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DURABILITY CHARACTERISTIC OF COCONUT FIBER AGGREGATE CONCRETE BOND IN LIGHTWEIGHT FOAM CONCRETE

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Abstract

The research paper probes into coconut fibre used as lightweight aggregate in concrete for thermal conditioning, specifically on durability. The durability properties of coconut fibre and coconut fibre lightweight aggregate concrete were examined on the thermal conditioning. The use of coconut fibre aggregate in construction was tested and verified. It ascertained the moisture content and water absorption capacity found to be 4.20% and 24% respectively. These values can be compared to the conventional aggregate used in normal times. The density of coconut fibre was found to be in the range of 550 -650 kg/m^3. They are within the specified limits of lightweight aggregate standards. The study conducted a related hydration test on coconut fibre fines with cement. The coconut fibre-cement ratio has been optimized to satisfy the criteria of structural lightweight concrete for insulation and thermal conditioning to ensure durability. The experiments for long-term investigation continued for 365 days on the compressive strength of coconut fibre aggregate concrete for three different curing conditions.

Keywords: Durability, Volume of Permeable Voids, Resistance, Rapid Chloride Penetrability, Residual Strength

I. Introduction

The research paper probes into coconut fibre used as lightweight aggregate in concrete for thermal conditioning, specifically on the durability. The durability properties of coconut fibre and coconut fibre lightweight aggregate concrete were examined on thermal conditioning. The use of coconut fibre aggregate in construction was tested and verified. It ascertained the moisture content and water absorption capacity found to be 4.20% and 24% respectively. These values can be compared to the conventional aggregate used in normal times. The density of coconut fibre was found to be in the range of 550 -650 kg/m^3. They are within the specified limits of lightweight aggregate standards. The study conducted related hydration test on coconut fibre fines with cement. Coconut fibre-cement ratio has been optimized to satisfy the criteria of structural lightweight concrete for insulation and thermal conditioning to ensure durability. The experiments for long-term investigation continued for 365 days on the compressive strength of coconut fibre aggregate concrete for three different curing conditions. They are 1. laboratory curing (full water immersion W1), 2. simulation of the practical curing (Site curing W2), and 3. air-dry (no curing W3) which are carried. An increase in the pulse velocity and compressive strength of coconut fibre aggregate concrete was found and biological decay was not found.

This enhanced continual increase in strength indicates that coconut fiber aggregate concrete does not deteriorate once coconut fibre aggregates are encapsulated into the concrete matrix mix. In the short-term study of 28 days, the properties of coconut fiber aggregate concrete on the flexural strength, splitting tensile strength, impact resistance, and elastic modulus were determined. The experimental durability bond strength of coconut fiber aggregate concrete was quite higher than the design bond strength by IS 456 and BS 8110 under curing conditions. The durability properties of coconut fibre aggregate concrete are comparable to other conventional lightweight concretes. The flexural behavior of reinforced coconut fiber aggregate concrete beams was comparable to control concrete and that of other lightweight concretes. The beams with low reinforcement ratios satisfied all the serviceability requirements as per IS 456 and BS 8110. Coconut fibre aggregate concrete is subjected to 100 ºC for 4 h and 200 ºC for 2 h, its residual strengths are 18 N/mm^2 and 18.40 N/mm^{2}respectively. These values accurately satisfy the criteria of structural lightweight concrete strength as per ASTM C 330. This coconut fibre aggregate concrete can offer 2 hours fire resistance and therefore it may be classified under type 3 constructions.

II. Durability Factors

In the case of reinforced types of concretes and structures or concrete structures, the durability factor is one of the most vital considerations. Since time measurement and scale are essentially important; the determination of concrete durability, in generality, is an uphill issue and task. Hence at the elevated degrees of temperatures, the factors of durability were obtained and determined by certain kinds of tests for CFFC. The tests were on the Volume of Permeable pore Voids (VPV), Water Absorption, Rapid Chloride Penetrations Test (RCPT), Sorptivity, and capacity resistance of the CFFC. On the tests conducted the resulting outcomes on durability properties of durability of CFAC (mix CF8) and CC (mix C6) have been presented.

