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Research Paper

Study on the performance of natural fiber reinforced concrete of different strength with DIP technique and T- Test Analysis

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This work focuses on the effect of natural plant fiber as reinforcement on the strength properties of concrete of different grade strength (M30-M50). Fibers of different length were added to the concrete mix at the rate 3% of the binder content. Three different lengths of fibers (10-30 mm) at fixed volume fraction were added to M30, M40 and M50 grades of concrete. The fresh and mechanical property of twelve different fiber reinforced concrete mixes was investigated. The effect of fibers on the pre cracking, post cracking behaviour of the concrete specimen was investigated using digital image processing technique and video measuring system images. Using the developed linear regression plot, empirical equations were formulated to establish relation between the compressive strength and other mechanical properties of concrete. From the study it can be concluded that the caryota fiber with rich cellulose content contributes to arrest the cracks at the initial stage of loading and prevents major crack plane in the post peak region. Fibers mainly contribute to increase the tensile property of concrete. The effect of fibers is more prominent in M30 mix concrete when compared to M40 and M50 concrete mixes.

1 Introduction

In the present environmental scenario, the concept of ‘sustainability’ and the term ‘ecofriendly’ plays an important role in the recent structural and economic development of construction industry. Naturally available materials such as wood, bamboo, hemp, jute, linen, straw, roselle, palm, sisal, abaca etc. and other ecofriendly materials which are available in abundance are used as the substitute for non-biodegradable and non-renewable construction materials. These natural materials are light weight, renewable and cost effective with zero impact to the environment [1]. New type of fibers such as kapok were used as bio fiber reinforcement to modify the rheological properties of virgin bitumen [2]. Giant reed fibers were used in bio lime-based mortar to improve the flexural toughness and used in the production of eco-compatible prefabricated bricks

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or joint mortars for masonry [3]. Water hyacinth fiber along with banana fiber and eggshell powder were used as biomaterial fillers for concrete reinforcement [4]. Prosopis juliflora bark along with banana fiber and Coconut fiber were used as bio fibers along with epoxy to produce hybrid bio composites [5]. Many new natural plant fibers are identified and used in combination with synthetic fiber and finds its application in automobile industry, structural application and construction industry. One such natural plant fiber is the kithul palm fiber which is also called as Caryota Urens fiber (CU) or Fish Tail Palm fiber (FTP) is a unique variety of palm fiber which is available in abundance in India has strong fibers and woody stems. Research works carried out to study the phytochemical composition, anti-oxidant, antimicrobial, anti-inflammatory property and FT-IR evaluation of caryota fiber showed that this fiber can be used as a resource of different bioactive compounds and antioxidants [6]. These Cellulosic fibers have good antimicrobial property when compared to synthetic fibers and are presently used in the production of sanitary products and Bio-mask [7]. The cellulose content of the fibers around 42% by weight results in the tensile strength of 1900-6400 MPa and the low density of CU fibers makes it an better alternative to synthetic fibers and provides better bonding with the polymer matrix [8]. CU fiber also has a very high temperature resistance up to 270°C. Many research work are also carried out to study the medicinal values of FTP fiber and its fruits [9, 10].The effect of silane treatment on the chemical composition, mechanical property and surface property of caryota fibers were studies recently and concluded that the silane treatment improves the cellulose content and reduces the hemi cellulose which has positive effect on the tensile property of fibers [11]. Many research work has been carried out using Caryota fibers as fiber reinforcement in polyester composites [12-14]. Caryota fibers also finds its application in the production of non-asbestos free break pad application [15].The application of caryota fibers in polymer composites are developing vigorously after 2019, but its application in concrete as fiber reinforcement has not been studied in detail. The author carried out research work using caryota fibers of different volume fraction and different length as fiber reinforcement in self-compacting concrete [16]. From the research outcome it was concluded that the fibers play a significant role in improving the tensile strength of concrete. The impact resistance of concrete is increased by 150% due to the addition of fibers. To further extend this research work, effect of Caryota fibers in different grades of concrete are to be studied in detail. This research focuses mainly on the effect of different length of fibers in three strengths of concrete namely M30, M40 and M50. The fresh property, and mechanical property of three grades of concrete are to be studied in detail and the role of fibers in the crack arresting mechanics is also studied using digital image processing techniques.

2 Experimental investigations

2.1 Materials

The materials for the preparation of concrete mix were selected based on IS 456-2000 codal provision and the ingredients used were Ordinary Portland cement of grade 53, M-sand and gravel of size 20 mm. Caryota fiber which has excellent tensile strength was used in the concrete mix to improve the mechanical property of concrete. Caryota fiber grow up to a length of 2-3 m and the diameter of fully matured fiber is around 210-240 µm. The density of fiber is 1.3 g/cm3, with a tensile strength and modulus of elasticity of 476 MPa and 2.8 GPa respectively. Fully matured caryota fiber is shown in the Fig. 1(a). The fiber bunch was cut from the peduncle portion of the fish tail palm tree and each strand were separated from the main stem and the fibers were gently beaten with a wooden hammer. The outer skin was removed, and the inner core of the fiber were extracted. The fibers were chemically treatment with silane solution and oven dried at 100 °C for 12 hours (Fig. 1(b)). Oven dried fibers were cut into 20 mm, 30 mm and 40 mm fiber lengths as shown in Fig.1(c).

