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UTILIZATION OF NATURAL FIBER IN CONCRETE - A REVIEW

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Abstract- *In the field of agriculture, huge quantities of waste are generated from different crops. The waste so generated is generally left untouched on the land which affects the fertility of soil or if the waste is burnt, it affects the environment. This waste contains large quantities of fiber which can be utilized in concrete to reduce the amount of waste and indirectly the cost of concrete.*
This paper reports review on different types of natural fibers such as industrial hemp, palm, coconut, san and banana leaves fibers that can be utilized in concrete and effect of such fibers on properties of concrete containing fibers. Such materials would increase the service life and reduce the life cost of the structure and would have appositive effect on social life and social economy.

Keywords-*Natural fibers, Fresh properties, Mechanical properties, Durability properties, Ductile properties.*

I. INTRODUCTION

In the present era, most of the population depends on the agriculture farming. Many types of crops are grown during a year. During sawing process of the crops huge amount of waste is generated. The waste so generated contains different types of fibers. This waste can be effectively utilized for construction purpose.
From many years, fibers are used in many construction activities like construction of houses, plastering of walls etc. [1]. The use of natural fibers in rural construction activities will result in economic structures which will be stronger and more durable thereby solving one of the major deficiencies in rural structures. The natural fibers have the potential to be used as reinforcement in cement and concrete matrices to overcome some inherent deficiencies of these materials. These fibers have got many benefits as compared to widely used artificial fibers because they are cheaper, renewable, nonabrasive, and available in large quantities and do not create health and safety problems during handling, processing and mixing operations.

Various researchers have investigated different properties of concrete by using various types of fibers like coconut, sugarcane bagasse, banana, san, date-palm, coir, eucalyptus, flax, bamboo, agave, elephant grass, sisal, rosella etc. to improve the properties of concrete. The construction industry is extremely conservative, and so the most likely development route is the use of the new materials to reduce the ever increasing demand of natural aggregates and sand. Various studies and experiments around the world have shown that natural fiber utilization in concrete is a viable and cost effective alternative to conventional building materials.

II. NATURAL FIBER

Fiber is a thread or **filament** from which a vegetable tissue, mineral substance or textile is formed. Fiber is dietary material containing substance such as cellulose, lignin and pectin that are resistant to the action or digestive enzymes. Fibers are a class of hair-like materials. They can be used as a component of compositematerials. Natural Fibers are obtained from plants (vegetable, leaves and wood), animals and various geological processes. Natural fibers are cheap and locally available in many countries. So their use as a construction material for increasing properties of composites, costs a very little (almost nothing when compared to the total cost of the composites). Their use can lead to have sustainable development [2].

Natural fibers are basically consist of two types-

2.1 Animal fiber:Animal fiber includes wool, hair and secretions, such as silk. Animal fiber for the most part comprises of proteins; illustrations mohair, fleece, silk, alpaca. Animal hairs are the fibers obtained from animals e.g. horse hair, sheep's fleece, goat hair, alpaca hair, and so on.

2.1.1 Animal hair (wool or hairs): Fiber or wooltaken from animals or hairy mammals comes in this category. e.g. sheep's wool, goat hair (cashmere, mohair), alpaca hair, horse hair, etc.

2.1.2 Silk fiber: Such fiber is generally secreted by glands (often located near the mouth) of insects during the preparation of cocoons.

2.1.3 Avian fiber: Fibers from birds, e.g. feathers and feather fiber.

2.2 Plant fiber: Plant fibers include seed hairs such as cotton; stem fibers such as flax and hemp; leaf fibers such as sisal and husk fibers such as coconut.

2.2.1 Coir/coconut fibers: Coir fiber is extracted from the outer shell of a coconut. There are two types of coir fibers, brown fiber which is extracted from matured coconuts and white fibers which is extracted from immature coconuts. Brown fibers are thick, strong and have high abrasion resistance. White fibers are smoother and finer, but are weaker than brown fibers [3].

2.2.2 Sisal fibers: Sisal fibers are stiff fibers extracted from an agave plant. These fibers are straight, smooth and yellow in colour. Strength, durability and ability to stretch are some important properties of sisal fibers [3].

2.2.3 Jute fibers: Jute fiber is produced from genus corchorus, family tiliaceae. It is a long, soft and shiny vegetable fiber having off-white to brown colour. High tensile strength and low extensibility are some key properties of jute fibers [3].

