for the production of concrete. Cement production results in the emission of large amount of carbon-dioxide into the atmosphere which may be serious threat to the environment in various forms. So, there is always a need for substituent to cement [4].

Admixtures have also been recognized as important components of concrete used to improve its performance. Most of the admixtures are available in market in the form of chemical composition. These chemical admixtures are very expensive and severely pollute the surrounding environment. So as to reduce the pollution, natural admixtures materials such as jaggery, kadukkai, grape and mulberry extract are used as admixtures, termed as Herbocrete. Herbocrete is the future material with the potential to be viable admixtures for improving the sustainability of buildings and other infrastructure components. The feasibility of developing the properties of concrete using locally available bio-degradable wastages could create eco-friendly concrete [5].

2. BACKGROUND OF THE STUDY

Eggshells are waste materials generated from chick hatcheries, bakeries etc, which can litter the environment and consequently constituting environmental problems or pollution which would require proper handling. The main advantage is that the eggshell powder can be used as a substitute in concrete production [4]. At the same time use of chemical admixtures are also increasing day by day which results in polluting the surrounding environment and to reduce such pollution, use of herbocrete can be a solution for the problem [7].

3. OBJECTIVE OF THE STUDY

To develop a sustainable concrete by effective utilization of herbocrete (Terminalia Chebula) and partial replacement of cement using egg shell powder.

4. MATERIALS AND TESTS

In this present investigation the following materials were used:

1. Portland Pozzolana Cement
2. Fine Aggregates (M-sand < 425μ)
3. Coarse Aggregates (20 mm)
4. Terminalia Chebula (Kadukkai)
5. Egg Shell

4.1 Cement

Portland Pozzolana Cement

Test for cement (IS 1489(Part 1):1991),

- Standard Consistency = 30%.
- Initial Setting Time = 1 hour 26 minutes.
- Final Setting Time = 550 minutes.
- Specific Gravity = 2.99

4.2 Fine Aggregate (M-sand < 425μ)

Table 1: Material properties of fine aggregate

Material Properties	**Test Results**
Specific gravity	2.54
Sieve analysis	Conforming to Zone II as per IS 383- 2016
Water absorption	1.27%
Bulk density	1.89 x 10^3 kg/m^3
Fineness Modulus	2.97

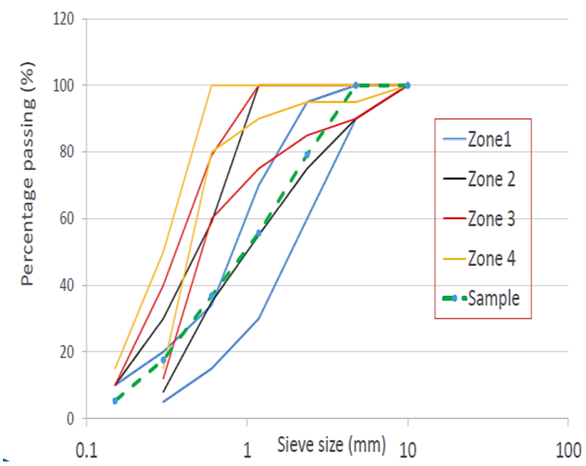

Fig 1: Grading curve of fine aggregate

4.3 Coarse Aggregate (20mm size)

Table 2: Material properties of coarse aggregate

Properties	**Results**
Specific gravity	2.77
Sieve analysis	Conforming to IS 383-2016
Water absorption	0.636%
Bulk density	1.83x 10^3 kg/m^3
Fineness Modulus	7.28

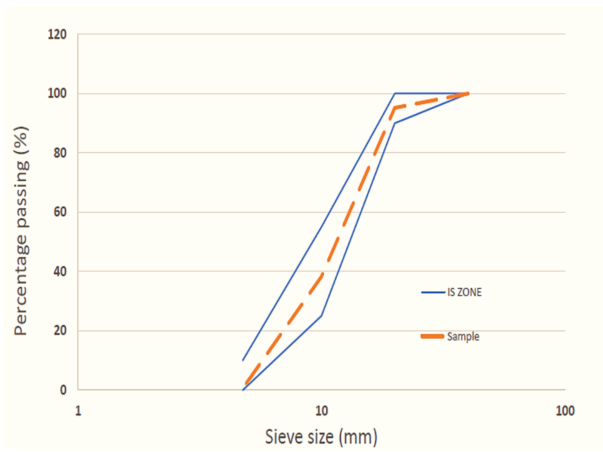

Fig 2: Grading curve of coarse aggregate

4.4 Terminalia Chebula

Our ancestors have used various plants as admixture in construction for more than 10000 years to improve overall performance of the structure. Herbal admixture will definitely improve the strength and durability of the mortar but at the same time it does not produce any harm to our environment. It can be used as both an admixture and medicinary plant. Terminalia Chebula, commonly known as black or chebulic myrobalan or kadukkai is a locally available natural admixture. Terminalia Chebula

