Strength development and crack pattern of coconut fibre reinforced concrete (CFRC)

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Abstract. Concrete fails suddenly under tension and cracks excessively when unreinforced. Steel rebar is conventionally used to reinforce concrete. However, it is expensive to many people in most developing countries. In tropical regions, natural fibres are abundantly available which when utilized will reduce cost of construction and improve performance.This paper focuses on the use of coconut fibres as reinforcement in concrete. Coconut fibres were extracted from coconut seeds and chopped into 40 mm in length. Concrete of mix ratio 1:2:4 was produced which contains coconut fibre of 1, 2, 3 and 4% by weight of cement. Compressive strength and modulus of rupture of CFRC specimens were determined following standard procedures at curing ages of 7, 21, 28 and 56 days. Also, crack pattern was monitored. The results showed that the water-cement ratio increased from 0.62 to 0.70 as coconut fibres (CF) increased from 0 to 4%, while the compressive strength only increased up to 2% CF but dropped afterwards when compared with normal concrete (NC). At 28-day, flexural strength of CFRC were 2.73, 2.79, 2.88 and 3.01 N/mm^2 at 1, 2, 3, and 4% CF content representing 107.5, 109.8, 113.4 and 118.5% of NC. There was gradual tensile failure in CFRC with minor to hair-like crack as compared to sudden failure with wide crack from tension zone to compression zone in NC. The study concluded that up to 2% content of CF is recommended for concrete reinforcement.

1 Introduction

Concrete fails suddenly under tension and cracks excessively when unreinforced. Steel rebar is conventionally used to reinforce concrete. But, it is expensive to many people in most developing countries. In tropical regions, natural fibres are abundantly available which when utilized will reduce the cost of reinforced concrete and improve its performance.

The use of natural fibre as reinforcing material is as old as man. Egyptians used straw in making mud bricks between 1200 and 1400 BC while in 2500 BC asbestos fibres were used in Finland to make clay pots [1]. However, the usage was more of tradition than technical.

In the recent past, there has been growing interest in studying the properties of coconut fibres and coconut fibre reinforced composite. In the work of Rao et al. in [2], tensile strength, specific tensile strength and density of coconut fibre were studied. They reported that the tensile and specific tensile strength were 500 MPa and 0.43 MPa respectively while the density was 1150 kg/m^3. But Munawar et al. [3], who measured similar parameters, found that the tensile and specific tensile strength and density were 137 MPa, 158 MPa and 870 kg/m^3 respectively. Different values were also reported by [4, 5]. The divergent reported properties of coconut fibres suggested that they do not have standard properties.

On the use of CF as reinforcing material in concrete, Baruah and Talukdarin [6], studied the strength characteristics of concrete containing between 0.5% and 2% coconut fibre (CF) of length 4 cm. They observed that strengths increased with increase in fibres volume fraction. The compressive strength, splitting tensile strength, modulus of rupture and shear strength were increased up to 13.7, 22.9, 28.0 and 32.7 % respectively. They concluded that natural fibres may be good alternatives to relatively more expensive steel, polyester or glass fibres.

Noor et al. [7] carried out a study on the physical and mechanical properties of concrete produced using chemical treated coconut chopped fibres in the proportion of 1.0, 3.0, 5.0 and 7.0% by volume. The concrete specimens were subjected to static loading. Their results showed that treated CF performed better than the raw ones. But the compressive strength decreased as the volume of CF increased for all the mixes. They concluded that CF can be used to produce structural lightweight concrete in the case of low-cost constriction.

But, dynamic properties of coconut fibre reinforced concrete (CFRC) showed that damping of CFRC beams increases and natural frequency decreases with increasing damage due to static loading for all cases. CFRC beam with 3 % fibre content has the highest damping and lowest natural frequency in the uncracked and cracked stage as compared to that of CFRC beams with fibre contents of 1 and 2 % [8].