2.2.4 Cotton fibers: Pure cellulose, cotton is the world’s most widely used natural fiber and still the undisputed “king” of the global textiles industry [3].

2.2.5 San fibers: San is a natural bast fiber, which also known as sunn hemp. It is extracted from san plant which is grown in many parts of Indian subcontinent, Brazil, Eastern and southern Africa. It has good physical and mechanical properties which is suitable for concrete.

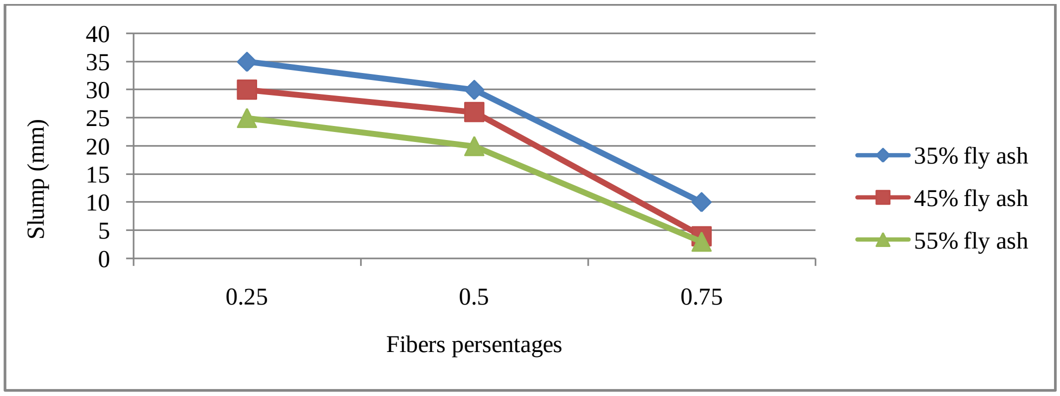
2.2.6 Roselle fibers: It also known as Belchanda among Nepalese. It is an annual or perennial herb. The plant is primarily farming for the production of bast fibre from the stem. The fibre may be used as a substitute for jute in making burlap.

2.2.7 Knef (Hibicus) fibers: It is a plant in the Malvaceae family also called Java jute. It is an annual or biennial herbaceous plant. It is cultivated for its fibre in India, Bangladesh and United States of America. The stems produce two types of fibre, a coarser fibre in the outer layer and a finer fibre in the core.

III. FRESH PROPERTIES OF NATURAL FIBER CONCRETE

3.1 Workability:

Siddique [4] replaced cement by fly ash in different percentages 35%, 45% and 55% by weight. San fiber was also added in different percentages 0.25%, 0.50% and 0.75% in concrete mixture. It was found that slump decreased with an increase in the percentage of san fibers. There was slump loss of 15 mm, 20 mm and 25 mm for 35%, 45% and 55% fly ash concrete, respectively. These fibers adversely affected the Vebe time of concrete also. The Vebe time was increased with increasing percentage of san fiber. The increased as in Vebe time for 0.25% as compared to 0.75% of san fiber was 24 s, 26 s and 32 s for 55%, 45% and 35% fly ash concrete respectively. The effects of the san fibers on the slump and Vebe time of fly ash concrete are shown in Figure 1 and Figure 2.



Figuer 1 Effects of san fibers on the slump of fly ash concrete [4]