Fig. 1 – Caryota urens Fiber (a) Raw fiber (b) processed fiber (c) cut fiber

2.2 Mix design and methodology

The concrete mix was designed to obtain a compressive strength of 30MPa , 40MPa and 50 MPa after 28 days of water curing. The water cement ratio was kept constant as 0.5. The fibers were cut into length of 10 mm , 20 mm and 30 mm and used as fiber reinforcment for concrtete mix. The flexural strength, toughness and energy absorption of concrete is more for short fibers rather than the long fiber [17], therefore three short lengths of fibers (10 mm, 20 mm and 30 mm) were chosen The quantity of fiber added to the concrete mix was kept constant at 3% of weight of binderas excess addition of fibers reduces the workability of concrete and also the mechanical strength [18].The addition of fibers beyond 0.5% has negative impact on the workability, air content and fiber distribution in fresh concrete [19-21], therefore the fiber volume was restricted to 3%.Totally 12 concrete mixes were prepapred by varying the length of fibers and grades of concrete. The quantity of material used for each mix is listed in Table 1. The mix ID was decided based on the length of fibers used and the Strength of concrete mix. For example, CUFRC-10-M30 represents Caryota Urens Fiber reinforced concrete with 10 mm fiber length and strength of 30 MPa. similarly, NC-M30 represent normal concrete mix of strength 30MPa.The fresh properties of normal and FRC was studied by conducting slump cone test and the hardened property of concrete namely the compressive strength, split tensile strength, flexural strength, modulus of elasticity was studied using cube and cylinder specimens. Cubes of size 150 mm were used to determine the compressive strength; cylinder specimens of dimension 150 mm × 300 mm were tested to determine the split tensile strength and modulus of elasticity. Beam specimen of size 100 mm ×100 mm × 500 mm were tested for modulus of rupture. The experimental test set up is shown in Fig.2.

Table 1 – Mix proportion

Specimen ID	Cement (Kg/m^3)	Sand (Kg/m^3)	Aggregate (kg/m^3)	Fiber length (mm)	FTP fiber (kg/m^3)	Water (kg/m^3)
NC-M30	470	930	1200	-	-	235
NC-M40	485	940	1350	-	-	242
NC-M50	510	960	1469	-	-	255
CUF-10-M30	470	930	1200	10	1.56	235
CUF-10-M40	485	940	1350	10	1.61	242
CUF-10-M50	510	960	1469	10	1.70	255
CUF-20-M30	470	930	1200	20	1.56	235
CUF-20-M40	485	940	1350	20	1.61	242
CUF-20-M50	510	960	1469	20	1.70	255
CUF-30-M30	470	930	1200	30	1.56	235
CUF-30-M40	485	940	1350	30	1.61	242
CUF-30-M50	510	960	1460	30	1.70	255

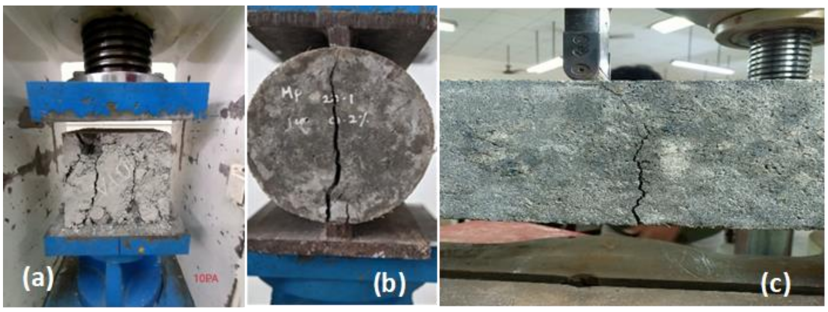


Fig. 2 – Experiment test setup (a) Compression (b) Split tensile (c) Flexure

3 Result and discussion

Experimental study was carried out to study the fresh property and hardened property of caryota urens Fiber Reinforced Concrete (FRC) of three different grades. The slump value, compressive strength, split tensile strength, modulus of elasticity, flexural strength values are tabulated in Table 2.

Table 2 – Fresh and hardened property of FTPF reinforced concrete

Specimen ID	Slump value (mm)	Compressive Strength (MPa)	Split tensile strength (MPa)	Modulus of elasticity (GPa)	Flexural strength (MPa)
NC-M30	70	31.33	2.52	25.75	3.2
CUF-10-M30	68	32.0	2.6	26.02	3.4
CUF-20-M30	67	33.20	2.8	27.03	3.55
CUF-30-M30	65	35.0	3.0	29,45	3.9
NC-M40	72	41.2	2.89	29.53	3.5
CUF-10-M40	70	43	3.0	30.16	3.93
CUF-20-M40	69	44	3.20	32.0	4.0
CUF-30-M40	67	46	3.40	33.89	4.3
NC-M50	73	51.3	3.22	32.95	4.0
CUF-10-M50	72	52	3.4	34.0	4.4
CUF-20-M50	70	53	3.62	35.67	4.5
CUF-30-M50	69	56	3.80	37.34	4.8

