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Effect of natural fish tail palm fiber on the workability and mechanical properties of fiber reinforced concrete

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ABSTRACT

To improve the pre-cracking behavior and post peak strength of concrete composites, a new variety of natural fiber called Fish Tail Palm Fibers was used as micro reinforcement in concrete. Fish Tail Palm Fibers (FTPF) are completely renewable natural resources and are available in abundance, in many parts of the country including India. Three different volume fractions, (0.1%, 0.2% and 0.3%), and three different lengths of fibers (10 mm, 20 mm and 30 mm) were chosen as the parameters for investigation. Silane treated FTPF was added to concrete and the fresh and mechanical properties were studied. The slump values were slightly affected by the increase in volume fraction of fibers, as the viscosity of concrete increases with fiber content. The compressive strength of the control specimen was 30 MPa (M30). The maximum compressive strength, splitting tensile strength, and flexural strength of Fish Tail Palm Fiber Reinforced Concrete (FTPFRC) specimens are 36 MPa, 2.82 MPa and 4.2 MPa respectively, which were recorded for specimens with 0.2 Volume Fraction (VF) and 30 mm Fiber Length (FL). The increase in the compressive strength, splitting tensile strength and flexure strength is about 20 %, 22% and 30 % with the addition of 0.2 VF of fibers. The findings indicate that the incorporation of fish tail palm fibers reduced the workability of concrete. But the mechanical characteristics such as compressive strength, splitting tensile strength, flexural strength, and impact resistance were enhanced with the increase in fiber content and fiber length.

1 Introduction

Nowadays, natural fibers are in the foreground due to the need to turn to alternative materials with low environmental footprints. Natural fibers are used to control cracks developed in concrete structures due to plastic and drying shrinkage, increase the tensile strength, toughness, and durability. The functionality of fibers depends on the geometric properties of fibers, fiber content, orientation and interaction with binders [1]. Many studies have been conducted to investigate the effects of fibers as a crack arresting medium in concrete [2]. Different natural fibers such as jute, hemp, flax, banana, bamboo, roselle, basalt, palm, sisal, abaca. etc. have been used by many researchers in the recent past to study the mechanical properties, fracture energy, impact strength, shrinkage characteristics, and durability properties of concrete elements [3]. In some of the developing southeast Asian countries, natural fibers such as hemp cotton and jute are used to produce fiber reinforced polymers that can be used as an alternative to carbon fiber

reinforced polymers (CFRP) and glass fiber reinforced polymers (GFRP)[4] Combinations of synthetic and natural fibers are also used to increase the strength properties and flow characteristics of self-compacting concrete [5]. Even though the mechanical property of natural fiber is less than that of synthetic fiber, it is always within the acceptable limit and suitable for concrete and other related applications [6].

Natural fibers are non-uniform with an irregular cross-section, which makes them unique and different from man-made fibers such as polypropylene, polyolefin, glass fibers etc. This property of fibers attracts more researchers to using natural fibers as reinforcement [7]. Many new plant fibers are identified, and their properties are studied in detail so they find their application in concrete as fiber reinforcement. Fish Tail Palm Fiber (FTPF) is also one of its kind, FTPF is a unique type of cellulosic fiber obtained from the peduncle portion of the fish tail palm tree. Those fibers were tested for chemical composition, mechanical strength, surface property

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and it was proved that this fiber can be used as a novel plant based natural fiber for improving the strength of polymer composites and concrete elements [8].

The FTPF used in this study is obtained from the Toddy palm tree, also known as the Fish Tail Palm Tree, which is a renewable resource with low production cost and wide availability in India. Toddy palm is a fast-growing feather palm that makes a beautiful addition to the landscape. It belongs to the family of *Aceraceae* and the fiber is also called *Caryota Urens* fiber [9]. Most automotive industries are supplanting synthetic fibers such as carbon and glass with cellulose fibers (FTPF) in polymer matrix reinforcement [10]. Much research work has been carried out using FTP fibers as fiber reinforcement in polyester composites [11]. It also finds its application in the production of non-asbestos free break pad applications [12]. The application of caryota fibers in polymer composites is developing vigorously after 2019, but its application in concrete as fiber reinforcement has not been studied in detail. Therefore, the main aim of this study is to study the effect of FTPF on the workability characteristics and mechanical properties such as compressive strength, splitting tensile strength, flexural strength, and impact resistance of concrete.

2 Literature review

Many researchers studied the fresh and mechanical properties of cement concrete, the strength of fiber-reinforced composites (FRC), and the thermal and acoustic properties of FRC using various natural fibers. When banana fiber stem is used as reinforcement in concrete, it increases flexural strength and spalling resistance [13]. Fiber length, fiber content, and chemical treatment of banana pseudo stems have a major influence on the flexural strength of banana pseudo stem-epoxy polymer composites [2]. Maximum stress transfer between the fibers and matrix was observed for a combination of banana-sisal (3:1) hybrid fiber reinforced polyester composites [14]. Cellulosic fiber chemical composition, mechanical strength, and micro-structure all play a significant role in the compressive, flexural, and impact strength of fabric reinforced cementitious polymers and geopolymer composites [15]. Cellulosic fibers such as jute and kelp are more suitable for soft natural mortars such as lime, but coconut fiber, which is rich in lignin is more suitable for cement mortar [16]. The addition of Indian mellow fiber and roselle fiber mat in a polymer matrix with saw dust as fillers resulted in the fabrication of automobile rear view mirrors, fan blades, and auto wheel hubs [17]. Coconut fiber reinforced concrete along with coconut rope in the column has better seismic performance and results in the development of low cost housing in seismic zones [18]. When compared to most of the natural fibers coconut fiber has the highest toughness value, which helps to improve the ductile behavior of concrete elements and their composites [19]. Coconut fiber when used as insulation for concrete roof slabs helps to reduce the energy consumption of the building by a maximum of 9% and helps in the cost reduction [20]. Wheat straw is another plant fiber that contributes to the flexural strength, energy absorption and increases the toughness indices of concrete pavement [21].

Jute is an easily available plant fiber that has excellent crack arresting behavior and high tensile strength [22]. Increasing the dosage of fibers beyond 0.5% has a negative

impact on the fresh properties of concrete. Alkali and polymer modification is the technique in which the durability of plant fibers can be increased in fiber reinforced concrete composites [23]. Tannin modified jute fiber along with mild alkali and diluted polymer emulsion are used to make paver blocks to meet the global demand for sustainable infrastructure development [24]. Kenaf fiber, being the outstanding renewable resource for the fabrication of composites, in combination with sisal and jute is used to produce fiber reinforced polymer composites [25]; [26]. Natural plant fibers (sisal, abaca, jute, etc.) are also used in combination with steel fibers and synthetic polypropylene fibers to improve the mechanical and durability characteristics of concrete elements [27].