II.i. Absorption of Water

The concrete characteristic for absorption is a major way and means for evaluating and assessing its durability it. This absorption of water is also defined and delineated as the transportation of the liquids in solids which have innumerable pores, which is due to the surface tension caused, which is acting in capillaries in them for absorption (Basher L. et.al., 2011) Water absorption of specimen scatters the indication of the volume into pores open. The figure below displays the absorption of water in CFFA with days under conditions of curing W1, W2, and W3. In the case of CFFC absorption of water in a period of 28 days was noticed to be 10.66 – 11%. It is dependent on the conditions employed for curing and the values of absorption reduce with days enhancing and increasing. In the period of a smaller number of days, specimen absorption of water did not show any distinctive effect. It was due to the various conditions of curing.

The absorbed moisture in LWC before batching from the aggregates pre-soaked it behaves as a reservoir internally. This ultimately assists and helps to the process of curing prolonged and longer. This curing period getting elongated and enhanced facilitates more additional number of days; than required for the curing internally. It was far beyond that normally given for the matrix of NWC (Holm T.A. and Bremner T.W. 2012). However, in the stages later major differences between curing and the rate of low degree of absorption were found. Hence curing in a proper manner is essential for CF aggregate foamed concrete to obtain greater durability in later stages of the concrete life.

Most of the LWCs have the capacity for higher water absorption in general in relation to NWC. It is only due to the porosity of concrete being higher in LWA cases. It is found that pumice aggregates in LWC measured approximately 4.8 to 16.7% of the absorption of water (Sahin R. et. al., 2016). Nonetheless, a review of accurate literature on the topic reveals that a comparatively higher and greater rate of water is absorbed. It absorbs at the rate of around 14 to 22% in the case of pumice aggregate LWC structures (Guduz L. and Ugur I., 2015). The capacity for absorption of water has the same outcome in pumice concretes which is valued in the span of around 19.1–22.2% (Sari D. and Pasamehmetoglu A.G., 2018).

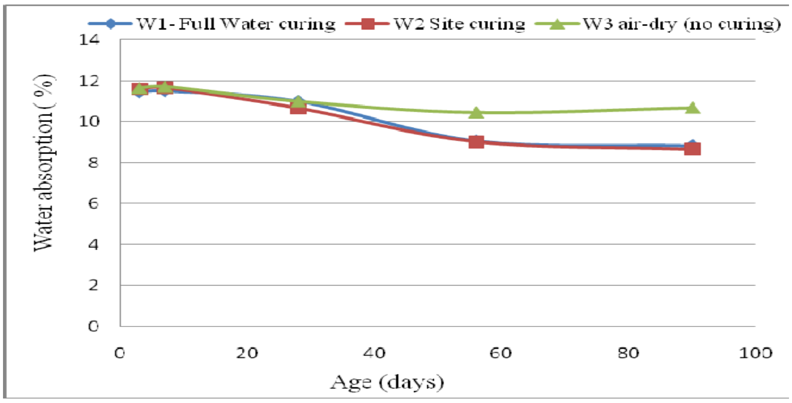
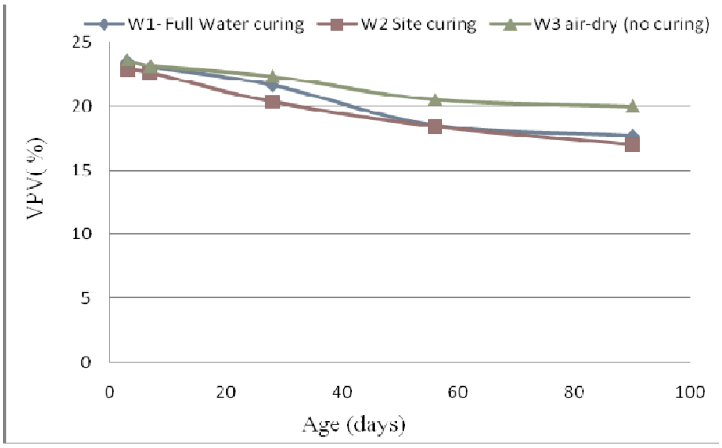