3.1 Fresh Property

The slump for concrete with 30 mm long fibers and 3% fiber content is shown in Fig. 3. The plot showing the variation of slump value with respect to fiber length (FL) for the three concrete mix is shown in Fig. 4. Addition of fibers reduces the viscosity of the concrte mix and affecte the slump. The absorption of moisture by plant fiber in concrete is also a reason for reduction in slump [22]. The reduction in slump value increases with the fiber content, therefore from the previous research findings the fiber volume was fixed to 3%, beyond which the fresh and mechanical property is affected.Fiber withhigher aspect ratio has adverse effect compared to short length fibers (10 mm). The longer length fibers (30 mm) increases the resistance to the movement of aggregate particle and reduces the flowability [16].The slump value for M30, M40 and M50 mix were 70 mm, 72 mm and 73 mm respectively. With the addition of short length fibers the slump value decreases by 3% for M30 and M40 mix and 1% for M50 grades of concrete. For short length fibers the number of fibers present in the concrete mix is more, which accumulates around the coarse aggregate and blocks the flow of concrete. For 20 mm and 30 mm fiber length the slump value decreases by 4% and 7% for M30 and M40 mix. For high strength concrete (M50) slump value reduces by 4% and 5% for FL-20 and FL-30, which is less compared to other two concrete mix. This may be due to the fact that in high strength concrete the quantity of coarse aggregate is more, therfore the fiber addition does not have much influence in the slump compared to M30 and M40 cocnrete.

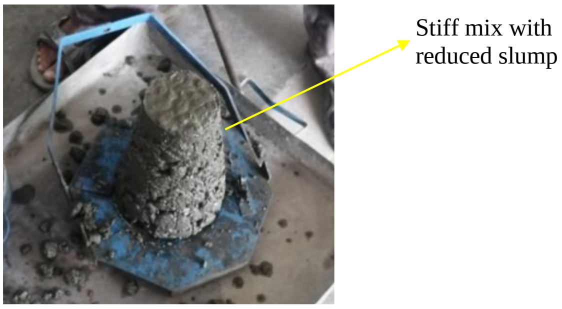


Fig. 3 – Slump cone of fiber reinforced concrete

The empirical correlation between the slump value (S) and Fiber length was obtained from linear regression analysis.Linear regression was carried out to develop relation between the slump value and the Fiber length for three grades of concrete and shown in Fig.5 . The developed equation for slump and fiberlenght for M30, M40 and M50 concrete is given by equ.(1) equ.(2) and equ (3). Three empirical equations were developed for three grades of concrete. All three-regression analysis showed a high coefficient of determination (R^2 ~ 0.98). The percentage decrease in slump value for three concrte mix for different fiber length is shown in Fig. 6

$$S = -1.6(f_{30}) + 71.5 \quad (1)$$

$$S = -1.7(f40) + 73.5 \quad (2)$$

$$S = -1.4(f_{50}) + 74.5 \quad (3)$$

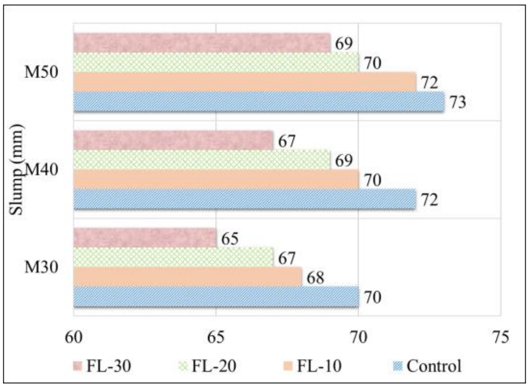


Fig. 4 – The slump value of M30, M40 and M50 grade caryota FRC with different fiber length

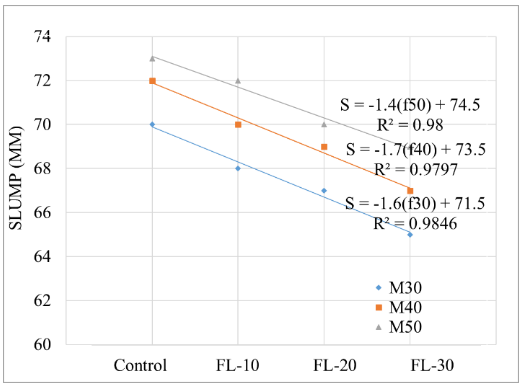


Fig. 5 – Linear regression plot of slump w.r.t fiber length for three concrete grade

Fig. 6 – Percentage decrease in slump with addition of fibers

3.2 Compressive Strength

The compressive strengthof concrete mix increases with the addition of fibers. The chemically treated CU fibers have a rough surface which helps to creates a strong bond with the cement matrix [14]. The bonding of fibers in the cement matrix is shown in concrete specimen and also using a digital video measuring system image in Fig.7. Without the fibers getting damaged , the stress is transferred from the fiber to the matrix. The CU fiber reinforced concrete forms a homogenous mix, and the fibers in the matrix also plays a role in the prevention of crack dvelopment inside the concrete core. The length of fiber also plays a role in the compressive strength devlopment [16, 23].The increase in compressive strength with the fiber length can be attributed to the fact that the stress transfer from matrix to the fiber is insufficient for short length fiber. On the other hand, stress is completely transferred from the matrix to fibers in case of long length fibers [24]. Use of fibers in concrete results in closely spaced cracks with reduced crack width. Fibers helps to bridge the crack, there by increases the strength of FRC [25].

The variation of compressive strength with the fiber length, for three grades of concrete is shown in Fig.8. Compared to 10 mm fibers, the fibers with higher aspect ratio contributes a maximum increase in compressive strength. Percentage increase in compressive strength for three grades of concrete is shown in Fig. 9. For M30 concrete the addition of 10 mm, 20 mm and 30 mm long fibers showed about 2%, 6% and 12% increase in the compressive strength respectively. For M40 concrete all the three length of fibers showed a reasonalble increase in strength of 4%, 7% and 12%. For high strenght concrete, the effect of fibers was very minimum compared to normal strenght concrete. For 30 mm long fiber the increase in compressive strength is about 9%. Therfore the role of fibers is more predominat in M30 and M40 concrete compared to M50 Grade mix. Similar result was reported by karamloo et al [26]. Therfore it can be concluded that fibers embedded in the concrete matrix plays a prominent role and contributes for the increase in compressive strength.