Prosopis Juliflora bark used as reinforcement along with banana and coconut fibers with epoxy resulted in FRP composites with increased flexural attributes and better mechanical strength and toughness indices. High density polyethylene composites reinforced with another unique fiber, curaua fiber, tend to improve the interfacial, mechanical, and morphological properties of composites [28]. The use of giant reed fibers and date palm fibers as fiber reinforcement for cement-based mortar significantly improves fracture toughness [29], impact strength, and flexure strength [30]. The mechanical properties and thermal behavior of concrete [31] improve with the addition of a very small amount of (0.05%) of water hyacinth fiber, along with banana fiber and bio-filler egg shell powder. Details of some research work carried out using natural plant fiber are listed in Table 1. From the previous literature study, it can be concluded that the characteristics of this unique FTPF in concrete have not been extensively studied. Therefore, the main aim of this work is to study the fresh properties, mechanical strength, and durability characteristics of M30 (30 Mpa) concrete, using FTPF as fiber reinforcement in the concrete mix. The two main parameters of investigation are, fiber length and volume fraction.

3 Experimental investigations

3.1 Materials

Concrete specimens were prepared by using ordinary Portland cement as a binder, gravel of a maximum size 20 mm as coarse aggregate and river sand as fine aggregate. The materials selection was based on the Indian standard code specification IS-456:2000[37]. To improve the mechanical strength and crack resistance characteristics of concrete, natural fibers, namely Fish Tail Palm Fibers (FTPF) were added to the concrete in different lengths and volume fractions. Fish tail palm fiber was obtained from the palm trees grown at Sri sivasubramaniya Nadar College of Engineering Campus, Chennai, India. The peduncle portion, which is shown in Figure. 1, was cut from the Fish Tail Palm tree (FTP) and the fiber was extracted. Fully matured fibers have fruits on the surface (Figure. 2). Each strand was separated from the main stem, and the impurities and fruits present on the surface were cleaned. After proper chemical treatment, the Fish Tail Palm Fibers (FTPF) of a strand length of 2 m were obtained from the stem. The step-by-step process of extraction of FTPF is shown in Figure. 3. The physical and chemical properties of FTPF are given in Table 2. The SEM image of the silane treated fiber is shown in Figure. 4.

Table 1. Few studies of fiber reinforced concrete using natural plant fibers

S.No	Author/Year	Type of fiber	Fiber Content	Parameter of study	Conclusion
1	Farooqi and Ali (2018) [21]	Wheat straw	1% of mass of concrete, 25 mm length	To improve flexural strength, toughness indices and energy absorption capacity	Delayed crack initiation and enhanced load capacity up to 7.5%
2	Islam &Ahamed (2018) [22]	Jute Fiber	lengths -10 mm & 20 mm. Volumes of 0 %, 0.25%, 0.50%, & 1.00%	Study of compressive and flexural strength @ 7,28 and 90days	addition of 0.50% jute fiber had an adverse impact on the fresh properties of concrete
3	Kundun et al (2020) [32]	Jute fiber	1% by weight of paver block (3-5 mm length)	surface modified jute fiber in controlling the physical and mechanical properties of concrete paver blocks.	30%, 49% and 166% higher compressive strength, flexural strength, and flexural toughness respectively
4	Pirmohammad et al (2020) [25]	Kenaf & goat wool	lengths (4, 8 and 12 mm) and contents (i.e., 0.1, 0.2 and 0.3% by weight of total asphalt mixture	Influence of kenaf and goat wool on mixed mode fracture strength of asphalt mixtures.	asphalt mixtures reinforced by 0.3% kenaf fibers with 8 mm & 0.3% goat wool fibers with 4 mm length demonstrate the best results
5	Alam&Riami (2018) [26]	kenaf, jute and jute rope fiber	Polymer composites	natural fiber reinforced polymer laminates for shear strengthening of reinforced concrete beam.	shear strengthened beams with kenaf, jute and jute rope composite plates higher failure load as compared to control beam
6	Qamaar et al (2018) [33]	Sisal+Rice straw	2% fibres by weight of cement	effectiveness of natural fibrous plaster for improving the out of plane lateral resistance of mortarless interlocked masonry walling was evaluated	The use of natural fibres within plaster did more to enhance the wall strength than fibres within blocks or mortar
7	Badagliacco et al (2020) [29]	Giant reed fiber	4cm, 8 cm and 12 cm fiber	investigate the bio-lime based mortar flexural toughness improvement due to the addition of common reed fiber	effectiveness of giant reed fibers in the manufacturing of green building materials, as bricks or laying mortars.
8	Niyasom&Tangboriboon (2021) [31]	Water hyacinth + banana fiber+ egg shell powder	3-13 cm long banana fiber and hyacinth fibers	The bulk density, true density, water absorption, compressive strength, tensile strength, flexural strength, and maximum load	Adding eggshell powder can reinforce and enhance physical and mechanical properties of concrete composites
9	Wongsa et al (2020) [34]	Sisal + Coconut	0.25-1%	Mechanical, thermal, and physical properties of geopolymer mortar reinforced with fibers were tested	Fibers improves the flexural and tensile strength, but reduces the workability, dry density.
10	Comak et al (2018) [35]	Hemp	Volume- 0%, 1%, 2%, 3% lengths - 6 mm, 12 mm & 18 mm	Durability and mechanical property of cement mortar	cement mortars with 2–3% amount and 12 mm length of hemp fiber give optimum results.
11	Tidarat et al (2019) [36]	Cotton,Jute,hemp	Jute hemp cotton polymer composites	compressive behavior of concrete confined with low-cost natural fiber reinforced polymer (NFRP)	NFRP is effective and suitable to enhance the confinement effect of concrete, especially Jute-NFRP.