Properties	**Results**
Specific gravity	1.89
Fineness modulus %	41
Bulk density kg/m^3	1081
Surface area m^2	290

Properties	**Results**
Total ash %	37.85
Acid insoluble ash %	31.55
Alcohol extract value %	3.58
Water extract value %	17.72
Bulk density	0.352 g/ml
Trapped density	0.512 g/ml

is commonly used in medicals. Kadukkai plant leaves powder can also be replaced partially with cement. The use of Terminalia Chebula could increase the mechanical

Element	**Results**	**Permissible Limits**
Iron %	18.03	-
Cadmium ppm	0.0064	0.3
Mercury ppm	0.00578	1
Arsenic ppm	0.0405	3
Lead ppm	0.2144	10

properties of concrete and thereby allow us to develop an eco-friendly concrete. Detailed experimental investigation were done to determine the optimum usage of these herbal products in cement mortar [6].

Table 3: Physical properties of kadukkai [6]

Table 4: Chemical properties of kadukkai [6]

4.5 Egg Shell

Egg shells are agricultural throw away objects produced from chick hatcheries, bakeries, etc. These consists of several mutually growing layers of CaCO3. The Egg shell primarily contains calcium, magnesium carbonate (lime) and protein [4].

Table 5: Physical properties of egg shell [4]

Table 6: Chemical composition of egg shell [4]

Oxide contents	**Percentage (%)**
CaO	96.35
SiO_2	0.01
P_2O_5	0.27
K2O	0.02
MgO	0.1
SO_3	0.16

5. METHODOLOGY

The experimental investigation on preparation of a sustainable concrete was performed in two ways:

1. Partial replacement of cement using egg shell powder and fermented kadukkai extract as a natural admixture.
2. Partial replacement of cement using egg shell powder and powdered kadukkai as a natural admixture.

5.1 PARTIAL REPLACEMENT OF CEMENT USING EGG SHELL POWDER AND FERMENTED KADUKKAI EXTRACT AS A NATURAL ADMIXTURE.

The kadukkai was crushed and grounded. The grounded kadukkai powder was mixed with suitable quantity of water (at 37g of kadukkai powder for 1L of water) to attain an accurate pH of 6 – 8.5 and kept (fermented) in a closed container for 30 days. The fermented kadukkai extract was filtered after 30 days.

Table 7: Compressive strength of M30 grade for various mix proportions at 7, 14 and 28 days

Mix	No.	Compressive Strength at 7 days(N/mm^2)			Compressive Strength at 14 days(N/mm^2)			Compressive Strength at 28 days(N/mm^2)		
		Load KN	Stress N/mm^2	Avg	Load KN	Stress N/mm^2	Avg	Load KN	Stress N/mm^2	Avg
Normal	1	500	22.22	22.22	680	30.22	30.37	940	41.78	41.33
	2	490	21.78		690	30.67		920	40.89	
	3	510	22.67		680	30.22		930	41.33	
4 % ESP and 2.5 % KE	1	520	23.11	23.70	730	32.44	32.44	970	43.11	42.81
	2	540	24.00		730	32.44		960	42.67	
	3	540	24.00		730	32.44		960	42.67	
8 % ESP and 5 % KE	1	560	24.89	24.89	770	34.22	33.93	990	44.00	44.30
	2	550	24.44		760	33.78		1000	44.44	
	3	570	25.33		760	33.78		990	44.00	
12 % ESP and 7.5 % KE	1	580	25.78	26.07	790	35.11	35.56	1030	45.78	45.63
	2	590	26.22		760	35.56		1030	45.78	
	3	590	26.22		760	36.00		1020	45.33	
16 % ESP and 10 % KE	1	620	27.56	27.71	860	38.22	38.37	1060	47.11	46.96
	2	620	27.56		870	38.67		1050	46.67	
	3	630	28.00		860	38.22		1060	47.11	
20 % ESP and 12.5 % KE	1	550	24.44	24.15	740	32.89	33.18	990	44.00	44.29
	2	540	24.00		750	33.33		1000	44.44	
	3	540	24.00		750	33.33		1000	44.44	

The waste eggshell pieces are collected from commercial areas like restaurants, hotels and hostels. It was cleaned and dried in oven at 80ºC for 2-3 days. Then it was crushed, grinded and powdered with help of crushing machines. The eggshell powder is being used for the partial replacement of cement, so it was sieved using 90 microns sieve. Then required quantity of eggshell powder is taken in account.