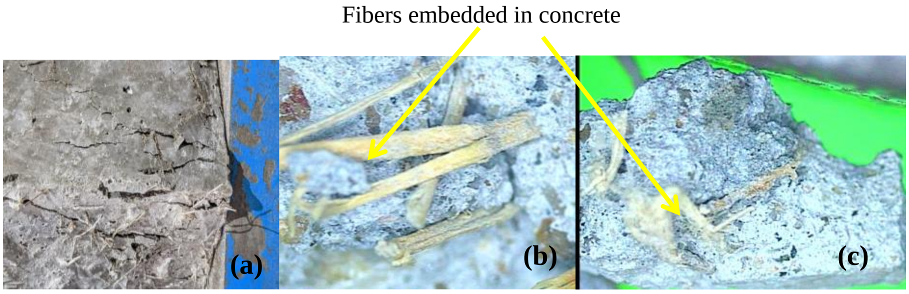


Fig. 7 – Compression test (a) Crushing of CU fiber cubes (b)&(c) Digital image of fibers embedded in concrete

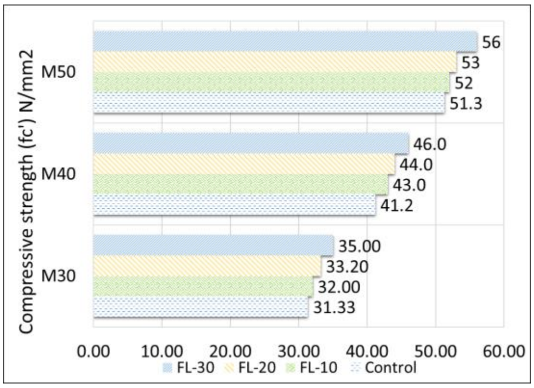


Fig. 8 – The compressive strength of three grades of FRC with different fiber length

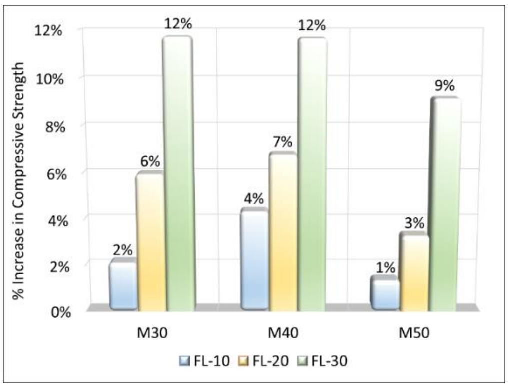


Fig. 9 – Percentage increase in Compressive Strength

3.3 Split tensile Strength

The fibers are added in concrete mainly to increase the tensile strength and impact resistance. Both synthetic and natural fibers are strong in tension, thereforeaddition of fibers enhances the tensile property and fracture energy of concrete speciemns [27]. Distribution of fibers in the concrete matrix reduces the stress concentration in a particular region and spreads the stress in different direction [28]. Once crack gets developed in concrete due to the applied load,fibers spreads the stress and prevents the fromation of wider cracks. Cement matrix which glues the fibers transfers the stress along the longitudinal length of the fibers as shown in Fig 10(a). In case of control M30 M40 and M50 mix the failure of the specimen was sudden with a single explict crack as shown in Fig. 10(b). the fibers arrest the micro cracks inside the concrete and helps to increase the splitting tensile strenght of FRC. The digital images of fibers arresting the crack is shown in Fig. 11. Previous research work also report the significance of fibers in the tensile property of concrete. Prakash et al [29] reported that addition of steel and polyproplene fiber increase the tensile strength of concrete. Wahyuni et al [30] reported that addition of bamboo fibers resulted in a splitting tensile strength of 3.9 MPa. Islam et al [22] reported an increasing trend in the splitting tensile strength of jute FRC for an aspect ratio of 100-200 and fiber content of 0.5%. The splitting tensile strength obtained from the presnt study is shown in Fig. 12. The plot is similar to the compression strength variation, but Compared to compressive strength, the contribution of fibers in the tensile strength is significant. The percentage increase in tensile strength for three grades of concrete is shown in Fig.13. For M30 concrtete, addition of 10 mm 20 mm and 30 mm fibers results in the tensile strenght of 2.6 Mpa, 2.8 MPa and 3 MPa respectively. The maximum increase in tensile strength is reported for CUF-30-M30 specimen, which is about 19% compared to control M30 specimen. For M40 and M50 concrete, the maximum percentage of increase in tensile strenght is 18%. Linear regression analysis was carried out to develop an emeprical equation to relate the split tensile strength (f_{st}) with the compressive strength (f_c'). The correlation between split tensile strength (f_{st}) and compressive strength (f_c'). For all the three grades of concrete with a high regression value (R^2 = 0.94) is shown in Fig. 14.