Durability of coconut fibre was studied. Sivaraja*et al*[9] investigated the performance of CRFC in sulphate environment. Effect of freezing and thawing was equally studied. They reported that CFRC concrete was less susceptible against sulphate attack in terms of mass loss and compressive strength deterioration while the effect of freezing and thawing on natural fibre reinforced concrete was higher than conventional concrete, the difference in mass loss and relative modulus of elasticity between fibre reinforced and conventional concrete was acceptable. They concluded that application of natural fibre reinforced concrete would be limited in marine areas. In the alkaline cement medium, fibre was reported undamaged after 12 years [10].

In Nigeria, large quantities of coconut fruits are produced mostly in the rainforest zone of South-West and South-South regions of the country with minor production in other geo-political zones [11]. According to [12] an estimated 36,000 hectares is cultivated while an estimated of 211,050 metric tonnes are produced annually as at 2010.

Despite large quantity of coconut fibre produced in the country, its usage has remained localized. It is being used to produce briquette as source of fuel for cooking, roofing materials and as fillers in pillows and beds. However, the shift to the use of petroleum products (gas and kerosene) as fuel, which is more convenient, lack of improved technology, as well as durability and stability problems associated with coir as roofing material have continued to militate against the full utilization of coconut fibres. The use of CF in concrete could be the best alternative way of recycling this waste. Since CF properties differ as the location and variety differ, there are scarce reports on the use of CF produced in the country as reinforcing material. Thus, this study becomes necessary. If the results are found suitable, the huge volume of CF available for disposal will be utilized to make construction more sustainable. The results from this study could also add to the body of available data on the use of CF in concrete.

2.0 Materials and Methods

2.1 Materials

The cement used in the study was Ordinary Portland Cement (OPC). Table 1 summarizes the chemical and physical properties of the cement. River sand of maximum particle size of 3.18 mm and crushed granite (maximum size of 12.5 mm) were used as fine and coarse aggregates while potable water was used as mixing water.Coconut fibres (CF), brown type, were collected from a local coconut processing centre in Epe, Lagos State, Nigeria (Figure 1). Strands of the fibre were extracted from the compressed natural form and chopped into uniform sizes of 40 mm long.

2.2 Mixing and Preparation of Samples

Concrete of mix ratio 1:2:4 (cement: sand: granite) which contained chopped CF of 1, 2, 3 and 4% by weight of cement was prepared with varied water-cement ratio. Then concrete cubes of sizes 150 mm and beams (150× 150 × 760 mm) were cast and cured in water for 7, 21, 28 and 56 days before testing. The mixing was thorough to ensure that the coconut fibres were evenly distributed within the concrete matrix. The same approach was adopted by [6].

Table 1: Properties of Cement

Material	**Chemical composition (%)**									**Physical properties**	
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**	**LOI**	**Sp. gravity**	**Fineness (m^2/Kg)**
OPC	18.33	5.00	2.75	60.11	1.15	3.21	0.08	0.00	7.22	3.09	355

Figure 1: Pieces of Red Coconut Fibres

2.3 Methods

2.3.1 Sieve Analysis and Properties of Aggregates

In order to determine the suitability of the aggregates used in this study, the particle size distribution of both the fine and coarse aggregates were carried out in accordance with BS 1377 Part 1 and 2. The particle size distribution curves were plotted. The grading for the aggregates and their relative combinations were numerically expressed in terms of uniformity coefficients (Cu) and curvature (Cc). Also, the water absorption and specific gravity of the aggregates were determined.