3.2 Methodology



Figure 1. Fish Tail Palm Fiber



Figure 2..Fully matured fibers with fruits on the surface

The effect of FTPF on the fresh and hardened properties of normal strength concrete was investigated. Fiber length and volume fraction were considered as the parameters of investigation. Because short fibers have higher flexural strength, toughness, and energy absorption than long fibers [38], three short lengths of fiber (10 mm, 20 mm, and 30 mm) were chosen at three different Volume Fractions (VF), namely 0.1%, 0.2%, and 0.3%. The addition of fibers beyond 0.5% has a negative impact on the workability, air content and fiber distribution in fresh concrete [39]. Therefore, the VF was restricted to 0.1-0.3%. To arrive at the mix proportioning of control concrete with a compressive strength of 30 MPa, three trial mixes were prepared. From the trial mix, the ratio of cement, sand, gravel, and water required to prepare the concrete mix was decided as 1:1.98:2.77:0.54:0.007. The superplasticizer content was slightly increased with the increase in fiber content. In total, ten concrete mixes were prepared, including the control mix. The quantity of material used for each mix is listed in Table 3. The FTPF was cut into 10 mm, 20 mm, and 30 mm lengths as shown in Figure. 5 and used as fiber reinforcement in concrete. The specimens were identified based on the presence of fibers, volume fraction and fiber length. For example, NSC-CM represents normal strength concrete-control mix with no fibers, and FRC-0.1-20 represents fiber reinforced concrete with a fiber volume fraction of 0.1% and a fiber length of 20 mm. For batching, coarse aggregate, fine aggregate, cement, and mineral additives were mixed in a concrete mixer for 5-8 minutes. The concrete-fiber mix compositions were prepared by adding FTPF fibers to the fresh concrete in the concrete mixer. Fibers were added gradually and slowly to avoid a balling effect due to fiber content, and were allowed to mix for another three minutes to ensure that the fibers were uniformly distributed in the concrete.

The fresh properties of normal and FRC were determined using the slump cone test, and for the hardened properties of concrete, compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, and impact resistance tests were done. Cubes of size 150 mm were prepared to determine the compressive strength. Cylinder specimens of dimension 150 mm × 300 mm were prepared to determine the splitting tensile strength and modulus of elasticity. A beam specimen of size 100 mm × 100 mm × 500 mm was prepared for modulus of rupture and a 150 mm × 65 mm disc was used for measuring the impact resistance. The fresh and hardened concrete tests carried out for FTPF reinforced concrete are shown in Figure. 6.

Table 2. Physical and chemical properties of FTPF

Chemical Composition	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Extractives (%)	Crystallinity index (%)
		72.51	8.97	11.75	6.77
Physical and Mechanical property	Length (m)	Diameter (µm)	Tensile strength (MPa)	Modulus of elasticity (GPa)	Density (g/cm ³)
	2-3	210-240	476	2.8	1.3



(a) Raw fibers from palm tree (b) Fiber stems immersed in water (c) Beaten fibers to remove outer skin (d) Fibers extracted from outer skin (e) Silane chemical treatment (f) Fibers washed in ethanol (g) Oven dried fibers (h) Fibers cut into different length

Figure 3. Step by step process of extraction of fish tail palm fibers

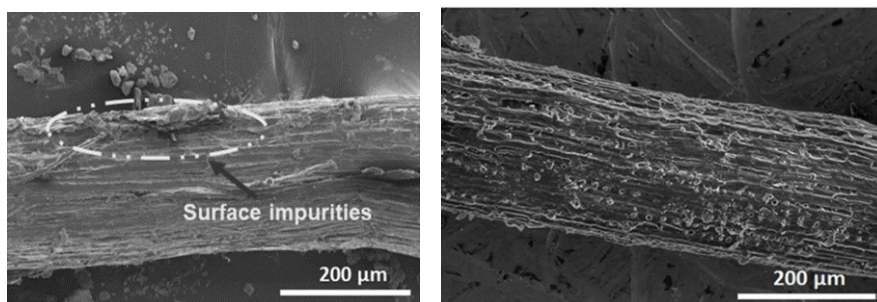


Figure 4. SEM image of (a) untreated and (b) silane treated FTPF [8]



Figure 5. Cut fish tail palm fibers of different length

Table 3. Mix proportion

Specimen ID	Cement (kg/m ³)	Sand (kg/m ³)	Aggregate (kg/m ³)	Fiber length (mm)	Fiber Content (kg/m ³)	Super plasticizer (kg/m ³)	Water (kg/m ³)
NSC-CM	470	930	1300	-	-	3.6	256
FRC-0.1-10	470	930	1300	10	1.02	3.6	256
FRC-0.1-20	470	930	1300	10	1.02	3.6	256
FRC-0.1-30	470	930	1300	10	1.02	3.6	256
FRC-0.2-10	470	930	1300	20	2.04	3.8	256
FRC-0.2-20	470	930	1300	20	2.04	3.8	256
FRC-0.2-30	470	930	1300	20	2.04	3.8	256
FRC-0.3-10	470	930	1300	30	3.07	4.0	256
FRC-0.3-20	470	930	1300	30	3.07	4.0	256
FRC-0.3-30	470	930	1300	30	3.07	4.0	256



Figure 6. Experimental test procedure for FTPF reinforced concrete(a) Slump test (b) Compression test (c) Splitting tensile strength test (d) Modulus of elasticity (e) Flexural strength

4 Result and Discussion

An experimental study was carried out to study the fresh and hardened properties of FTPFRC for three different fiber lengths and three volume fractions of fibers. The slump value, compressive strength, split tensile strength, modulus of elasticity, and flexural strength values are tabulated in Table 4. Three specimens were tested for each case, and the mean values are listed along with the coefficient of variation.

4.1 Fresh property of FTPF reinforced concrete

The slump flow test was carried out to determine the workability of concrete. Workability is an important parameter for concrete construction, in addition to the quality of ingredients used in concrete. The addition of fibers to concrete increases the viscosity of concrete and restricts the distribution of the cement matrix, thereby reducing the slump value [40]. Natural fibers tend to absorb moisture from the wet concrete, which again influences the slump value [5]. The presence of fibers increases the surface area of concrete, which reduces the amount of free water available for the mobility of cement particles [41]. In addition, the fibers also affect the relative mobility of coarse aggregate and the

free flow of concrete. Wang et al. [42] studied the effect of fiber length and volume fraction on the slump value of concrete. The lowest slump value of 15.8 mm was recorded for a volume fraction of 0.4% basalt fiber, and it was concluded that with the increase in volume fraction of fibers, the slump values decreased. Prakash et al. [43] studied the influence of sisal fiber on the lightweight coconut shell aggregate concrete and concluded that the increase in fiber content from 1% to 4% reduces the slump value by 50%. Short fibers improve the workability compared to long fibers, because the latter have a large surface area that provides interference and blockage to aggregate, thereby reducing the workability [44]. The conclusion from previous research work supports our present study of FTPFRC. The density of concrete slightly decreases with the increase in fiber content. For control mix, the density is about 2450 kg/m³, which reduces to 2435 kg/m³, 2410 kg/m³ and 2390 Kg/m³ for concrete with 0.1%, 0.2% and 0.3% fiber content,

respectively. A very minimal change in density was observed for the change in length of fibers.