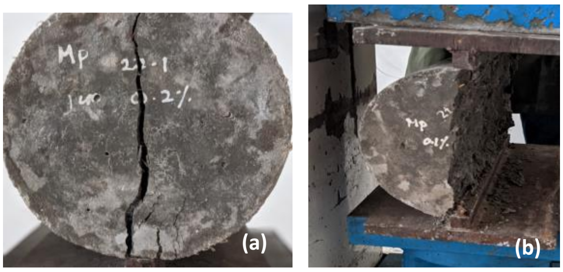


Fig.10 – Failure of cylinder specimen with and without fibers

Fig. 11 – VMS images of fibers arresting the splitting cracks

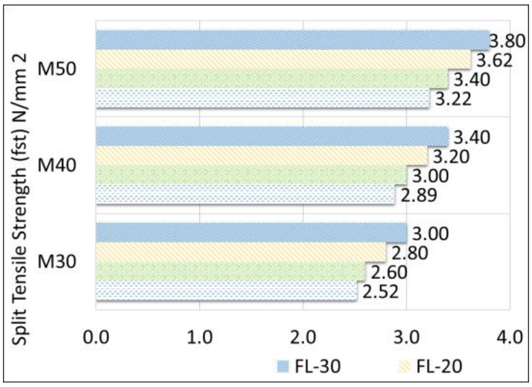


Fig. 12 – Variation of Split tensile strength

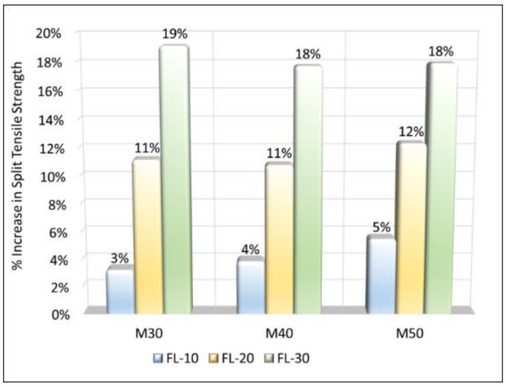


Fig. 13 – Percentage increase in split tensile strength

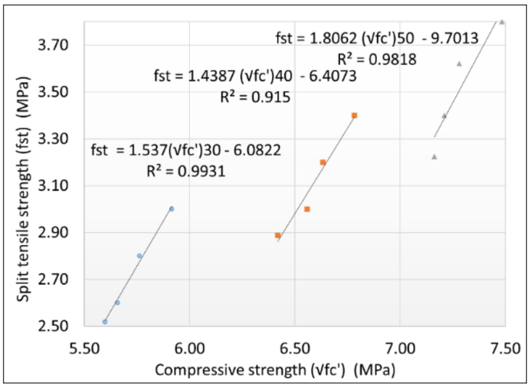
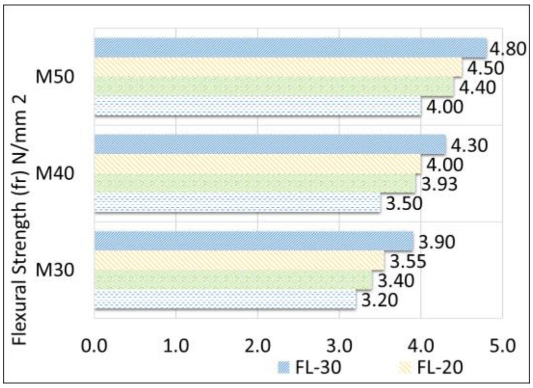


Fig. 14 – Relation between split tensile strength (f_{st}) and $\sqrt{fc'}$

3.4 Flexure Strength

When the maximum tensile capacity of the specimen is reached the failure started in the tension region with the development of minor cracks. Due to the tensile strength offered by the natural fiber the failure of the specimen was ductile in nature. The fibers present in the concrete, bridges the crack developed inside the core region and improves the post cracking behaviour of FRC [31]. In the present study, the flexural strength increases with the increase in length of fibers. short fibers arrest the micro cracks and long fibers arrest the macro cracks which consumes more energy for crack to propagate in the concrete and increases the crack resistance [18].