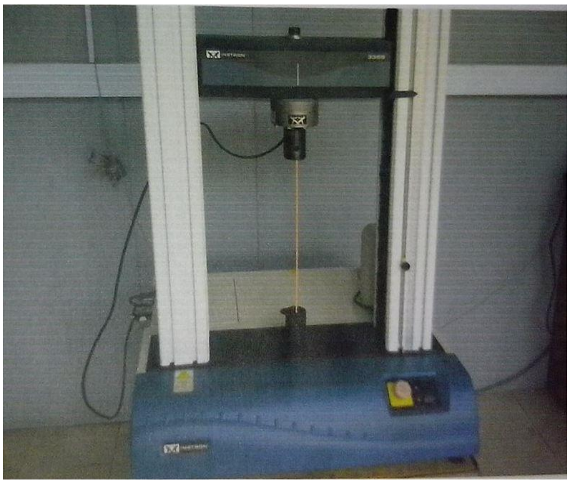


Figure 2: Testing of Tensile Strength of Coconut Fibre Using Instron Machine

Diameter and density of the CF were also determined. Average of 10 readings was recorded in each case.

2.3.3 Slump, Compressive and Flexural Strengths of Coconut Fibre Reinforced Concrete

The slump for each of the concrete mix was determined in accordance with the provisions of BS 1881:Part102. In order to maintain the same consistency for all the mixes, the slump value was kept at 60 mm and the water-cement ratio to achieve that was measured. Compressive strength test at the end of each curing age was performed as described in BS 1881-107. The experimental set up for flexural strength is shown in Figure 3. The force that caused flexural failure was recorded and the flexural strength as expressed as modulus of rupture (MOR) was determined from the Equation (1) of ASTM C78. Average of three readings was recorded for each concrete mix specimen. Flexural crack progression was monitored.

2.3.2 Properties of Coconut Fibre

The tensile strength of the CF was determined using Instron mechanical testing machine (Figure 2) at Centre for Energy and Research Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria. The procedure specified in ASTM D638 – 10 was followed.

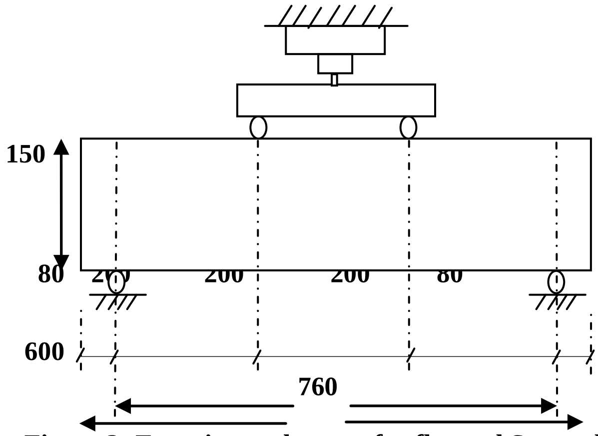


Figure 3: Experimental set-up for flexural Strength Test

3.0 Results and Discussion

3.1 Particle Size Distribution and Physical Properties of Aggregates

The particle size distribution curves of the sieve analysis carried out on the aggregates (fine and coarse) are shown in Figure 4. The coefficients of uniformity (Cu) were 2.85 and 2.33 while that of curvature (Cc) were 1.03 and 1.08 for sand and granite respectively (Table 2). These coefficients are within the values accepted for well graded aggregates [13]. The import of this is that the aggregates are fit for concrete production. The specific gravities were 2.56 and 2.62 respectively; their water absorption capacities were 18.3 and 17.10 for sand and crushed granite respectively.

3.2Physical and Mechanical Properties of Coconut Fibre

In order to assess the characteristics of coconut fibre used in this study, the parameters that measure its physical and mechanical properties were determined. The average results as compared to those of other researchers are presented in the Table 3. It is observed that the average diameter, length and density of the coconut fibre are 0.32 mm, 82.23 mm and 720 kg/m3

These values are within the range proposed by other authors (Table 3). But for the mechanical parameters, tensile strength and tensile strain were 1.66 MPa and

respectively.

0.31 respectively while the elongation was 31.8%. The results differ appreciably from those obtained by [14, 15, 5, 4].