Fig. 1. CSAC Absorption of Water (Source: Own database, 2024)

II.ii. The volume of Permeable Voids (VPV) of CFFC

The volume of Permeable Voids (VPV) of CFFC is aptly cured in W1, W2, and W3 in different stages of curing conditions is displayed below in the figure. In certain stages of day 3 and day 7, devoid of proper curing (W3) did not display distinctive outcomes in VPV about other specimens undergone the same curing process in conditions (W1 and W2). An identifiable difference was observed between the W3 (specimen which was uncured with water) and W1 (Specimen cured with water). It was because the absorbed wetness from the presoaked aggregates; before batching; treated as a domestic reservoir. This performance helped and assisted to prolong and lengthening the process of curing of products tested. The process of curing with better, improved, and advanced curing will cater numerous a greater number of days of curing done internally. In exceeding that this was as such normally given for the NWC matrix (Sahin R. et. al., 2006). It is a clear indication and recommended that though the aggregates of CF even render domestic curing for a longer period, curing of the exterior properly is essential to lessen the voids in their volume in the concrete. This is specifically in the much later stage.

Fig. 2. VPV of CSAC: Different Conditions of Curing (Source: Own Compilation, 2024)



Normally values of around 12-16%VPV are found in conventional NWC (Khatib J.M. and Mangat P.S. 1995). The above table demonstrates the outcomes of pore voids permeable under the conditions of curing viz. W1, W2, and W3. VPV of CFFC VPV spans from about 0.38 to 22.35% in a period of 28 days. The resulting inference displayed that the usage of aggregates of CF barely contributed to and influenced to increase and enhancement in the grand aggregate total of VPV in relation to and compared to the normal and conventional NWC. This is attributed to the nature of porosity and absorbent characteristics of CF aggregate in the given conditions. On the other resulting outcome found in the research study was better than the rest of LWA concretes, wherein the VPV quality span from 8.6% to 22.5% approximately.

Table 1: Permeable Pore Voids Volume and Their Outcome

Testing Days	**Void Percentage in Types of Curing**		
	W1	**W2**	**W3**
3	23.55	22.90	23.60
7	23.05	22.66	23.15
28	21.64	20.38	22.35
56	18.51	18.44	20.54
90	17.71	17.01	20.00

(Source: Own Compilation, 2024)

III. Sorptivity Behaviour

Sorptivity behaviour offers a practical and pragmatic display and warning of concrete pore structures existing. The low and lesser sorptivity behaviour values reflected higher and greater opposition towards the absorption of water in the concrete. Commonly it is observed that the concretes with better quality have sorptivity characteristic values which are lower and lesser than around 0.1 mm/min0.5. The essential sorptivity character of CF concrete aggregated is given in the table below. The sorptivity character of CF concrete aggregate at 28 days was found to be around 0.095–0.104mm/min0.5. This was in W1 by curing with water fully. Similarly curing with water fully was about0.055– 0.065 mm/min0.5in W2 curing site, about 0.125–0.135 mm/min0.5in W3 under conditions for curing air dry, and so forth. The values mentioned were compared with the other LWC which are prepared and developed from the expanded shale (Liapor) and sintered pulverized fuel ash (Lytag). These have sorptivity characteristic values of around 0.03 and 0.06 mm/min0.5in sequence. CFFC relatively has a lower and lesser sorptivity value. This is due to the cement paste being higher and better quantity and quality. This was produced and manufactured with a lower and lesser w/c ratio, which is of the rate of 0.42 only. It argues that a higher and better degree of compaction was demonstrated to improvise and develop the concrete sorptivity character for reduction or elimination of the pores that are bigger in the paste (Hall C. and Yau MHR, 1987). The method of compaction which is adopted and taken up for CFFC ostensibly and empirically looks to produce and generate any concrete with a lower level and degree of sorptivity behaviour. In a host of the coarse type of LWA, a paste of cement slowly infiltrates into the outside aggregates into a specific depth and deep. It results improve and enhance the inter-facial zone of the aggregate (Saricimen H.et. al., 1996). This as well will be the same in CFFC. This improvised and advanced interface zone of the aggregate together with the aggregate capacity of CF to cater to curing internally results and infers in the lesser and low sorptivity character in the specimens cured (W1 and W2 curing) about specimens that are uncured (curing W3). The Sorptivity characteristic values of the CFFC at various stages and days within these three conditions of different curing are demonstrated in the figure below.