The cement concrete was designed for M30 grade (1:1.24:2.37) with a target strength of 38N/mm^2. The cement concrete was prepared by adding water, cement, coarse and fine aggregates. In which cement was partially replaced by using egg shell powder at different mix percentage such as 4%, 8%, 12%, 16% and 20% by weight of cement. Fermented kadukkai extract was added to the mix at the rate of 2.5%, 5%, 7.5%, 10% and 12% by weight of water. Total of 9 cubes were casted for each mix. The moulds were filled by hand or trowel, lightly tamped and finishing of concrete cube is done by vibrating machine. It was then stored in a undisturbed suitable container for a period of 24 hours and at room temperature. After the expiry of this period the specimens shall be takeout from the moulds and immersed in water in laboratory for 28 days specimen.

Table 8: Split tensile strength of the optimum mix percentage

Table 9: Flexural strength of the optimum mix percentage

Mix	No.	Flexural / Split Tensile Strength at 7 days (N/mm²)			Flexural / Split Tensile Strength at 14 days (N/mm²)			Flexural / Split Tensile Strength at 28 days (N/mm²)		
		Load KN	Stress N/mm²	Avg	Load KN	Stress N/mm²	Avg	Load KN	Stress N/mm²	Avg
Normal	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	298	[illegible]	[illegible]
	2	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	
	3	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	
16 % ESP and 10 % KE	1	[illegible]	[illegible]	[illegible]	286	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	2	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	
	3	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	

Sl. No.	Time	Duration (Minutes)	Recorded Current (Ampere)	Charge Passing (Coulombs)
1	09.00am to 09.30am	30	0.50	540
2	09.30am to 10.00am	30	0.45	1640
3	10.00am to 10.30am	30	[illegible]	[illegible]
4	10.30am to 11.00am	30	0.35	2015
5	11.00am to 11.30am	30	0.30	2150
6	11.30am to 12.00pm	30	0.25	2080
7	12.00pm to 12.30pm	30	0.20	2165
8	12.30pm to 01.00pm	30	0.23	2648
9	01.00pm to 01.30pm	30	0.25	2970
10	01.30pm to 02.00pm	30	0.22	2922
11	02.00pm to 02.30pm	30	0.20	2890
12	02.30pm to 03.00pm	30	0.17	2565
13	03.00pm to 03.30pm	30	0.15	2348
14	03.30pm to 04.00pm	30	0.18	3330
15	04.00pm to 04.30pm	30	0.16	3370
			Average	2367.67 (Moderate)

Table 10: Rapid Chlorine Permeability test of the optimum mix percentage

5.1.1 Test Procedure

The compressive strength of the cubes were tested at 7 days, 14 days and 28 days. From the results, optimum mix percentage was determined, on which split tensile strength, flexural strength test and RCPT test were conducted and their performance were analysed.

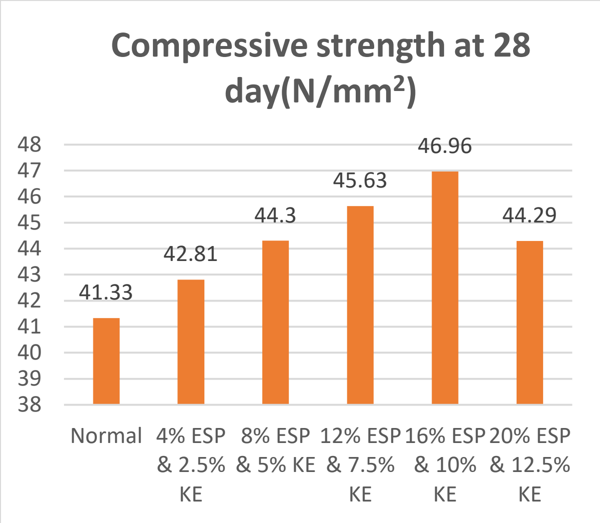

Fig 3: Compressive strength comparison after 28 days.

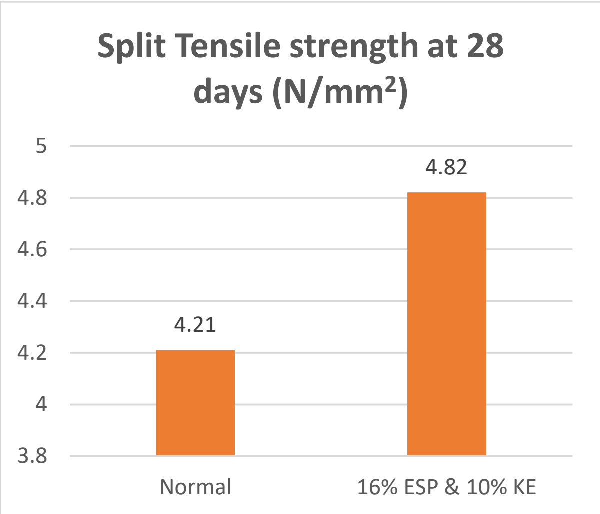

Fig 4: Split tensile strength comparison of normal and optimum mix percentage after 28 days.