The plot showing the variation of slump value with respect to fiber length (FL) and volume fraction (VF) is shown in Figure. 7. For the volume fraction of 0.1% the slump value decreased from 80 to 77 for a change in fiber length from 10 mm to 30 mm. With the increase in volume fraction from 0.1 to 0.2% the slump value slightly decreases. With a constant slump value, the increase in fiber length also affects the slump value. The lowest slump value of 65 mm was recorded for FRC with 0.3% VF and 30 mm FL. The empirical correlation between the slump value (S) and fiber volume fraction was obtained through linear regression analysis, which is shown in Figure. 8. Three empirical equations were developed for three fiber lengths. All three-regression analyses showed a high coefficient of determination (R² = 0.95-0.98).

Table 4. Fresh and hardened properties of FTPF reinforced concrete

Specimen ID	Slump value (mm) (CoV %)	Compressive Strength (MPa) (CoV %)	Splitting tensile strength (MPa) (CoV %)	Modulus of elasticity (GPa) (CoV %)	Flexural strength (MPa) (CoV %)
NSC-CM	83 (1.21)	30.1 (1.2)	2.3 (0.67)	27 (.123)	3.5 (0.21)
FRC-0.1-10	80 (1.9)	30.2 (1.02)	2.59 (0.67)	27.56 (1.34)	3.80 (0.32)
FRC-0.1-20	78 (1.42)	30.33 (1.5)	2.60 (0.45)	27.9 (1.32)	3.81 (0.11)
FRC-0.1-30	77 (0.45)	30.92 (1.34)	2.62 (0.32)	28.2 (1.02)	3.89 (0.12)
FRC-0.2-10	76 (.135)	32 (0.91)	2.61 (0.12)	27.92 (1.12)	3.90 (0.23)
FRC-0.2-20	75 (1.11)	33.3 (1.32)	2.63 (0.34)	28.5 (1.05)	3.91 (0.11)
FRC-0.2-30	73 (.120)	36 (1.1)	2.82 (0.05)	30 (1.11)	4.20 (0.21)
FRC-0.3-10	72 (0.56)	32.9(1.03)	2.66 (0.21)	28.4 (.136)	3.95 (0.23)
FRC-0.3-20	68 (1.32)	33.8(1.24)	2.70 (0.42)	28.72 (1.45)	4.02 (0.14)
FRC-0.3-30	65 (1.08)	35 (1.42)	2.75 (0.12)	29.98 (1.03)	4.10 (0.16)

Note: Three specimens tested for each hardened concrete test and the coefficient of variation percentage are shown in bracket

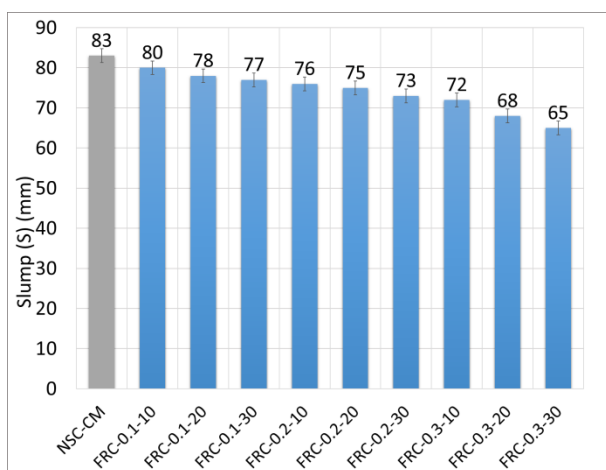


Figure 7. Slump values of FTPFRC

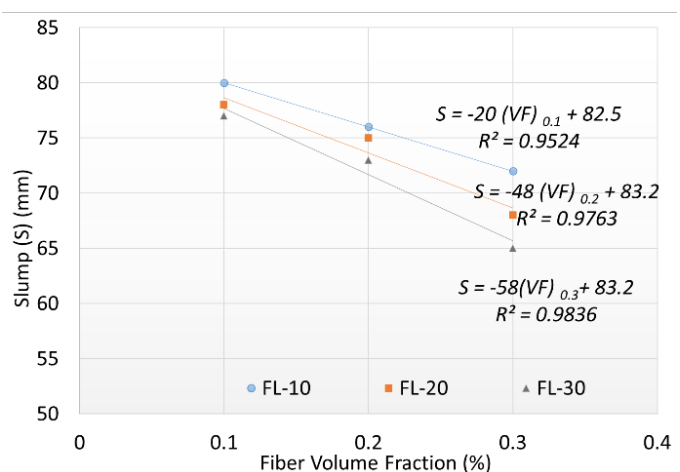


Figure 8. Linear correlation between slump and fiber volume fraction

4.2 Compressive Strength

The compressive strength of FTPFRC with different volume fractions and fiber lengths is shown in Figure. 9. The compressive strength does not show a significant increase with a volume fraction of 0.1%- at 10-mm fiber length. The strength gradually increases to 0.2% volume fraction. A maximum of 19% increase in compressive strength was obtained for 0.2 VF with 30 mm FL. For 0.3% VF, the increase in strength is about 9%, 12% and 16% for 10 mm, 20 mm, and 30 mm long fibers, respectively. Compared to the strength of specimen with 0.3%VF, only 30 mm FL showed a reasonable increase in strength of about 16%. As the fiber content increases, the concrete becomes more porous due to fiber clustering and interaction with large particles, which reduces the strength of the concrete specimen with 0.3 VF of fibers. Improper compaction and packing of concrete materials may also contribute to the reduction in strength. When comparing short and long fibers, the contribution of short fiber is minimal when compared to long fibers (30 mm). Compared to all the three-volume fractions, FRC with 0.2%VF and 30 mm FL showed a better performance in compression.

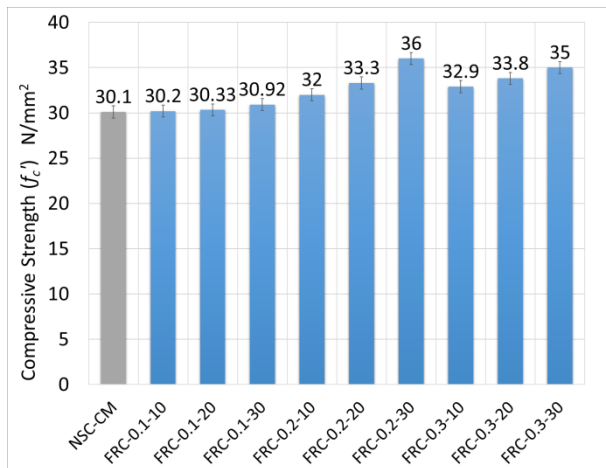


Figure 9. Compressive strength of FTPERC with different fiber length and volume fraction

The work done by Chakraborty et al. [23] proved that the fiber length plays a major role in improving the compressive strength of mortar, but only up to a certain volume fraction (1% wt. of cement). Prakash et al. [45] reported that the addition of sisal fiber and polypropylene fibers to concrete increases the compressive strength of coconut shell aggregate concrete. They reported a maximum compressive strength of 35 MPa for light weight concrete. 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 the fibers in the case of long length fibers [46]. Use of fibers in concrete results in closely spaced cracks with reduced crack width. Fibers also help to bridge the crack, which increases the strength of FRC [19]. It can be clearly stated that, previous research work on FRC supports our present experimental results.