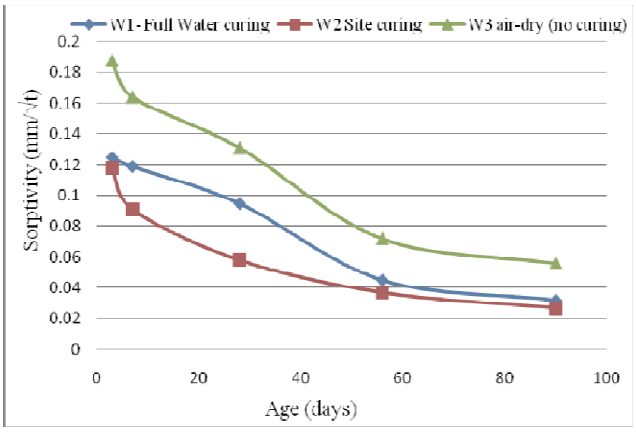


Fig. 3. CSAC Sorptivity in Different Conditions of Curing (Source: Own database, 2024)

Table 2: CFFC Sorptivity Results in Curing W1

Time (t) Min	Sorptivity Reading (mm/ √t)				
	3 Days	7 Days	28 Days	56 Days	90 Days
0	0	0	0	0	0
1	0.128	0.121	0.100	0.047	0.033
2	0.127	0.122	0.102	0.046	0.032
3	0.126	0.124	0.103	0.046	0.033
4	0.125	0.119	0.104	0.047	0.032
6	0.124	0.118	0.103	0.048	0.031
9	0.126	0.123	0.104	0.048	0.031
12	0.127	0.124	0.099	0.047	0.032
16	0.124	0.123	0.099	0.046	0.032
20	0.122	0.120	0.098	0.047	0.031
25	0.126	0.122	0.097	0.046	0.031
30	0.125	0.119	0.096	0.045	0.032
45	0.126	0.120	0.096	0.044	0.031
60	0.128	0.121	0.095	0.045	0.029

Source: Own Compilation, 2024

Table 3: CFFC Sorptivity Results in Curing W2Curing

Time (t) Min	Sorptivity (mm/ √t)				
	3 Days	7 Days	28 Days	56 Days	90 Days
0	0	0	0	0	0
1	0.121	0.093	0.065	0.037	0.027
2	0.123	0.091	0.063	0.037	0.026
3	0.122	0.088	0.055	0.036	0.025
4	0.120	0.089	0.057	0.037	0.027
6	0.119	0.090	0.059	0.039	0.028
9	0.122	0.091	0.058	0.038	0.027
12	0.125	0.095	0.058	0.039	0.028
16	0.125	0.094	0.058	0.036	0.025
20	0.121	0.092	0.057	0.036	0.025
25	0.120	0.090	0.056	0.038	0.026
30	0.118	0.091	0.058	0.037	0.027
45	0.119	0.089	0.057	0.035	0.025
60	0.121	0.091	0.061	0.033	0.024