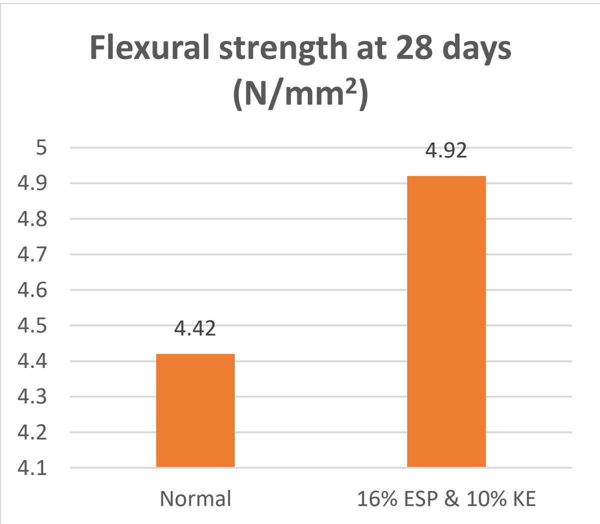

Fig 5: Flexural strength comparison of normal and optimum mix percentage after 28 days.

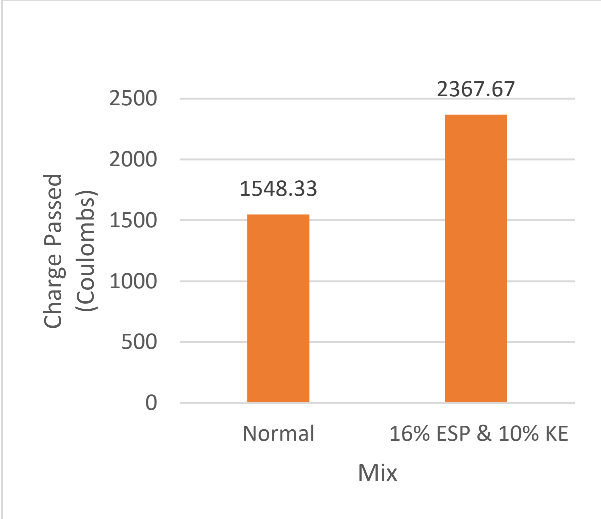

Fig 6: RCPT test result of optimum mix after 28 days.

5.2 PARTIAL REPLACEMENT OF CEMENT USING EGG SHELL POWDER AND KADUKKAI POWDER AS A NATURAL ADMIXTURE.

Kadukkai were collected from local medicinary shops. It was then cleaned and dried in oven at 100-150ºC for 7 days. Later it was crushed, grinded and powdered with help of crushing machines. Since the powder is to be used along with the cement, it was sieved using 90 microns sieve.

Waste eggshell pieces are collected from commercial areas like restaurants, hotels and hostels. It was cleaned and dried in oven at 80ºC for 2-3 days. Then it was crushed, grinded and powdered with help of crushing machines. The eggshell powder is being used for the partial replacement of cement, so it was sieved using 90 microns sieve. Then required quantity of eggshell powder is taken in account.

The cement concrete was designed for M30 grade (1:1.24:2.37) with a target strength of 38N/mm^2. The cement concrete was prepared by addition of water, cement, coarse and fine aggregates. In which cement was partially replaced by using egg shell powder at different mix percentage such as 3%, 6%, 9% and 12% by weight of cement and powdered kadukkai was added to the mix at the rate of 1%, 2%, 3% and 4% by weight of cement. Total of 9 cubes were casted for each mix. The moulds were filled by hand or trowel, lightly tamped and finishing of concrete cube is done by vibrating machine. It is then stored in an undisturbed suitable container for period of 24 hours and at room temperature. After the expiry of this period the specimens shall be takeout from the moulds and immersed in water in laboratory for 28 days specimen.

5.2.1 Test Procedure

The compressive strength of the cubes were tested at 7 days, 14 days and 28 days. From the results, optimum mix percentage was determined, on which split tensile strength, flexural strength test and RCPT test were conducted and their performance were analysed.