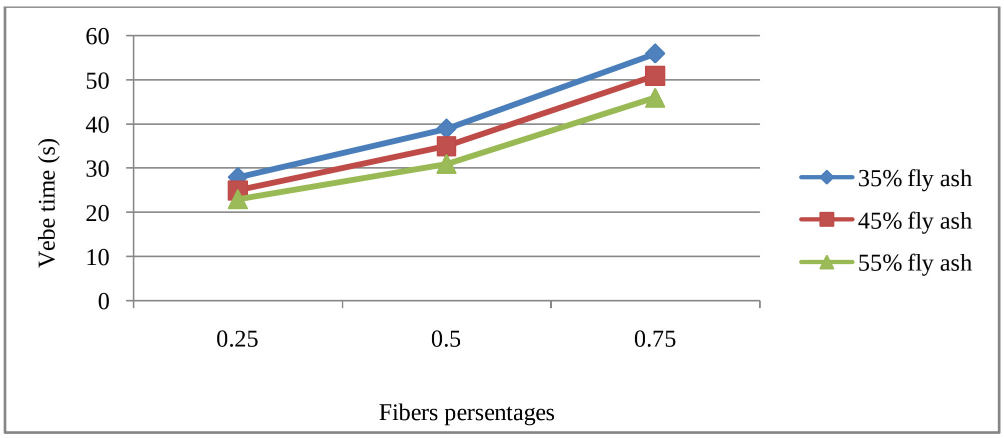


Figure 2 Effects of san fibers on the vebe time of fly ash concrete [4]

Rahuman and Yeshika [5] added sisal fiber in concrete in different percentage (0.5%, 1.0% and 1.5%) by weight of cement. There was an increase in slump value from 4mm to 53mm after addition of super plasticizer. Degree of workability for concrete mixture with 0.2% super plasticizer and water cement ratio 0.45 provided good workability.

Table 1 Slump value for 1.5% sisal fiber [5]

W/C ratio	Slump values in mm	
	Without super plasticizer	With super plasticizer
0.35	1	14
0.40	3	26
0.45	4	53

Vajje and Murthy [6] used different types of fiber (blast rock, jute, sisal, hemp, banana and pineapple) with different fiber – cement ratio (0.5%, 1.0% and 1.5%) in concrete. Slump decreased with the increasing fiber-cement ratio due to water absorption by fiber. The slump values of different fibers are shown in Table 2.

Table 2 Slump value of different natural fiber in concrete [6]

Slump value of plain concrete is 92mm			
Type of the fibre	Slump in mm for fibre-cement ratio		
	0.5%	1.0%	1.5%
Blast Rock Fiber	78	62	60
Jute	70	45	50
Sisal	72	55	60
Hemp	75	52	65
Banana	72	50	58
Pineapple	74	65	56

IV. MECHANICAL PROPERTIES OF NATURAL FIBER CONCRETE

4.1 Compressive strength:

Ramakrishana and Sunderarajan [2] used different types of natural fiber (coir, sisal, jute and hibiscus cannabinus) in the concrete mixture under natural dry condition and with fiber after exposing in various mediums (H_2O, $Ca(OH)_2$, and NaOH) in two different types of immersion. Coir was used 0.15% by weight of cement and sisal, jute and hibiscus was used 0.2% by weight of cement. The compressive strength of control mix without fiber was 27.0 N/mm2. It was found that maximum reduction in compressive strength for coir and hibiscus was 56.7% and 14.2%, respectively in Ca(OH)2 medium and for sisal and jute in H2O medium reduction was 32.2% and 51.4%, respectively. The results of compressive strength for different natural fibers are shown in Table 3.

Table 3 Compressive strength for fiber concrete mixture [2]

Fiber types	Compressive strength (N/mm^2)						
	H_2O		$Ca(OH)_2$		NaOH		Natural dry condition
	1	2	1	2	1	2	
Coir	15.6	16.9	7.5	11.8	14.8	16.6	17.3
Sisal	9.4	12.8	10.8	7.8	10.8	10.0	13.8
Jute	5.5	10.2	6.8	6.7	9.0	10.0	11.3
Hibiscus	8.8	7.5	7.5	4.5	8.9	5.0	6.8

[1] alternative wetting and drying and [2] continuous in immersion mediums

Siddique [4] replaced cement by fly ash in different percentages 35%, 45% and 55% by mass. San fiber was added in different percentages 0.25%, 0.50% and 0.75% in concrete mixture. It was reported that the addition of san fibers decreased marginally the compressive strength of fly ash concrete. The decrease was 8-13%, 4-8% and 2-9% at 35%, 45% and 55% fly ash content. It was also reported that san fiber reinforced fly ash concrete at 28 days, a reduction in compressive strength between 2 to 12% was observed depending on the fly ash content and fiber percentage. It was concluded that presence of fiber induced porosity and reduced the compressive strength.