Source: Own compilation, 2024

Table 4: CFFC Sorptivity Results in Curing W3

Time (t) min	Sorptivity (mm/ √t)				
	3 Days	7 Days	28 Days	56 Days	90 Days
0	0	0	0	0	0
1	0.186	0.167	0.130	0.075	0.064
2	0.186	0.166	0.132	0.075	0.062
3	0.184	0.164	0.128	0.074	0.054
4	0.188	0.167	0.129	0.072	0.058
6	0.190	0.171	0.135	0.077	0.058
9	0.192	0.171	0.133	0.076	0.057
12	0.185	0.164	0.130	0.075	0.056
16	0.186	0.167	0.129	0.073	0.057
20	0.184	0.166	0.134	0.073	0.055
25	0.184	0.165	0.133	0.071	0.055
30	0.188	0.164	0.131	0.072	0.056
45	0.184	0.165	0.133	0.068	0.055
60	0.183	0.164	0.125	0.066	0.054

Source: Own compilation, 2024

III.i. Rapid Chloride Penetrability Test (RCPT)

The results of RCPT for CFFC and CF specimens are demonstrated in the two figures below respectively. RCPT treatment values in CFFC in 28 days vacillate from around 2765 to 3880 coulombs. In 28 days, like that, the treatment values for CFspan were from 2460 to 2690 coulombs in the reading. The relevant literature says that for LWC made from clay which is expanded, the RCPT value spans from around 2115 to 3336 coulombs. In the invitation to Table below the CFFC and CC display moderate and modest chloride-ion penetrability, where in different conditions specimens are cured viz. W1, W2, and W3 by creating a greater quality of CFFC for their varied usage. Though RCPT treatment values show the penetration of chloride moderately, reduction in charge with the passing of age demonstrates improvisation and increase in structure pores in CFFCmatrix. It is established with factor evaluation scales and measures.

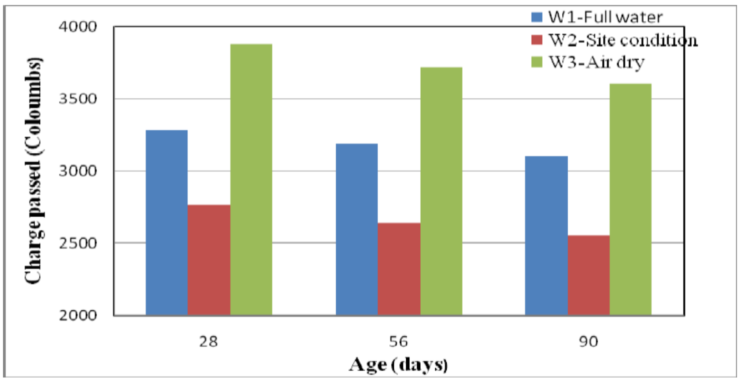


Fig. 4. CFAC RCPT Values of in Curing Differently (Source: Own compilation, 2024)

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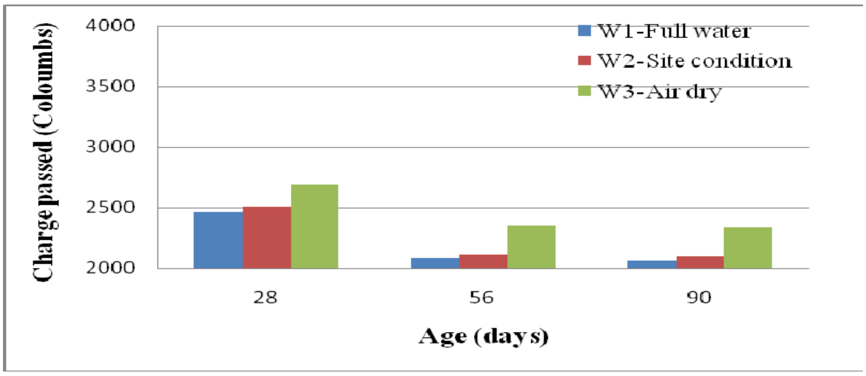

Fig. 5. Values of RCPT of CC in Curing Differently (Source: Own compilation, 2024)

Table 5: Rating of RCPT Ratings as per ASTM C1202

Passed Charge - coulombs	Penetrability of Chloride Ion
> 4,000	High
2,000-4,000	Moderate
1,000-2,000	Low
100-1,000	Very Low
< 100	Negligible

(Source: Own compilation, 2024)