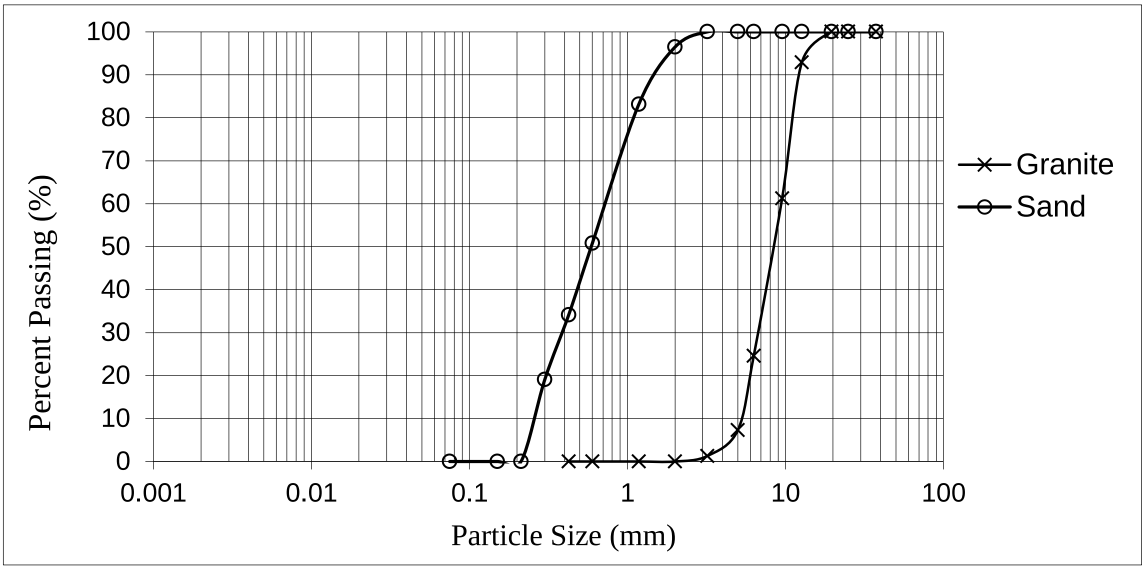


Figure 4: Particle Size Distribution Curves for the Sand, Granite and PKS.

The difference could be attributed to test conditions and variations in coconut fibres from different part of the world. Despite the relative low tensile strength, it is observed that the CF used has resistance to break easily as shown by the elongation value (31.8%) compared to values of other authors and as shown in the stress-strain deformation of the CF specimen (Figure 5). The elastic modulus could be determined by determining the slope of the linear portion of the curve. The variations in properties of coconut fibres make it difficult for their frequent use as construction materials[16]. Thus, it is necessary to test CF for its mechanical properties whenever it will be used.

Table 3: Properties of Coconut Fibre

Reference	Physical Properties			Mechanical Properties		
	Diameter (mm)	**Length (mm)**	**Density (Kg/m3)**	**Tensile Strength (MPa)**	**Tensile Strain**	**Elongation (%)**
***Coconut Fibre (strand)**	**0.32**	**82.23**	**720**	**1.66**	**0.31**	**31.8**
[3]	0.40- 0.10	60- 250	-	15- 327	-	-
[13]	0.11– 0.53	-	670- 1000	108- 252	-	13.7– 41
[14]	0.1- 0.4	-	-	174	-	10 - 25
[4]	0.27 ± 0.073	-	870	137 ± 11	-	-

*Average test results of this study

3.3 Effect of Coconut Fibre on Mixing Water Requirement

In order to ensure constant consistency for all the mixes, the workability of the concrete mix was fixed with a slump value of 60 mm. The value selected was to produce true slump of workable concrete. The water-cement ratio required to achieve the slump as the content of coconut fibre varied is presented in Table 4.