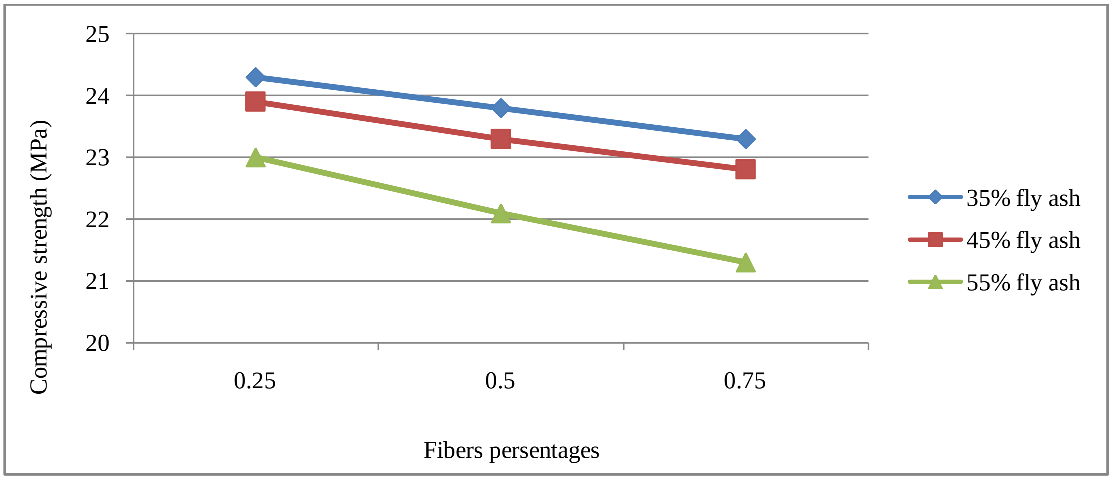


Figure 3 Effect of san fibers on the compressive strength of fly ash concrete [4]

Rahuman and Yeshika [5] added sisal fiber in concrete in different percentage (0.5%, 1.0% and 1.5%) by weight of cement. It was concluded that compression strength increased by 50.5% after addition of 1.5% fiber for M20 mix design, whereas the increase was up to 52.5% for the same percentage addition of fiber in M25.

Table 4 Percentage increased in compression strength of fiber content [5]

Percentage of Addition of Fiber	Percentage Increase In Strength (N/mm^2)	
	For M20	For M25
0.5%	0.168	4.36
1.0%	30.83	38.33
1.5%	50.53	52.51

Ismail [7] used Roselle fibres in concrete by different fiber – cement ratio (0, 0.25, 0.50, 0.75, 1.0, 1.5, 2.0 and 3.0) by weight of concrete. It was concluded that compressive strength increased by 3.8% for 0.25 fiber cement ratio and decreased by 7.3% for 1.5 fiber cement ratio.

Table 5 Compressive strength for different fiber cement ratio [7]

Fiber cement ratio	Compressive Strength (Mpa)
0	57.5
0.25	59.7
0.50	58.9
0.75	57.9
1.0	57.7
1.5	53.3
2.0	49.2
3.0	42.9

Kshatriyaet al. [8] added jute fiber in concrete, which was two different ways treated by NaOH or non - treated. The fiber was replaced by 1% weight of cement. It was concluded that compressive strength increased by 8.7% and 17.5% for non - treated and treated jute fiber, respectively.

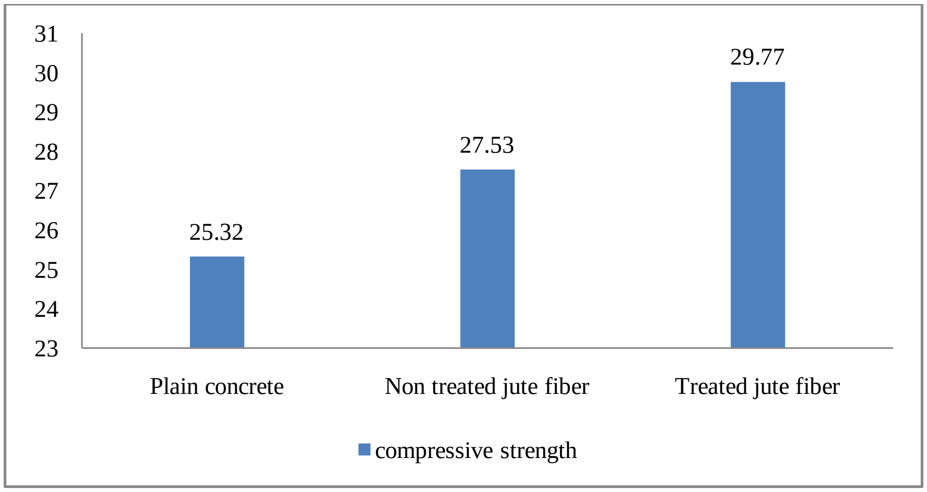


Figure 4 Compressive strength of fiber concrete [8]