As was observed and found specimen's level of temperature in the context continued to enhance and increase when the testing started progressing. After the tests were completed, it was observed that the temperature became higher on tested specimens. It was determined and obtained from the examination of the physical properties of the specimens subjected to tests. The standard research literature demonstrates that the occurrence of this phenomenon is there because the lower and lesser grade and quality of concretes; in comparison to HSC and HPC concretes; tend to generate more heat because temperature rise is directly related to the voltage and current product. Therefore, the lower and lesser the concrete quality; the greater and higher the current in a set voltage, causing and generating greater energy heat production. This heating process takes more and more increase and enhancement in the charge that is passed over. It can be experienced and validated when the temperature is tested; and when it remains constant. Finally, and conclusively conclude that the concretes with lower and lesser quality will be worse even; than what it would be otherwise in the context. Hence this is also in the case of CFFC. In the given context values of RCPT indicate the penetrability of moderate chloride. The decrease and reduction in charge which is naturally passed with the days/age display that there exists an improvement and enhancement of structure pores in the matrix of CFFC because of the process of continuous hydration in the products of cement.

IV. CFFC capacity of Resistance at Temperatures when Elevated

After 28 days specimen cubes sinked in water were taken outside. Wiped off with the grit and surface water from the specimens. The small tiny fins projecting fins were trimmed and removed from the specimens. These specimens after that were placed in the furnace. It was heated at 100°C, 200°C, 300°C and 400°C. It was done for periods 1, 2, 3, and 4 hours respectively for the specifics. Inside the heating furnace; after placing the specimens inside, the temperature was fixed at 100°C, 200°C, 300°C and 400°C. Then the requisite time was ensured and allowed to reach and achieve the temperature peak inside the furnace, to the requisite desired level of temperature. These specimens were permitted and allowed inside the furnace for 1-2-3 and 4 hours respectively. This duration of time was calculated and measured when the furnace attained the temperature peak. Three cubes were placed and used for the test in each of the cases. Later than the duration of the specific allocated time, these specimens were enabled and allowed in the heat furnace slowly normally cooling to the normal temperature of the room before testing for the strength of compression. Concrete when heated to higher temperatures, because of the chemical and physiological changes, the existing natural colour changes and it keeps changing. In the specimen, these colour changes and fine cracks that were formed in the process of reaction were observed in specimens. They were observed for meticulous changes. The outcome of the temperature test results on the CFFC cubes are found to be an average of the three specimens tested. They are also demonstrated in the Table below. Due to temperature variation; surface cracks and colour change formation on CFFC have been demonstrated in Figures below at 100°C, 200°C, 300°C, and 400°C for a duration/period of 4 hours in each of the cases respectively and accordingly.

IV.i. Cubes of CFFC in Different Temperatures for a Duration

It was tested with the cubes of CFFC at 100°C, 200°C, 300°C, and 400°C for 4 hours and the results are shown below.

Table 6: CAAC Test of Temperature Results of Cubes

Temperature	(h) Duration	Weight Loss (kg/m^3)	Strength of Residual (N/mm^2)	Strength of Residual (percentage)
100°C	1	10	24.90	93
	2	22	22.00	82
	3	45	18.10	68
	4	68	18.00	67
200°C	1	155	20.20	76
	2	230	18.40	69
	3	254	15.40	58
	4	278	13.20	49
300°C	1	256	11.20	42
	2	370	8.70	33
	3	430	6.80	25
	4	497	5.95	22

400°C	1	317	9.75	37
	2	463	6.55	25
	3	522	5.30	20
	4	560	4.50	17

(Source: Own compilation, 2024)

The properties of correlation were studied. It was done between the residual strength and colour changes on the temperature variation which were established for concretes that are conventionally produced (Viswanatha C.S., 2017). These are reflected in the tables below respectively.