It is observed that the w/c increased as the content of CF increases. At 1, 2, 3 and 4% content of CF, the w/c were 0.63, 0.66, 0.68 and 0.70 respectively while the normal concrete had w/c of 0.62. This indicated that CF absorbed moisture. Since concrete required moisture for its strength development, the use of CF could be an advantage in this regard and could cause biodegradation of the fibre at later age.

3.4 Compressive Strength of Coconut Fibre Reinforced Concrete

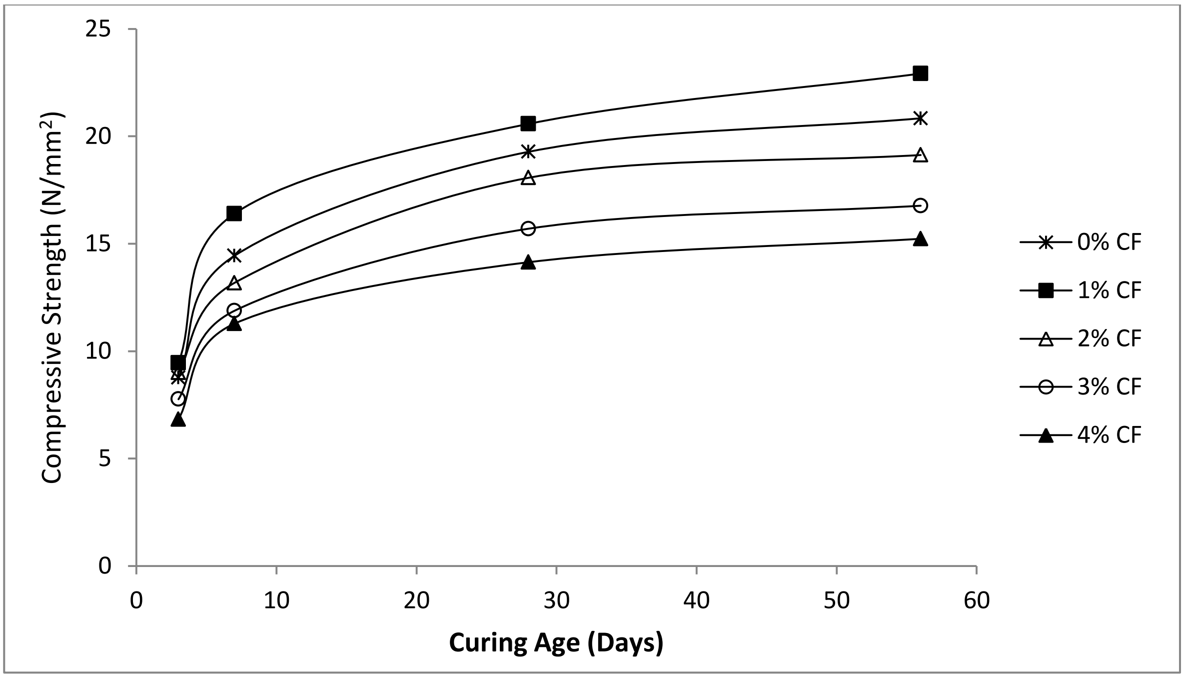
The compressive strengths of the concrete containing different proportions of CF are plotted against curing ages as shown in Figure 5. It is observed that, for all the mixes, the strength increased with age. It is also observed, with the exception of 1%, that the compressive strength decreased with increase in CF content. On monitoring strength development, it is seen that, at early age of 3 days, the compressive strength of concrete mixes containing 1 and 2% CF were 9.45 and 9.01 respectively as against that of normal concrete (8.77) while the concrete mixes with 3and 4% CF were in the order of 7.76 and 6.83. Similartrend was observed in case of 7-day strength only that normal concrete had strength higher than that of concrete containing 2%. But, at 28 days, when the strength of normal concrete was compared with that of CFRC of 1%, the compressive strength was 6.7% above strength of normal concrete, and is reduced up to 6.3, 18.6 and 26.7 % for CFRC with fibre content of 2, 3 and 4%.