Table 11: Compressive strength of M30 grade for various mix proportions at 7, 14 and 28 days

Mix	No.	Compressive Strength at 7 days(N/mm^2)			Compressive Strength at 14 days(N/mm^2)			Compressive Strength at 28 days(N/mm^2)		
		Load KN	Stress N/mm^2	Avg	Load KN	Stress N/mm^2	Avg	Load KN	Stress N/mm^2	Avg
Normal	1	500	22.22	22.22	680	30.22	30.37	940	41.78	41.33
	2	490	21.78		690	30.67		920	40.89	
	3	510	22.67		680	30.22		930	41.33	
3 % ESP and 1 % PK	1	510	22.67	22.82	700	31.11	31.26	930	41.33	41.63
	2	510	22.67		710	31.56		950	42.22	
	3	520	23.11		700	31.11		930	41.33	
6 % ESP and 2 % PK	1	530	23.56	23.71	710	31.56	31.71	940	41.78	42.37
	2	540	24.00		710	31.56		960	42.67	
	3	530	23.56		720	32.00		960	42.67	
9 % ESP and 3 % PK	1	540	24.00	24.15	740	32.89	32.74	990	44.00	43.55
	2	540	24.00		740	32.89		970	43.11	
	3	550	24.44		730	32.44		980	43.56	
12 % ESP and 4 % PK	1	520	23.11	23.11	710	31.56	31.41	950	42.22	41.78
	2	510	22.67		700	31.11		940	41.78	
	3	530	23.56		710	31.56		930	41.33	

Table 12: Split tensile strength of the optimum mix percentage

Mix	No.	Split Tensile Strength at 7 days(N/mm^2)			Split Tensile Strength at 14 days(N/mm^2)			Split Tensile Strength at 28 days(N/mm^2)		
		Load KN	Stress N/mm^2	Avg	Load KN	Stress N/mm^2	Avg	Load KN	Stress N/mm^2	Avg
Normal	1	164	2.32	2.33	222	3.14	3.16	298	4.22	4.21
	2	166	2.35		224	3.17		298	4.22	
	3	164	2.32		224	3.17		296	4.19	
9 % ESP and 3 % PK	1	166	2.35	2.36	228	3.23	3.24	302	4.27	4.28
	2	168	2.37		228	3.23		304	4.30	
	3	166	2.35		230	3.25		302	4.27	

Table 13: Flexural strength of the optimum mix percentage

Mix	No.	**Flexural Strength at 7 days(N/mm^2)**			**Flexural Strength at 14 days(N/mm^2)**			**Flexural Strength at 28 days(N/mm^2)**		
		Load KN	Stress N/mm^2	Avg	Load KN	Stress N/mm^2	Avg	Load KN	Stress N/mm^2	Avg
Normal	1	5	2.50	2.42	6	3.00	3.33	9	4.50	4.42
	2	5	2.50		7.5	3.75		8	4.00	
	3	4.5	2.25		6.5	3.25		9.5	4.75	
9 % ESP and 3 % PK	1	5	2.50	2.50	7	3.50	3.42	9.5	4.75	4.58
	2	5	2.50		7	3.50		9	4.50	
	3	5	2.50		6.5	3.25		9	4.50	

Table 14: Rapid Chlorine Permeability test of the optimum mix percentage

Sl. No.	Time	Duration (Minutes)	Recorded Current (Ampere)	Charge Passing (Coulombs)
1	09.00am to 09.30am	30	0.47	1200
2	09.30am to 10.00am	30	0.43	1736
3	10.00am to 10.30am	30	0.39	1909
4	10.30am to 11.00am	30	0.37	1962
5	11.00am to 11.30am	30	0.34	2041
6	11.30am to 12.00pm	30	0.29	2136
7	12.00pm to 12.30pm	30	0.26	2094
8	12.30pm to 01.00pm	30	0.22	2131
9	01.00pm to 01.30pm	30	0.21	2326
10	01.30pm to 02.00pm	30	0.24	2809
11	02.00pm to 02.30pm	30	0.23	2938
12	02.30pm to 03.00pm	30	0.28	2673
13	03.00pm to 03.30pm	30	0.20	3850
14	03.30pm to 04.00pm	30	0.16	3370
15	04.00pm to 04.30pm	30	0.14	3180
			Average	2423.67 (Moderate)

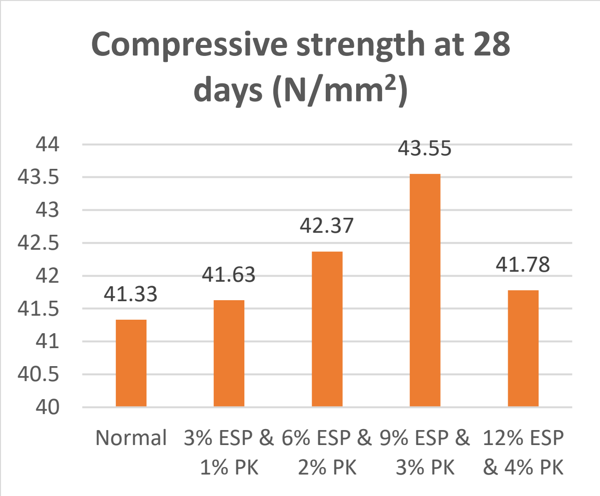

Fig 7: Compressive strength comparison after 28 days.