Table 7: Colors of Concretes Conventionally Produced Due to Temperature

Range of Temperature	Conventional Concrete Colours
0º - 300º C	In Original Colours noChange
300º - 600º C	Red or Pink Colour
600º - 900º C	Whitish Gray or Purple Colour
Above 900º C	Buff Colour

Source: Own Compilation, 2024

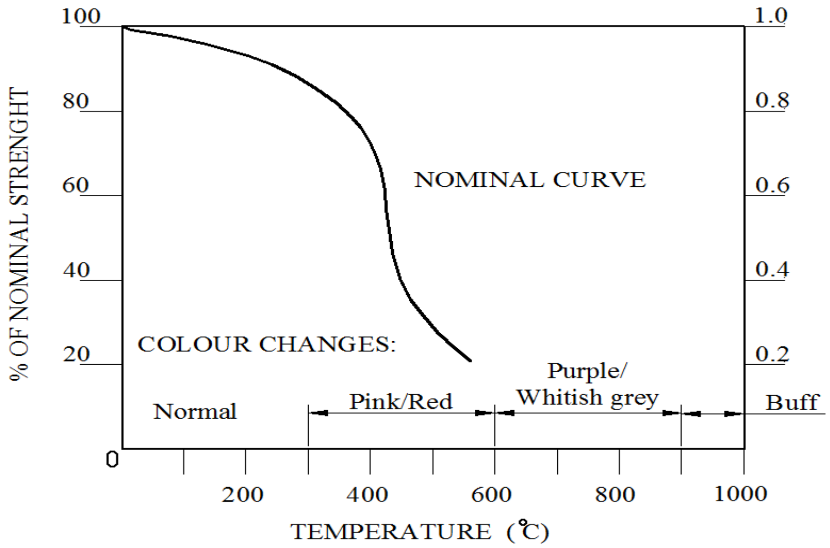

Fig. 5. Residual and Colour Strength Versus Concrete Temperature
(Source: Own compilation, 2024)

V. CFAC Changes in Colour

Concretes which are conventional do not change their colour up to 300ºC. Their bare residual strengths are 98-92-88 and 70 percent at 100ºC-200ºC-300ºC and 400ºC respectively (Swamy R.N. and Ibrahim A.B., 2017). This CFAC research study reveals that up to a degree of 100°C after a duration and span of 3 hours; no change in colour takes place. However, after a period of 3 hours at a degree of 100°C CFAC colour change in to a light faint white colour. Then at around temperature 200°C up to 1 hour, no change in colour takes place, again after 1 hour and 2 hours changing of colour takes place to a light faint brown. Similarly, after 3 hours change in colour takes place from a faint light brown to a faint yellow-brown colour. At a temperature of 300°C after 1 hour and 2 hours, change in color takes place to a faint brown colour. After 2 hours colour changes to a faint whitish gray and then it slowly changes to a faint white colour. At a temperature of 400°C for 1 hour change in colour takes place to a faint light brown, after 1 hour change in colour takes place to a faint light ash colour. Then after 2 hours change in colour takes place from faint light ash to faint light yellow, and after 3 hours change in colour takes place from faint light yellow to faint light gray.

V.i. CFAC Residual Strength

The CFAC residual compressive strength is found to be approx. 93-82-68 and 67 percentage at a temperature of 100°C at a period and duration of 1,2,3 and 4hours,76-69-58 and 49 percentage at temperature 200°C at a duration of 1,2,3 and 4hours, 42-33-25 and 22 percentage at temperature 300°C at a duration of 1,2,3 and 4hours,37-25-20 and 17 percentage at a temperature of 400°C at a duration of 1, 2, 3 and 4hours respectively. This is of its original strength. The figures below display temperature versus residual strength and time versus percentage of residual strength of the CFAC under study.