Nadgouda [9] used 3%, 5%, and 7% (by weight of cement) of coconut fibre in the concrete mix. It was presumed that the compressive strength of concrete goes on decreasing with an increasing in the fiber content of the concrete mix. The compressive strength results with varying fiber content (0%, 3%, 5% and 7%) are shown in Figure5.

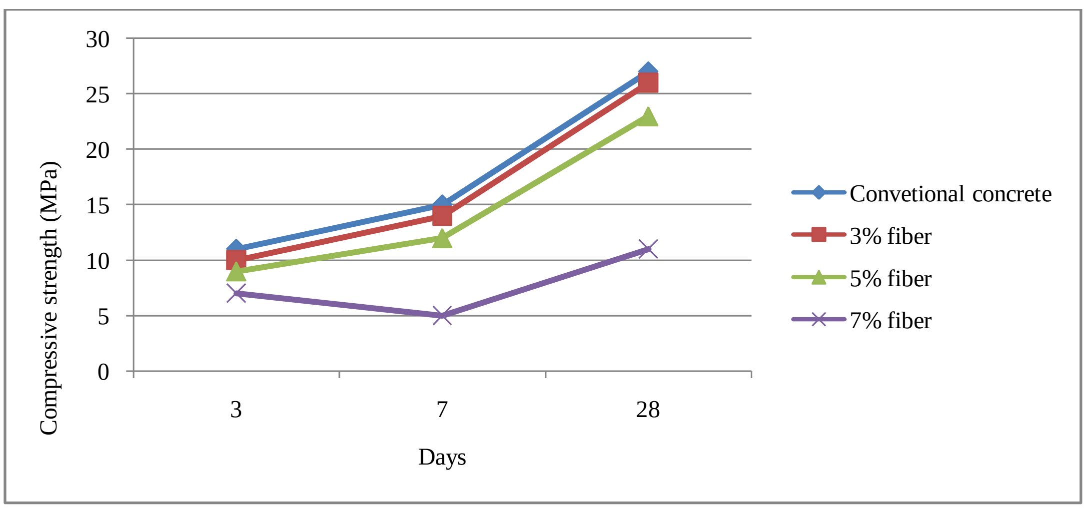


Figure 5 Compressive strength at different fiber percentages [9]

4.2 Tensile strength

Ramakrishana and Sunderarajan [2] used different types of natural fiber (coir, sisal, jute and hibiscus cannabinus) in the concrete mixture under natural dry condition and with fiber after exposing in various mediums (H_2O, $Ca(OH)_2$, and NaOH) in two different types of immersion. Maximum reduction in tensile strength was observed due to the effect of saturated lime on sisal, jute and hibiscus cannabinus fibres. After 60 days of alternate wetting and drying in saturated lime, sisal and hibiscus cannabinus fibres were completely destroyed, whereas, coir fibres were able to retain about 20– 40% of its original strength.

Table 6 Tensile strength of fibres after 60 days of alternate wetting and drying [2]

Fibre type	Tensile strength (N/mm^2)			
	Natural dry condition	Alternate wetting and drying in		
		Sodium hydroxide	Saturated lime	Fresh water
Coir	15-327	7.6-150.5	3-143.7	3-178.1
Sisal	31-221	5-55	(*)	1-164
Jute	29-372	2.7-34	3.5-16.3	7.5-58.5
Hibiscus	18-180	10	(*)	3-37

Note: (i) (*)—indicates that the fibres failed to take any load.
(ii) The range of values indicated corresponds to the lowest and the highest tensile strength of each type of fibre after the durability studies.

Siddique [4] replaced cement by fly ash with different percentages 35%, 45% and 55% by mass. San fiber added in different percentages 0.25%, 0.50% and 0.75% in concrete mixture. It was reported that addition of san fiber increases the tensile strength of fly ash concrete in the rangeof 11-8% at a fiber content of 0.25% and 27-22% for fiber content of 0.75% in case of high volume fly ash concrete (Fly ash - 35, 45 and 55%).