4.3 Splitting tensile strength

The addition of fibers enhances the tensile strength and fracture energy of concrete specimens [47]. The fibers not only act as micro reinforcement, but also contribute to the strength of the concrete. The failure pattern of a cylinder specimen reinforced with 0.3% VF of fibers is shown in Figure. 10. From the figure, it is clearly visible that the fibers play an important role in reducing the stress concentration in concrete matrix. Once a crack develops in concrete, the fibers distribute the stress in different directions and prevent the formation of wider cracks. In the case of a control specimen with no fibers, the failure of the specimen was a single explicit crack. The cement matrix glues all the reinforcing fibers into shape and transfers the stress through them along their longitudinal direction [48]. Prakash et al [50] reported that the addition of steel and polypropylene fiber increased the tensile strength of concrete. Wahyuni et al. [51] reported that the 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 present study is shown in Figure.11. The plot is similar to the compression strength variation. The tensile strength increases with the addition of fibers from 2.3 to 2.5 MPa for 0.1 F and 10 mm FL. For the same VF, the length of fibers does not have major impact. FRC with 0.2%VF and 30 mm FL showed a maximum tensile strength. Again, comparing the specimen with 0.3% VF, only 30 mm FL showed a significant increase in tensile strength. As the fiber content increases, the concrete becomes more porous due to fiber clustering and interaction with large particles, which reduces the strength of the concrete specimen with 0.3 VF of fibers. Improper compaction and packing of concrete materials may also contribute to the reduction in strength. From the experimental observations, it can be concluded that the mechanical properties of FRC show a maximum value of 0.2 VF and 30 mm FL.



Figure 10. Failure pattern of fiber reinforced cylinder specimen

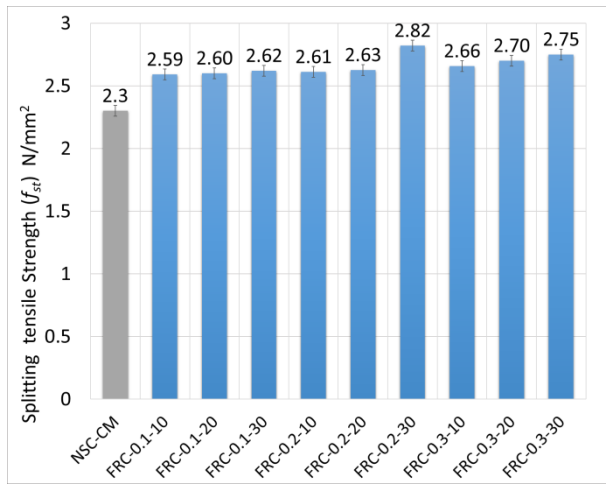


Figure 11. Splitting tensile strength of FTPERC with different fiber length and volume fraction

The regression analysis was carried out to develop an empirical equation to relate the split tensile strength (f_{st}) with the compressive strength (f_c'). The correlation between split tensile strength and compressive strength with a high regression value ($R^2 = 0.94$) is shown in Figure. 12. The American Concrete Institute code [52] suggests equ (1) to correlate the splitting tensile strength with the compressive strength

$$f_{st} = 0.53\sqrt{f_c'} \quad (1)$$

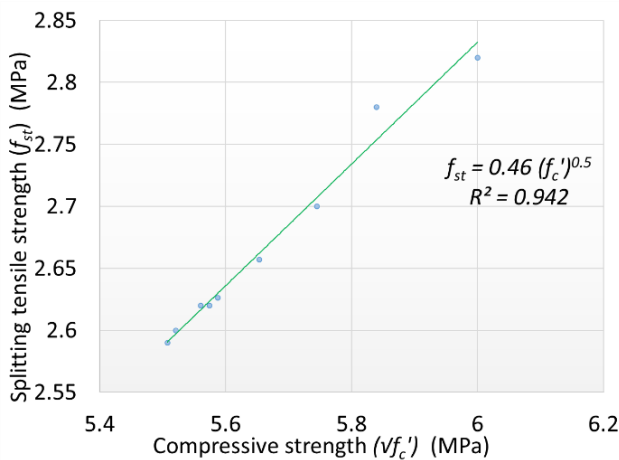


Figure 12. Regression plot of splitting tensile strength and compressive strength

According to European standards [53] the correlation between splitting tensile strength and compressive strength is given by equ (2)

$$f_{st} = 0.3(f_c')^{2/3} \quad (2)$$

The correlation between splitting tensile strength and compressive strength according to the Japanese Concrete Institute code [54] and the New Zealand code [55] is given by equ (3) and equ (4)

$$f_{st} = 0.13(f_c')^{0.85} \quad (3)$$

$$f_{st} = 0.44\sqrt{f_c'} \quad (4)$$

The comparison between the present experimental result and the standard codal correlation equation for splitting tensile strength and compressive strength is shown in Figure. 13. From the plot, it is clearly visible that the experimental results agree well with the correlation predicted by standard codes. The proposed equation for correlating splitting tensile strength with compressive strength of fish tail palm fiber reinforced concrete is given by equ (5)

$$f_{st} = 0.46\sqrt{f_c'} \quad (5)$$

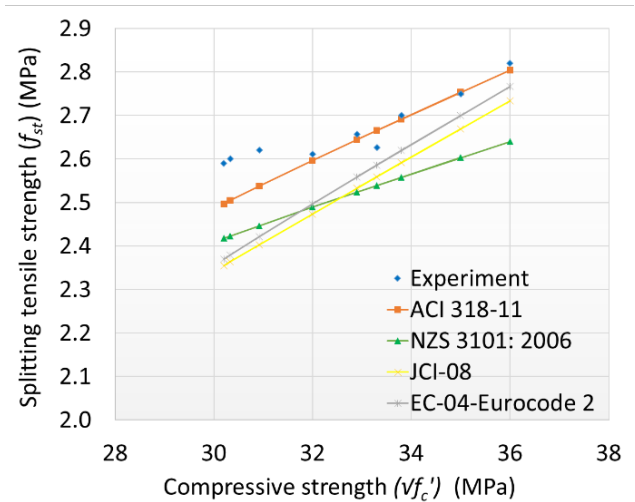


Figure 13. Comparison of experimental splitting tensile strength value Vs standard codal values