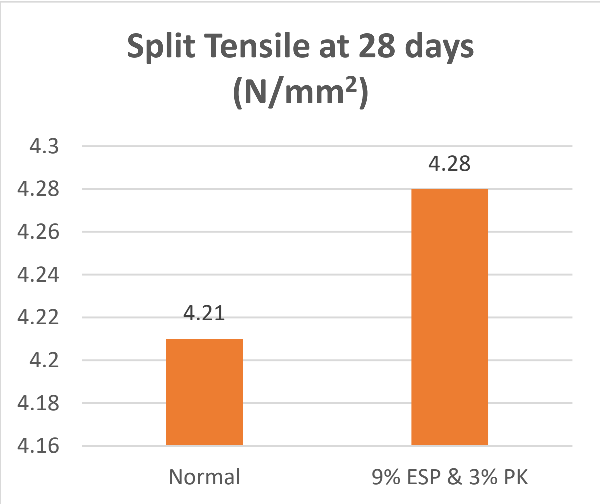

Fig 8: Split tensile strength comparison of normal and optimum mix percentage after 28 days.

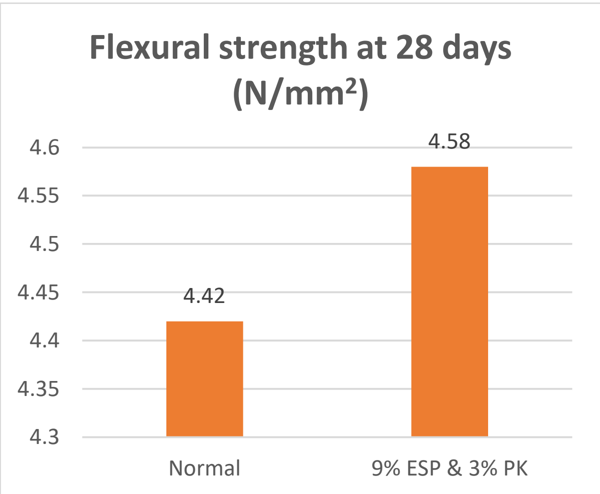

Fig 9: Flexural strength comparison of normal and optimum mix percentage after 28 days.

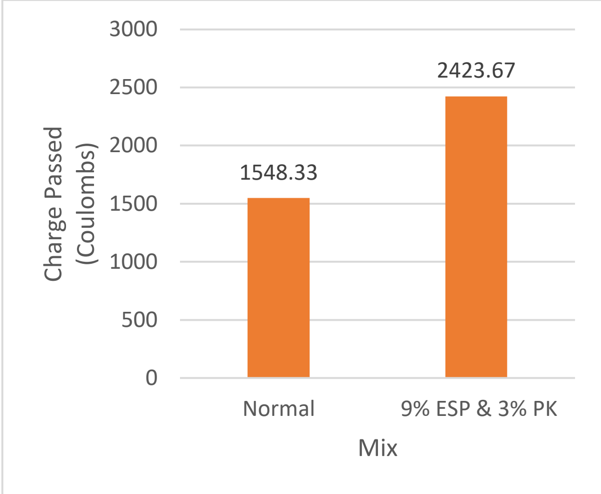

Fig 10: RCPT test result of optimum mix after 28 days.

6. RESULT AND DISCUSSION

6.1 Normal consistency and Setting time

Normal mix with chemical admixture requires lower water for the standard consistency compared to cement replacement by egg shell powder and natural admixture. Presence of calcium and carbohydrates in egg shell and kadukkai accelerated the hydration of the cement paste and consequently decreasing setting by 0.06%.

6.2 Workability

Intentionally low workability control concrete mix was designed to check the effect of admixture addition on slump enhancement. There was a slump enhancement due to addition of fermented kadukkai extract in the mix. Chemical admixture has a good dispersion effect of cement particles causing a reduction in the viscosity of the concrete. Following chemical admixture, the fermented kadukkai extract has the best workability; but in general, there is a good workability enhancement indicating the usefulness of natural admixture to enhance flow ability of concrete. Improving of workability due to natural extract could be related to carbohydrate content in the Kadukkai.