Similar pattern was observed in case of 56-day strength. It is interesting to note that, the 28-day strength for normal and up to 2% CFconcrete were above the minimum strength of 17 for use as structural concrete.

The test results showed that coconut fibre had influence on the compressive strength development of concrete. At lower content of CF, up to 2%, the relative increase in strength observed could be due to the potential of CF to resist compressive stress. But higher fibre content in CFRC might have caused voids resulting in decreased compressive strength.

Table 4: Effect of Coconut Fibre on the Water-Cement ratio at Constant Slump

Content of CF (%)	Water/Cement Ratio	Slump(mm)
0	0.62	60
1	0.63	60
2	0.66	60
3	0.68	60
4	0.70	60



3.5 Flexural Strength of Coconut Fibre Reinforced Concrete

Flexural strength (or modulus of rupture) is one of the principal factors in concrete pavement design as it measures the resistance of the concrete to flexural force. Results of the flexural strength test for all the concrete mixes containing different volume fraction of CF are presented in Table 5. Increased flexural strength of CFRC is evident compared to normal concrete. It is observed that the flexural strength increased with increase in fibre fraction from 1 to 4% for all the ages. Quantitatively, at age 3 days, flexural strength increased from 1.52 for normal concrete to 2.51 for 4% CF concrete representing about 65% higher. Also, at 7, 28 and 56 days, the flexural strength of 4% CFRC were about 145, 118 and 118% of the normal concrete (0%)

respectively. It was observed that the relative increase in flexural strength reduced with age and became constant between 28 and 56 days (118%). The implication of this was that, CF did not influence the relative flexural strength at later age. It could also be attributed to the fact that coconut fibre is biodegradable and possibly reduced bond strength between concrete ingredients which may result in early failure compared to when less volume of fibres are used. However, improved flexural strengths noticed at early ages could be due to increased denseness of the paste, improved paste-aggregate bond and occasioned by the presence of coconut fibre. Due to the possible negative effect of higher volume of CF in concrete, a maximum of 2% volume fraction could be recommended.

The relationship between compressive and flexural strength could be assessed by the strength ratio (SR). Strength ratio, as used in this study, denotes the ratio of flexural strength to corresponding compressive strength. The SRs for all the concrete specimens at different ages are summarized in Table 5. It is noticed that SRs increased with increase in fibre content but reduced with increase in age but became relatively constant at 28 days and above. The reason for this may be credited to positive influence of age on compressive strength (Figure 5) and relative low flexural strength at 28 days and above.

This trend further confirmed that age did not appreciably influence flexural strength of CFRC especially at ages above 28 days due to possible degradation of CF in the alkaline concrete medium. However, this defect could be minimised by pre-treatment of the fibre which was not considered in this study. The alkaline and acidic effect on CFRC had been studied extensively by [9]. Results of this study are comparable with those obtained by [17 and 7].

Table: Flexural Strength and Strength Ratio of Concrete Fibre Reinforced Concrete

Coconut Fibre (CF) Content (%)	Flexural Strength (N/mm^2)				Strength Ratio (SR)			
	Curing Age (Days)				Curing Age (Days)			
	3	7	28	56	3	7	28	56
0	1.52	1.96	2.54	2.73	0.173	0.136	0.132	0.131
1	2.1	2.44	2.73	2.92	0.222	0.149	0.133	0.133
2	2.31	2.72	2.79	3.01	0.256	0.206	0.154	0.157
3	2.41	2.84	2.88	3.09	0.311	0.239	0.183	0.184
4	2.51	2.85	3.01	3.23	0.367	0.253	0.213	0.212

3.6 Effect of Coconut Fibre on Flexural Crack of Concrete Beam

When concrete beams are subjected to flexural loading, there is tendency for flexural stress to develop which has the potential to initial cracks when the concrete carrying capacity is exceeded. The absence of crack is of considerable importance in maintaining the continuity of a concrete structure and in many cases in the prevention of corrosion of reinforcement.