4.4 Flexural strength

The failure of the specimen started in the tension zone with the development of tension cracks, as the maximum tensile capacity of the specimen was reached. The failure of the beam was ductile in nature, which can be explained by the fact that the fibers bridge the crack within the concrete and improve the post cracking behavior of FRC [56]. The failure pattern of the beam along with the bridging of micro cracks by the fibers is shown in Figure. 14. Failure of the specimen occurs once the maximum tensile capacity of the fiber is reached. Awwad et al. [57] studied that the flexural strength of hemp FRC is increased by fiber content and resulted in a ductile post-cracking behavior of FRC. It has been demonstrated that the addition of roselle fiber [58], flax fibers [59], jute [26], and sisal fiber [60] improves concrete flexural strength while also increasing toughness and residual strength. In the present study also, the flexural strength increased with the VF of fibers. Flexural strength increased from 3.5 MPa for the control specimen to 4.2 MPa and 4.1 MPa for the 0.2VF and 0.3VF with 30 mm FL, respectively. The maximum flexural strength is about 12% of its corresponding compressive strength. The variation of flexural strength with FL and VF is shown in Figure. 15. The length of fibers does not have a major influence on the flexural strength for lower volume fractions. But for higher VF, the fiber length plays a crucial role and improves the flexural strength.

The ratio of splitting tensile strength to compressive strength varies from 0.076, 0.084, 0.078, and 0.078 for control specimens and specimens with 0.1 VF, 0.2 VF, 0.3

VF of fiber reinforced specimens, respectively. From the ratio, it is clear that the addition of fibers equally contributes to the tensile strength and compressive strength of concrete. The ratio of flexural strength to compressive strength varies from 0.11, 0.125, 0.117 and 0.117 for control specimens and specimens with 0.1 VF, 0.2 VF, 0.3 VF of fiber reinforced specimens with 30 mm fiber length, respectively. From the ratios, it is much clear that the contribution of fibers to the flexural strength is much greater than the splitting tensile strength.



Figure 14. Failure pattern of fiber reinforced beam specimen

A linear regression analysis was carried out to develop an empirical equation to relate the flexural strength (f_r) with the compressive strength (f_c'). Figure.16 depicts the regression analysis correlation developed between flexural strength (f_r) and compressive strength (f_c'), and the developed equation has a high regression value ($R^2 = 0.98$). The American Concrete Institute code [52] suggests equ (6) to correlate the flexural strength with the compressive strength

$$f_r = 0.62\sqrt{f_c'} \quad (6)$$

According to European standards [53] the correlation between flexural strength and compressive strength is given by equ. (7)

$$f_r = 0.435(f_c')^{2/3} \quad (7)$$

The correlation between flexural strength and compressive strength according to and the New Zealand code [55] is given by equ. (8)

$$f_r = 0.6\sqrt{f_c'} \quad (8)$$

The comparison between the present experimental result and the standard codal correlation equation between flexural strength and compressive strength is shown in Figure. 17. From the plot, it is clearly visible that the experimental results agree well with the correlation predicted by standard codes. The proposed correlation equation for flexural strength and compressive strength of fish tail palm fiber reinforced concrete is given by equ. (9)

$$f_r = 0.5771\sqrt{f_c} \quad (9)$$

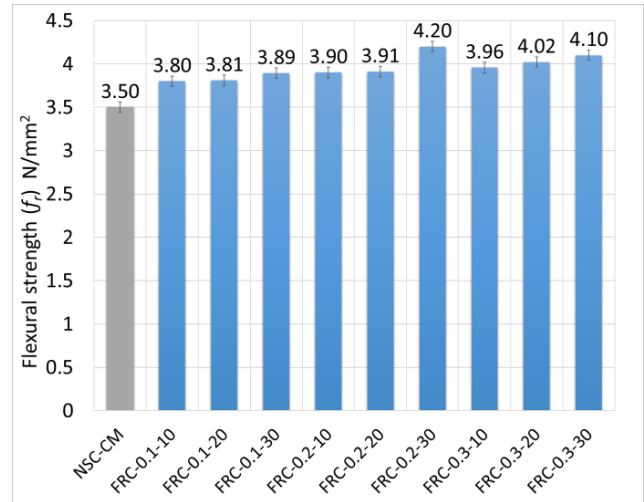


Figure 15. Flexural strength of FTPERC with different fiber length and volume fraction

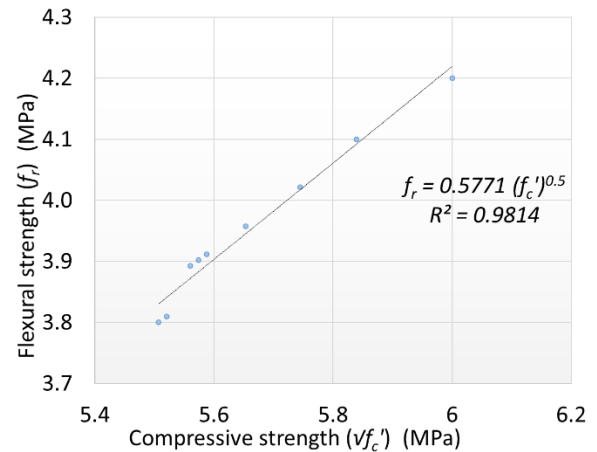


Figure 16. Regression plot of flexural strength and compressive strength

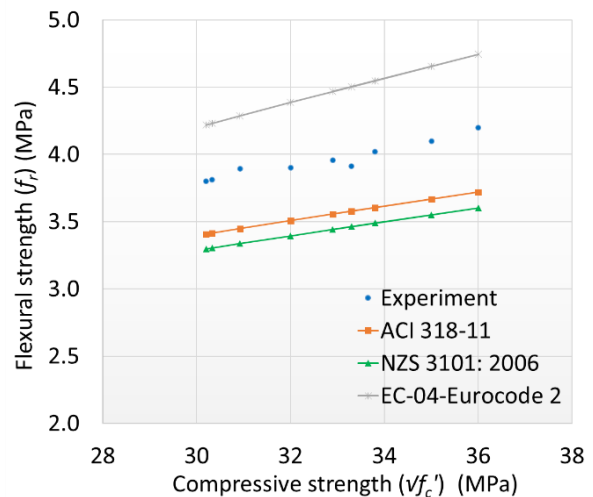


Figure 17. Comparison of experimental flexural strength with standard codal values