Fig. 15 – Failure pattern of beams with shortlength fibers



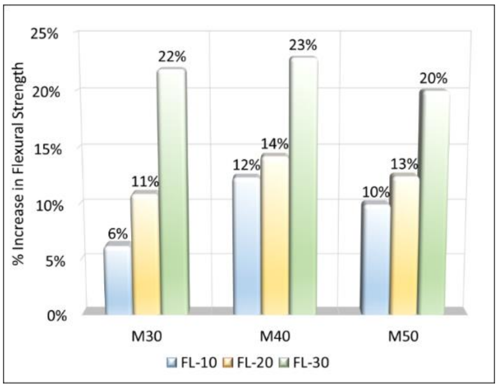


Fig. 16 – Flexural strength of CU fiber reinforced concrete

Fig. 17 – Percentage increase in Flexural strength

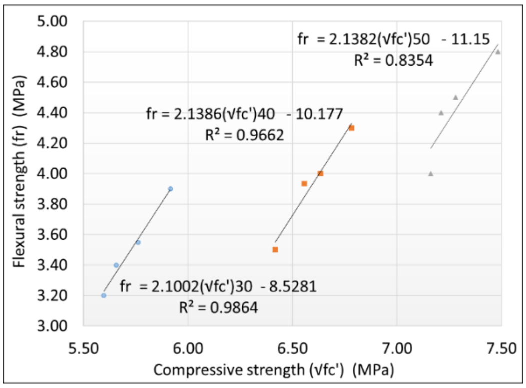


Fig. 18 – Relation between Flexural strength and $\sqrt{fc'}$

The failure pattern of fiber reinforced beam with the low and high aspect ratio fibers is shown in Fig. 15. Fibers bridges the cracks and increase the residual strength of beams. The variation of flexural strength with fiber length for three grades of concrete is shown in Fig. 16. Flexural strength of control M30 concrete increases from 3.2 MPa to 3.4 MPa, 3.55 MPa and 3.9 MPa with the addition of 10 mm, 20mm and 30 mm long fibers respectively. Similarly, for M40 concrete the flexural strength from 3.5 MPa to 3.93 MPa, 4 MPa and 4.3 MPa with the addition of 10mm, 20mm and 30mm long fibers respectively. For high strength concrete mix (M50) the maximum flexural strength of 4.8 MPa was recorded for M50 mix with 30 mm CU fiber. For all the three grades of concrete the long fibers provides better improvement in flexural strength compared to short fibers. Short fibers attracts only micro cracks, while long fibers take the additional responsible of carrying the loads after achieving the peak load and thereby delaying the appearance of the macro-cracks [32]. The percentage increase in flexural strength for all the three grades of concrete for three different fiber length is shown in Fig. 17. For M30 and M40 mix the maximum percentage of increase in flexural strength was around 22-23%. Compared to higher strength concrete, fiber plays a significant role in improving the flexural toughness for M30 and M40 mix. On comparing the percentage increase in split tensile and flexural strength, it is very much clear that the contribution of fibers to the flexural strength is much more than the split tensile strength and compressive strength. The correlation between flexural strength (f_r) and compressive strength (f_c'). For all the three grades of concrete with a high regression value (R^2 = 0.9-0.98) is shown in Fig. 18.

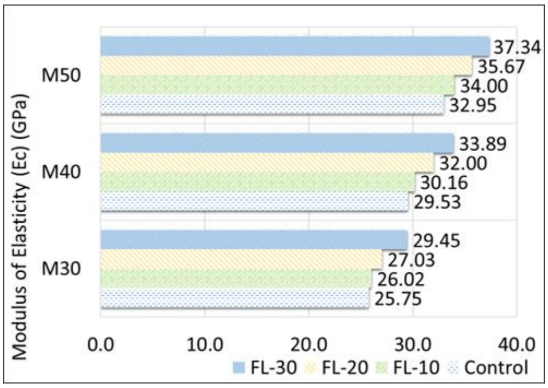


Fig. 19 – MoE plot of CU fiber reinforced concrete

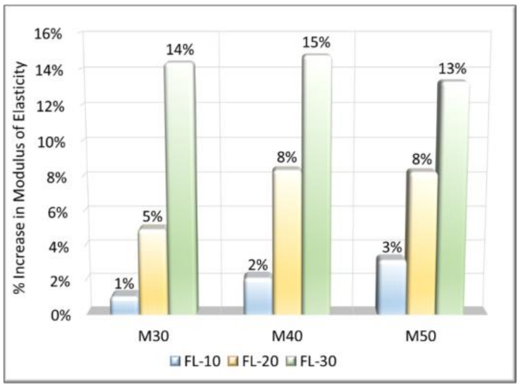


Fig. 20 – Percentage increase in Modulus of Elasticity

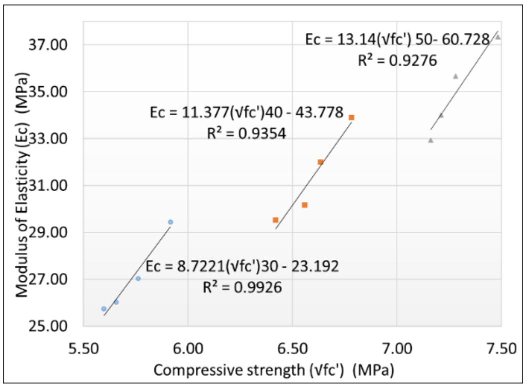


Fig. 21 – Relation between modulus of elasticity and $\sqrt{fc'}$

3.5 Modulus of Elasticity

Within the elastic region the ratio of direct stress and corresponding strain of concrete specimen is known as Modulus of elasticity (E_c). The tensile strength of fibers in the concrete matrix help to increase the modulus of elasticity(MoE) of concrete [19]. This MoE of concrete play a major role in the pre cracking behaviour of concrete specimen. With the increase in the volume of fiber the MoE also increases. But addition of excess amount of fibers reduces the compaction characteristics and thereby reduces the mechanical strength [33]. Compared to short fibers the long fibers are more effective in stress redistribution. With the increase in length of fibers the ductility of the specimen is increased and there by the MoE also increases. The long fibers distribute the stress concentration in different direction, thereby reducing the strain localization within the concrete. both the long and short fibers restrains the crack at the initial stage and reduces the stress concentration and further prevents the growth of cracks width at the post cracking region [27]. Prakash et al [29] reported that addition of steel fibers increases the elasticity of coconut shell aggregate concrete by 17%. Addition of sisal fibers also tends to increase the MoE by 6% for addition of 3% Volume of fibers [34]. The MoE increases up to a maximum of 9% with the addition of sisal fiber in self-compacting concrete, but beyond 4% volume of fibers the MoE decreases [35]. In case of short length fiber reinforced concrete, the elasticity of concrete increases as large number of fibers is involved in the crack arresting mechanism and prevents the development of new cracks and also reduces the stress concentration. The variation of MoE with the fiber length for three grades of concrete is shown in Fig. 19. The percentage increase in the MoE values for all three grades of concrete is shown in Fig.20.The MoE for M30 concrete varies from 25.75 GPa to 26.02 GPa, 27.03 GPa and 29.45 GPa with the addition of 10 mm 20mm and 30 mm long fibers respectively. Similarly, for M40 concrete the MoE varies from 29.53 to 33.89 GPa with the addition of 30 mm long fibers. For M50 concrete the MoE varies from 32.95 GPa to 34.00 GPa, 35.67 GPa and 37.34 GPa with the addition of 10 mm 20mm and 30 mm long fibers respectively. From the plot it is clearly visible that MoE value gradually increase with the length of fibers. A maximum of 14%, 15 % and 13 % increase in the MoE values was recorded for 30 mm long fiber reinforced M30 and M40 and M50 concrete respectively. Comparing the contribution of short length and long length fibers, the former contributes only 1-3% increase in MoE value, but the latter contributes to a maximum of 14-15% increase in the value compared to control specimen. The linear regression analysis was carried out to develop an emeprical equation to relate the Modulus of elasticity (E_c) with compressive strength ($f_c^{'}$) is shown in Fig. 21.