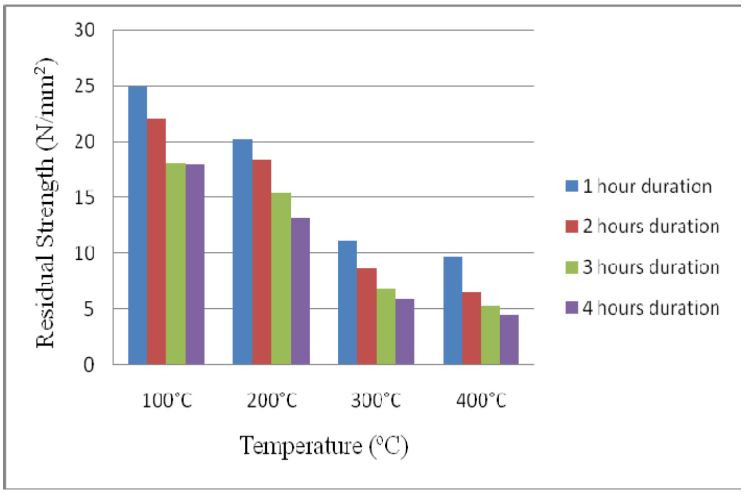

Fig. 6. CFAC Residual Strength Versus Temperature (Source: Own compilation, 2024)

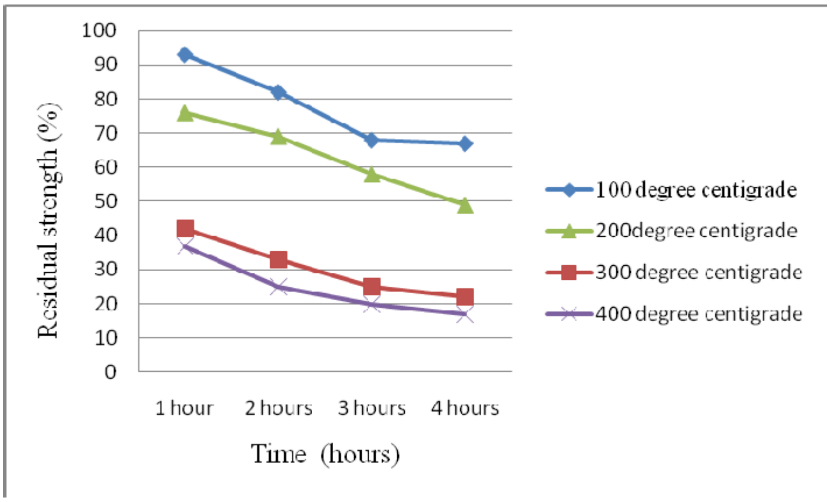

Fig. 7. CFAC Residual Strength Percentage Versus Time (Source: Own database, 2024)

VII. Remarks and Conclusion

The properties of durability in the coconut fibre aggregate concrete, in the given test volume for its sorptivity, permeable voids, and rapid chloride penetration, essentially in values, do reasonably compare to other researchers which they have obtained as per the criteria. Herein the test of rapid chloride penetration resulting outcomes span from around 2765 to 3880 coulombs throughout 28 days. This measure shows a moderate chloride-ion penetrability in the material. Nonetheless, the decrease and reduction in charge travelling and passed with the concrete days/period, demonstrate that there is reasonable improvement in the structural pore in the matrix of coconut fibre aggregate concrete. It happened for the continuous process of hydration in the cement products under test. When in a standard process CFAC is subjected and exposed to a temperature of 100 ºC for 4 hours and to a temperature of 200 ºC for 2 hours, the residual strengths of the product are found to be 18 N/mm2 and 18.40 N/mm2 respectively which is evidently measured. These all findings of values essentially satisfy the standard criteria of the structural LWC strength (ASTM C 330) [176], which barely requires a minimum period of 28 days of compressive strength and greater than 17 N/mm2. These CFAC tests recommend that it can provide a fire resistance of 2 hours (Santhakumar A.R., 2017). Thus, this type of CFAC can be categorically classified and recommended for type 3constructions. Hence the classified category is proved for practical use in concretes intended. The use of coconut fibre aggregate concrete as structural lightweight concrete for thermal conditioning and insulation is highly recommended for use. This coconut fibre aggregate is a potential construction material, a material for thermal conditioning, and is durable for sustainable use as a CFAC.

Conflicts of interest

All authors declare that they have no conflicts of interest regarding this article.

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