4.5 Modulus of elasticity

The modulus of elasticity is the ratio of stress to the corresponding strain of a concrete specimen within the elastic zone. Fiber tensile strength governs the modulus of elasticity (MoE) of concrete [61], which plays a major role in the pre-cracking behavior of concrete specimens. The addition of fibers helps improve the mechanical properties of concrete and composites [62]. As the fiber content increases, the ductility of the concrete specimen is also increased, and the MoE also increases. Addition of fibers increases the stress redistribution and reduces the strain localization within the concrete. The fibers restrain the crack at the beginning, reducing stress concentration and preventing crack growth in the post-cracking region [47]. Prakash et al. [50] reported that the addition of steel fibers increases the elasticity of coconut shell aggregate concrete by 17%. The addition of sisal fibers also tends to increase the MoE by 6% for the addition of 3% volume of fibers [45]. 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 [58]. The MoE of the FTPFRC with different VF and fiber lengths is shown in Figure. 18. As the fiber content increases, the elasticity of concrete increases as a greater number of fibers are involved in the crack arresting mechanism, which prevents the development of new cracks and also reduces the stress concentration. For the VF of 0.1 %, the increase in MoE value is about 4% for the FL of 30 mm. For 30 mm fiber length, the MoE increases by 11% for VF of 0.2% and 0.30%. From the result, it is clearly visible that the length of fibers also plays a minor role in increasing the elasticity of fiber reinforced concrete.

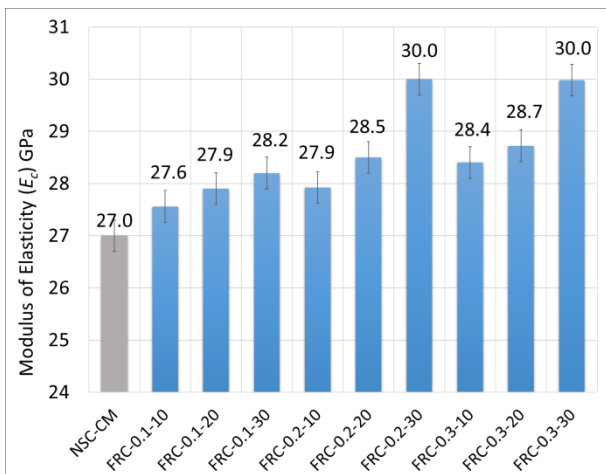


Figure 18. Modulus of elasticity of FTPFRC

The linear regression analysis was carried out to develop an empirical equation to relate the modulus of elasticity (E_c) with the compressive strength (f_c'). The correlation obtained between modulus of elasticity (E_c) and compressive strength (f_c') with a high regression value ($R^2 = 0.93$) is shown in Figure. 19. The American Concrete Institute (ACI) code [52] suggests equ (10) to correlate the MoE with the compressive strength

$$E_c = 4.73\sqrt{f_c'} \tag{10}$$

According to European standards [53] the correlation between flexural strength and compressive strength is given by equ (11)

$$E_c = 22(f_c'/10)^{0.3} \tag{11}$$

The correlation between modulus of elasticity and compressive strength according to the Japanese Concrete Institute code [54] and the New Zealand code [55] is given by equ (12) and equ (13)

$$E_c = 0.63(f_c')^{0.45} \tag{12}$$

$$E_c = 3.32\sqrt{f_c'} + 6.9 \tag{13}$$

The comparison between the present experimental result and the standard codal correlation equation for MoE and compressive strength is shown in Figure. 20. From the plot, it is clearly visible that the experimental results agree well with the correlation predicted by standard codes. The proposed equation for correlating modulus of elasticity with the compressive strength of fish tail palm fiber reinforced concrete is given by equ (14)

$$E_c = 4.233\sqrt{f_c'} \tag{14}$$

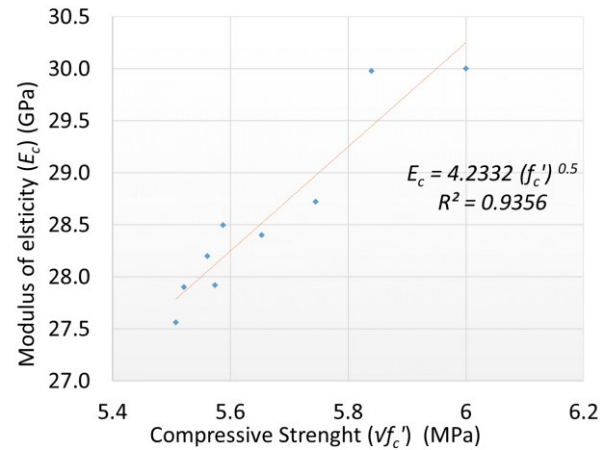


Figure 19. Correlation relation between MoE and compressive strength

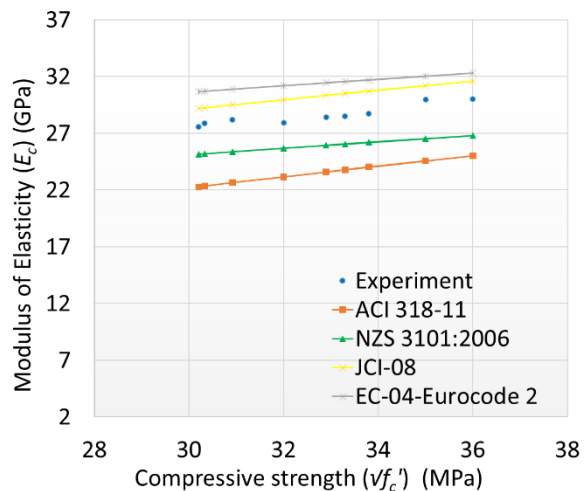


Figure 20. Comparison of experimental MoE with the standard codal prediction

4.6 Impact resistance

The repeated dropping weight test method was used to measure the impact strength and energy absorption capacity of FRC. The addition of natural fibers helps to improve the fracture properties and impact resistance of FRC [63]. When compared to plain cement mortar panels, the impact resistance of mortar panels reinforced with coir, sisal, jute, and hibiscus increases by 3-18 [64]. Hybridization of synthetic fibers with natural fibers not only makes the environment friendly but also increases the impact resistance and load carrying capacity of composites [65]. Wang et al. [66] studied the impact resistance of coconut

fiber reinforced concrete cylinders and reported that fiber reinforcement results in the formation of tiny microcracks at the initial stage of impact load, which propagates through different fiber lengths across the cylinder and results in the ultimate failure of the specimen. Prakash et al. [58] showed that the addition of 4% of roselle fiber increases the impact resistance by about 100%. Thus, fibers prevent the sudden failure of a concrete specimen and play an important role in the post cracking behavior of concrete. The addition of 4% of sisal fiber increases the impact strength by 91 % for coconut shell aggregate light weight FRC [50]. In the present study the number of blows recorded for the First Crack, Ultimate Crack and the impact energy is listed in Table 5.