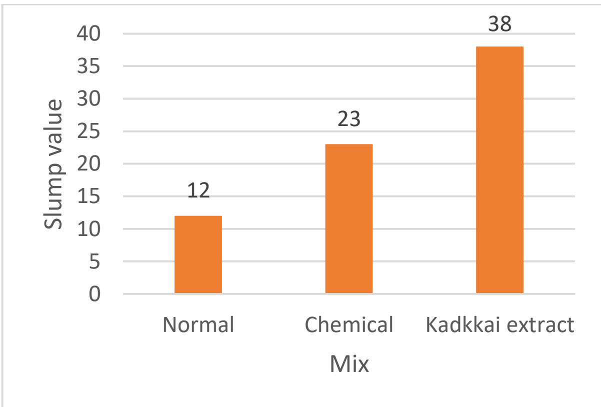

Fig 11: Slump Value

6.3 Water Absorption

One can find an increase of absorption after chemical admixture addition but a reduction on using natural admixture and cement replacement. From the result there is an improvement of microstructure of hardened concrete due to natural admixture and egg shell powder in the concrete mix. The water absorption reduction could be attributed due to the improvement of microstructure of hardened cement paste and pore segmentation.

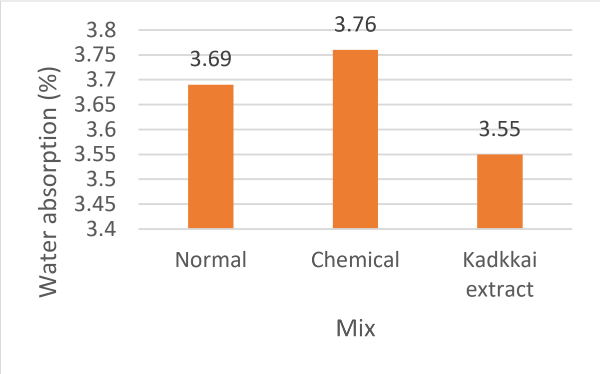

Fig 12: Water Absorption

6.4 Compressive Strength

Variation of compressive strength percentage for different concrete mixes is shown in “Table 7” and “Table 11”. When fermented kadukkai extract and egg shell powder was used, there is a compressive strength enhancement by 1.136 times the target strength and when powdered kadukkai and egg shell powder was used, there is a compressive strength enhancement by 1.054 times the target strength. This early strength enhancement has many benefits such as early removal of formwork to increase product ability. Since the same water/cement ratio was used for all mixes the strength enhancement for concrete with designed mix could be attributed to the dispersion effect of the admixture, in which it makes cement particles distribute well and as a result homogeneity of the mix increases leading to reducing local defects.

The strength enhancement can be attributed to the existence of mineral compounds. Potassium is the most important mineral that existed in both kadukkai and egg shell powder. With the cement paste hydration progress, there is a chance for the potassium mineral, in a sufficient amount, to cause precipitation inside the capillary pores inside the cement paste mass, especially at the early ages, causing segmentation of such pores, increasing homogeneity, and as a consequence increasing compressive strength.

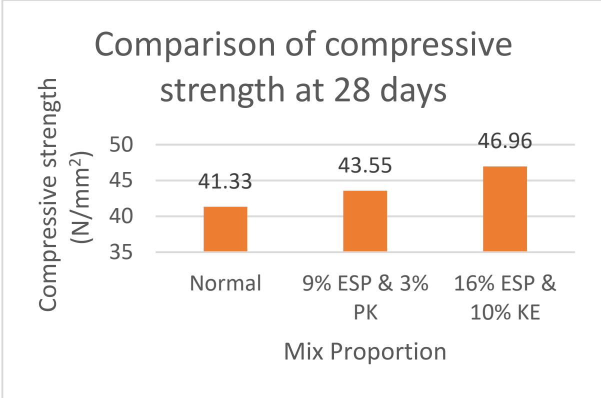

Fig 13: Optimum mix compressive strength at 28 days

6.5 Splitting Tensile Strength

The splitting tensile strength of optimum mix percentage is shown in “Table 8” and “Table 12”. There is a tensile strength enhancement by 1.145 times the target strength on using egg shell powder and kadukkai extract. These results indicate that there is more beneficial effect of using both materials to enhance splitting tensile strength. The modified microstructure of concrete with minerals precipitation in the pore structure seems to have more beneficial effect for concrete subjected to tension.