During flexural loading of the CFRC beams, it is evident that coconut fibre reinforcement directly affected the flexural cracks developed. Figure 6 shows the crack patterns for normal concrete (NC) beam and CFRC beams at 28-day testing. On visual observation, cracks initiated from the tension zone (bottom of the beam) where the bending moment was suspected to have been higher and progressed inward towards compression zone (top of the beam), *zero bending moment.* But, the crack was more pronounced in the case of normal concrete (NC) in which no fibre was used when compared with those with different volume fraction of fibres. It could also be seen that the crack reduced as the fibre content increases.

The interpretation of this behaviour could be attributed to the presence of CF which prevents progression of cracks due to crack-arresting, crack thinning and crack bridging effect of CF.

Generally, there appears to be at least three stages in the cracking process. In each stage, coconut fibre is suspected to play crucial role in arresting crack formation and progression.

In Stage I: before loading, intrinsic volume changes in concrete due to shrinkage or thermal movements can cause strain concentrations at the aggregate–paste interface. Within this stage localized cracks are initiated at the microscopic level and at isolated points throughout the specimen where the tensile strain concentration is the largest. This shows that these cracks are stable and, at this load stage, do not propagate. Luisito et al. in [18] showed that CF has low thermal conductivity which makes it suitable for roofing material. This is also an advantage in arresting crack. Since, CF is likely to have low thermal conductivity compared to other ingredients of concrete, its presence in concrete could stem down the thermal movements caused by heat of hydration developed in concrete matrix. Thus, it hindered the early formation of cracks.

During Stage II, as the applied load increased beyond Stage I, the crack system multiplies and propagates but in a slow stable manner in the sense that, if loading is stopped and the stress level remains constant propagation ceases. The extent of the stable crack propagation stage will depend markedly upon the applied state of stress, being very short for 'brittle' fractures under predominantly tensile stress states and longer for more 'plastic' fractures under predominantly compressive states of stress. In this Stage, concrete is need of material to sustain it in resisting the bending stress. As earlier established, CF is a tough materials that could provide needed resistance to limit propagation of cracks when optimum volume fraction is used.

At the last Stage, this occurs when, under load, the crack system has developed to such a stage that it becomes unstable and the release of strain energy is sufficient to make the cracks self-propagate until complete disruption and failure occurs. Once Stage III is reached failure will occur whether or not the stress is increased as shown in Figure 6 for normal concrete (NC). But, when CF is incorporated in concrete, this could be prevented as cracks propagate gradually (Figure 6).

NC (0%)

CFRC (1%)

CFRC (2%)

CFRC (3%)

CFRC (4%)

Figure 6: Crack Progression in Coconut Fibre Reinforced Concrete Beam under Flexural Loading

4 Conclusion

In this study, various volume fractions of chopped coconut fibre were used to reinforce concrete. The strength development and crack patterns were studied concluded as follows:

1. The water-cement ratio increased 0.62 to 0.70 as the volume fraction of CF increased from 1 to 4% by weight of cement. This indicated that

CF absorbed moisture which could be to the benefit of concrete at early stage when moisture is needed for strength development and could cause biodegradation of the fibre at later age.

2. Compressive strength increased with age for all the mixes and reduced with increase in volume fraction of fibres except at 1% CF. But, at 28th day, compressive strength of concrete containing 1% CF, was 6.7% above that of normal concrete, and is reduced up to 6.3, 18.6 and 26.7 % for CFRC with fibre content of 2, 3 and 4%.
3. Concrete containing various fraction volume of CF has flexural strength higher than that of normal concrete at different ages only that the influence was not appreciable above 28 days when the strength ratios were almost constant.
4. Flexural cracks reduced with increase in content of coconut fibre. Thus, Coconut fibre played substantial role to limit flexural crack formation and propagation at every stage of crack formation.

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