Table 5. Impact energy of fish tail palm fiber reinforced concrete

Specimen ID	Number of blows for first crack (N ₁)	Number of blows for ultimate crack (N ₂)	Impact energy (N ₂ -N ₁) *mv ² /2 N-m
NSC-CM	6	10	81.38
FRC-0.1-10	7	12	101.725
FRC-0.1-20	8	14	122.07
FRC-0.1-30	9	18	183.105
FRC-0.2-10	8	13	101.725
FRC-0.2-20	9	16	142.415
FRC-0.2-30	10	21	223.795
FRC-0.3-10	9	14	101.725
FRC-0.3-20	10	20	203.45
FRC-0.3-30	12	24	244.14

The impact energy plotted with respect to fiber volume fraction is shown in Figure. 21. From the plot, it can be concluded that for low VF (0.1) the increase in impact energy is not prominent. But for 0.2VF and 0.3VF of fibers, the impact energy shows a considerable increase for 20 mm and 30 mm of the fiber length. Thus, in addition to fiber volume fraction, fiber length also plays a role in the post cracking behavior of concrete. When compared to a control specimen, the increase in impact energy is about 175% and 200 % for 0.2VF and 0.3 VF with 30 mm fiber length. All the FTPFRC showed improved performance in arresting the micro cracks and resulted in higher impact resistance compared to the unreinforced control specimen. Out of all the nine FRC mixes, the specimen with 0.2 VF-20 mm FL and the 0.3VF with 30 mm FL specimen show better mechanical properties and impact resistance. Linear regression analysis was carried out to correlate the number of blows between the first crack and the ultimate crack for FL 10, FL20, and FL 30 mm and the plot is shown in Figure. 22. The equation developed showed a high regression value (R² = 0.96-1). The three-equation developed between Ultimate Crack (UC) and First Crack (FC) for 10 mm, 20 mm, and 30 mm fiber lengths is given by equ. (15), equ. (16), and equ. (17) respectively.

$$UC_{20} = 3(FC_{20}) - 10.33 \tag{16}$$

$$UC_{30} = 2.57(FC_{30}) - 4.57 \tag{17}$$

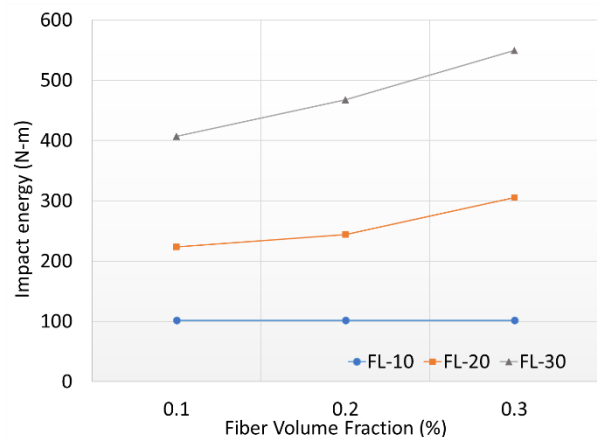


Figure 21. Relation between impact energy and fiber volume fraction

$$UC_{10} = FC_{10} + 5 \tag{15}$$

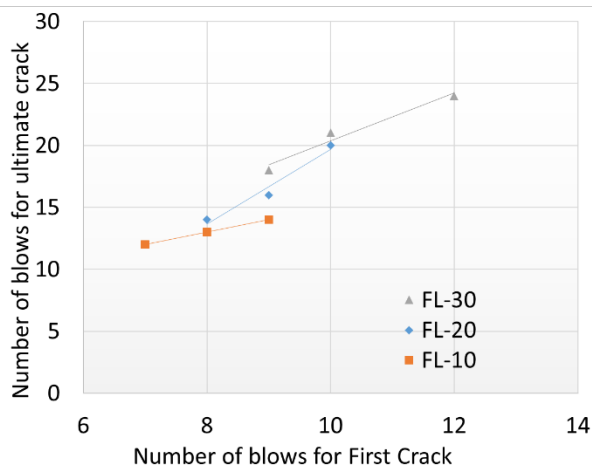


Figure 22. Correlation between number of blows for first and ultimate crack for different FL and VF

5. Conclusion

The experimental investigation was carried out on concrete with a 28-day compressive strength of 30 MPa that was reinforced with natural fish tail palm fiber for three different volume fractions and three different fiber lengths. The following conclusion can be drawn:

- For a fiber volume fraction of 0.3%, the slump value decreases and reduces the workability. The viscosity of the concrete matrix is increased by 0.3 VF, and the fibers prevent the even distribution of the cement matrix, which is more prominent for 30 mm fiber length.

- The contribution of fibers to the compressive strength of concrete is a minimum of 2%, for 0.1 VF of fiber addition. The maximum increase in compressive strength of 20% was recorded for a concrete specimen with 0.2% VF and a 30 mm fiber length, followed by a specimen with 0.3VF and a 30 mm FL, which showed a strength increase of 16%.

- The tensile strength of fibers contributes mainly to improving the crack arresting mechanism of concrete in the pre cracking as well as in the post peak region. Once cracks develop in concrete, the fibers share the stress and distribute the stress across the cross section, which reduces the stress concentration and prevents the formation of wider cracks. The maximum increase in splitting tensile strength and flexural strength is about 22% and 20%, which was observed for mix with 0.2VF and 30 mm FL.

- The impact energy of all the FTPFRC specimens increases with the addition of fibers. The maximum increase in impact energy of 175% and 200% was recorded for 0.2 VF with 20 mm and 30 mm FL. Thus, the fiber length also contributes to absorbing the impact load and increasing the impact resistance.

- These micro fibers prevent crack formation at the micro level and improve the strength properties and impact resistance of concrete elements. Due to the study of the residual strength and strain energy properties of fish tail palm fiber reinforced concrete, a detailed investigation has to be carried out.

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Authors' contributions:

Vijayalakshmi Ramalingam: Investigation, Data curation, Writing – original draft

Keerthika Ramesh: Investigation and data curation

Modhagapriyan Arumugam: Investigation and data curation

Vaishnavi Muralidharan: Investigation and data curation

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