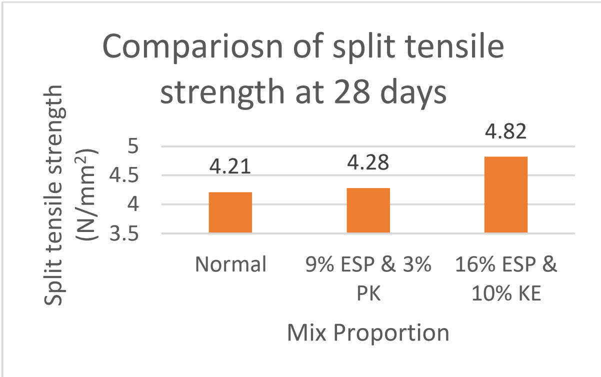

Fig 14: Optimum mix split tensile strength at 28 days

6.6 Flexural Strength

The flexural strength of optimum mix percentage is shown in “Table 9” and “Table 13”. There is an increase in flexural strength by 1.113 times the target strength while using fermented kadukkai extract and egg shell powder. It was observed that there is an increase in flexural strength with increase in compressive strength. Further, based on compressive strength enhancement, the existence of kadukkai and egg shell is important to change the behavior of concrete near the ultimate stress, and in this way they have an impact on the final failure.

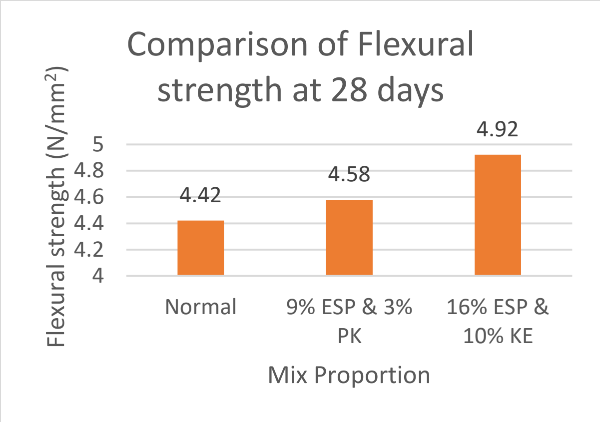

Fig 15: Optimum mix flexural strength at 28 days

6.7 Chloride Ion Permeability

The rapid chlorine permeability of optimum mix percentage is shown in "Table 10" and "Table 14". One of the most important factors affecting the permeability of concrete is the internal pore structure, which in turn is dependent on the extend of hydration of the cementitious materials. The curing conditions and the age of the concrete thus largely determine the ease with which chloride ions can move into a concrete. The RCPT test was carried on optimum mix proportions, which showed that they have a moderate chloride ion permeability compared to the normal mix with low chloride ion permeability.

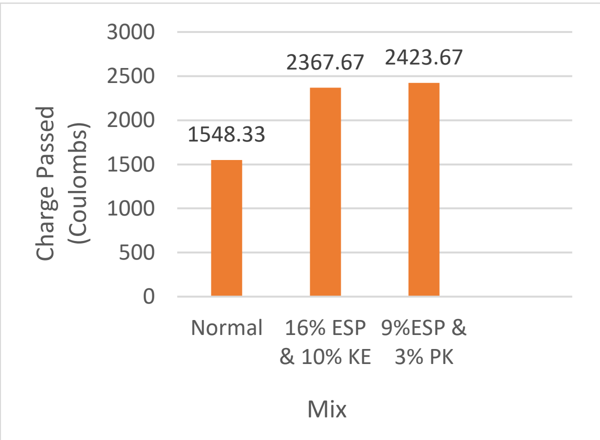

Fig 16: RCPT test result on optimum mix

7. CONCLUSION

The incorporation of egg shell and kadukkai in concrete mix will modify the hard and fresh properties of concrete. The usage of natural materials will lead to reduction of carbon dioxide emission from the concrete and it will enhance the mechanical behavior of concrete. The use of fermented kadukkai extract increased the workability of concrete at constant liquid to cement ratio. Introduction of kadukkai extract and egg shell powder reduced the porosity of mortar measured using the MIP apparatus, while the mean and average pore sizes are significantly reduced for all mortars containing Herbocrete. Water absorption percent has been decreased in it when compared to plain concrete.

The results shows that the maximum compressive strength for concrete is achieved with 16% of egg shell powder and 10% of fermented Kadukkai extract at 28 days is 46.96 N/mm2. When powdered kadukkai was used, the maximum compressive strength was attained with 9% egg shell powder and 3% kadukkai powder at 28 days is 43.55 N/mm2. In both methodology concrete shows an improved mechanical behaviour. From the experimental work results, it is clear that use of egg shell along with kadukkai could increase the compressive strength, split tensile strength and flexural strength of concrete and thereby helps in the reduction of chemical admixtures and cement usage.

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