Table 3 – Correlation equation with regression value

S.No		Emperical equation	Regression value (R^2)
Relation between split tensile strength and compressive strength			
1	*M30*	$f_{st} = 1.537(\sqrt{fc'})_{30} - 6.0822$	$R^2 = 0.9931$
2	M40	$f_{st} = 1.4387 (\sqrt{fc'})_{40} - 6.4073$	$R^2 = 0.915$
3	M50	$f_{st} = 1.8062 (\sqrt{fc'})_{50} - 9.7013$	$R^2 = 0.9818$
Relation between Flexural strength and compressive strength			
4	*M30*	$f_r = 2.1002(\sqrt{fc'})_{30} - 8.5281$	$R^2 = 0.9864$
5	M40	$f_r = 2.1386(\sqrt{fc'})_{40} - 10.177$	$R^2 = 0.9662$
6	M50	$f_r = 2.1382(\sqrt{fc'})_{50} - 11.15$	$R^2 = 0.8354$
Relation between Modulus of Elasticity and compressive strength			
7	*M30*	$E_c = 8.7221(\sqrt{fc'}) - 23.192$	$R^2 = 0.9926$
8	M40	$E_c = 11.377(\sqrt{fc'}) - 43.778$	$R^2 = 0.9354$
9	M50	$E_c = 13.14(\sqrt{fc'})- 60.728$	$R^2 = 0.9276$
Relation between split tensile strength and Flexural strength			
10	*M30*	$f_{st} = 0.7174 (f_r)_{30}+ 0.2097$	$R^2 = 0.9676$
11	M40	$f_{st} = 0.6374 (f_r)_{40} + 0.6149$	$R^2 = 0.8685$
12	M50	$f_{st} = 0.738(f_r)_{50} + 0.2452$	$R^2 = 0.9357$

Table 4 – Group statistics of mechanical properties of FRC

	Specimen	N	Mean	Std. Deviation	Std. Error Mean
Slump value	A	4	67.5000	2.08167	1.04083
	2.00	4	69.5000	2.08167	1.04083
Compressive strength	A	4	32.8825	1.60973	0.80486
	2.00	4	43.5500	2.00250	1.00125
Tensile strength	A	4	2.7300	0.21510	0.10755
	2.00	4	3.1225	0.22515	0.11257
Modulus of elasticity	A	4	27.0625	1.68431	0.84215
	2.00	4	31.3950	1.96592	0.98296
Flexural strength	A	4	3.5125	0.29545	0.14773
	2.00	4	3.9325	0.32999	0.16499

3.6 Linear Regression Analysis

Similarly linear regression analysis was carried out to develop an emeprical equation to relate the split tensile strength (fst) with compressive strength (fc'), flexural strength (fr) with the compressive strength (fc'), Modulus of elasticity (Ec) with compressive strength (fc') and split tensile strength (fst) with flexural strength (fr). The developed equation shows a high regression value. (R2=0.9-0.98). The developed equation connecting compressive strength, split tensile strength, flexural strength and modulus of elasticity is listed in Table. 3

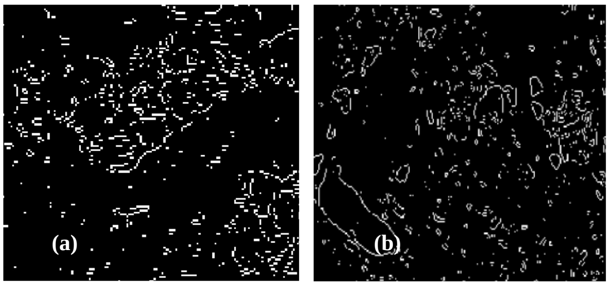


Fig. 22 – Edge detection image of (a) control and (b) fiber reinforced concrete

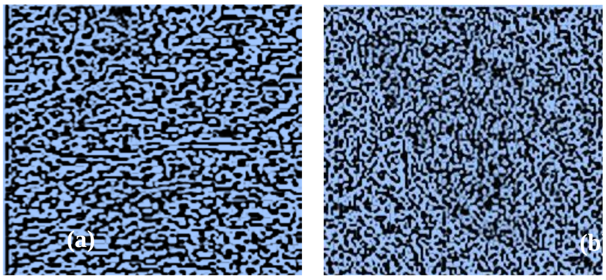


Fig. 23 – Filtered image of (a) control, and (b) fiber reinforced concrete

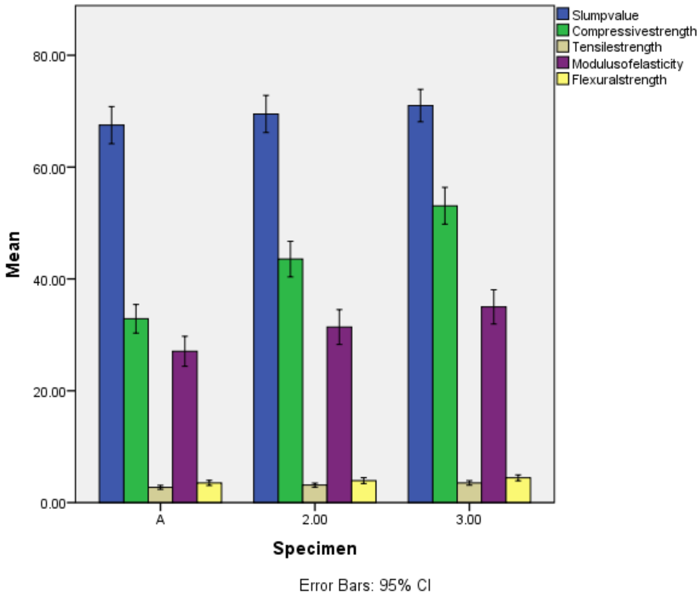


Fig. 24 – The mean values of fresh and hardened properties of CU fiber reinforced concrete

4 Digital Image Processing and T test analysis

The digital image of concrete samples are acquired using X-ray Computed Tomography (CT) imaging which uses digital geometry processing and generates a 3D images from a series of 2D x-ray images. 2D digital image is nothing but a 2D function of the form f(x,y) where f(x,y) is the numerical value of the 2D-matrix at the point x,y. The value at any point (x,y) depends on the intensity of light that is reflected from the object at the point that corresponds to the image. The acquired images are processed and analyzed using computer MATLAB software. Initially, the acquired original color (RGB) image is converted into gray scale image for further processing. Later, the image is processed to detect the edges of the concrete composition. Clear analysis of masses, air-voids, fibre inclusion and cement will help in getting the volumetric information of the concrete composition. Different image processing operations are performed in the X-ray obtained image. First operation carried out is edge detection using various edge detection operators such as Canny, Sobel, Roberts and Perwitt in which Sobel operator gives a clear picture about the edges in the concrete structure. The obtained RGB images are converted in to grey scale images which have intensity range of 0 to 255. Secondly, enhancement of edges is performed by adjusting the contrast and applying Laplacian filtering technique to analyse the edges further. The original image is of resolution of 975 X 1100 pixels. The resultant figure is obtained using Canny edge detection filter for better quality. Fig. 22 shows the grey scale edge detected image for specimen without fibre and with fibre. It is clearly noticed that the presence of closed edges indicate the bonding of the concrete fibres. Fig. 23 shows the grey scale filtered image for specimen without and with fibre. As mentioned in the experimental analysis, the concrete without fibre crumbled immediately when it undergoes a heavy blow and the one with fibre results in closely spaced crack and a delayed failure because of bridging effect of the fibre in the concrete. In Fig. 20 it is noticed that the continuous edges indicates the crack information along the fibre length. From the results of image processing, it is clear that the presence of fibre plays a major role in collapse of a concrete structure. Once the fresh and hardened properties were assessed the T-test analysis was run using SPS software and the variance and mean deviation for the slump value, compression, splitting, flexural and modulus of rigidity value were obtained. The mean, standard deviation values and error for the properties of CU fiber reinforced concrete is listed in Table 4. The plot showing the group statistics of mean for the fresh and hardened properties is shown in Fig. 24.

5 Conclusion

From the experimental investigation and digital image processing of Caryota Urens fiber reinforced concrete of different grades with different fiber lengths, the following conclusion can be derived

- The increase in the fiber content has an impact on the slump values of the concrete. The viscosity of concrete is reduced due to high fiber content. with long fibers the slump value is affected in M30 and M40 grade concrete. For higher grade concrete the number of fibers per unit area is less when compared to aggregate content, and effect is very minimal.

- As the fiber length increases the compressive strength of concrete also increases. The stress transfer takes place completely from the matrix to the fibers in case of long fibers. But with short fibers, the stress transfer is incomplete. Therefore, long fibers are more effective when compared to short length fibers. For M30 concrete a close network of fibers are available for stress transfer which result in maximum of 12% increase in compressive strength.

- The variation of splitting tensile strength and flexural strength plot is like compressive strength variation. M30 and M40 concrete showed a maximum of 19% and 23% increase in strength with the addition of 30 mm long fibers. The tensile property of fibers, contribute mainly to the split tensile strength and flexural strength.

- The Modulus of elasticity (MoE) of concrete play a major role in the pre cracking behaviour of concrete specimen. With the increase in length of fibers the ductility of the specimen is increased and there by the MoE also increases. The long fibers distribute the stress concentration in different direction, thereby reducing the strain localization within the concrete. Comparing the contribution of short length and long length fibers, the former contributes only 1-3% increase in MoE value.

- The digital image processing techniques carried out on normal concrete and fiber reinforced concrete, showed that the fiber reinforced concrete showed closely spaced cracks within the concrete core. The fibers in the concrete arrest the cracks in the pre cracking region and spreads the crack in different direction. Thus, the mechanical property of concrete is increase with the addition of long fibers. and the fibers are more effective for M30 and M40 concrete compared to high strength concrete.

- The T test analysis carried out on the fresh and hardened properties of concrete showed the standard deviation and mean variance value lies within the range of 1-2. The error value reported were very less in the range of 0-1.

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