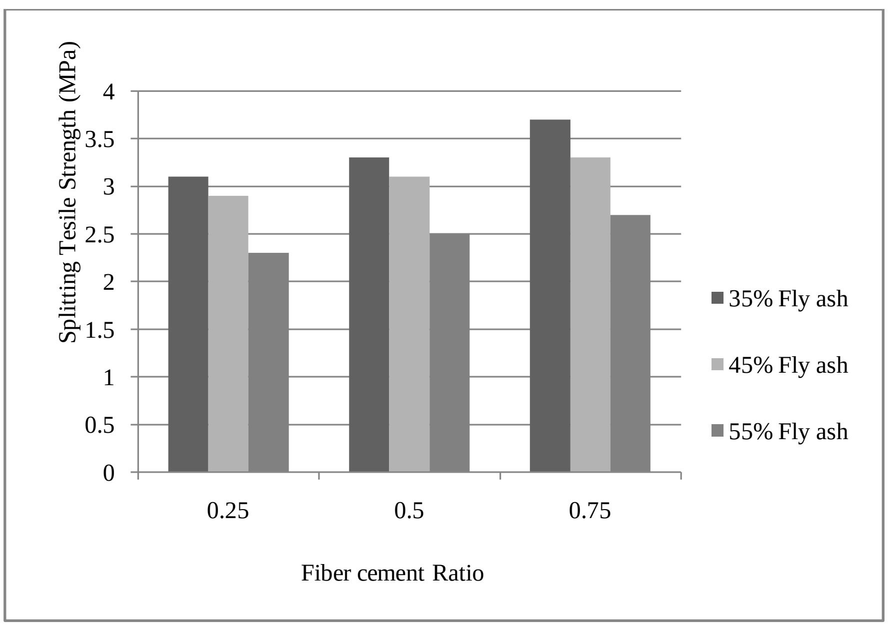


Figure 6 Effect of san fibers on the splitting tensile strength of fly ash concrete [4]

Rahuman and Yeshika [5] added sisal fiber in concrete in different percentage (0.5%, 1.0% and 1.5%) by weight of cement. The increased tensile strength for M20 mix design with 1% and 1.5% addition of fiber was 41.3% and 44.3%, respectively. There was a decrease in percentage increase in tensile strength for M25 when compared with M20. The increase in tensile strength for M25 mix design with 1% and 1.5% addition of fiber is 30.8% and 36.0%, respectively.

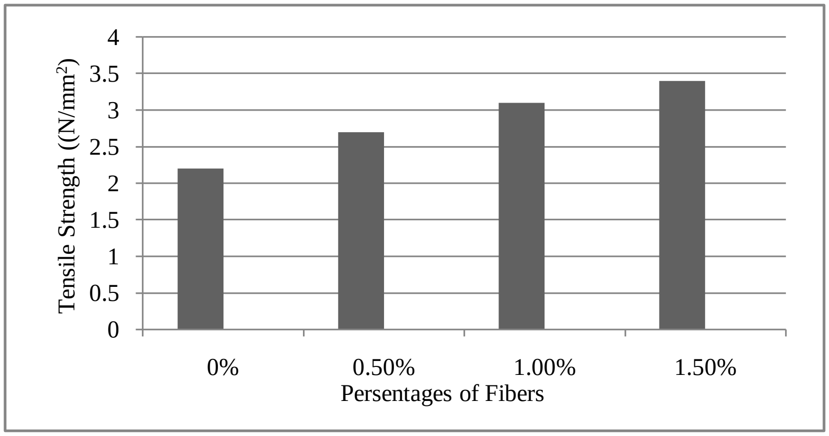


Figure 7 Tensile strength at different fiber percentages [5]

Ismail [7] used Roselle fibres in concrete by different fiber – cement ratio (0, 0.25, 0.50, 0.75, 1.0, 1.5, 2.0 and 3.0) by weight of concrete. It was reported that at lower fiber content (0.25%), the tensile strength decreased slightly (11.4%), while it increased by about 53% at 3% fiber content.

Table 7 Tensile Strength for different F/c ratio [7]

Fibre-Cement Ratio ($F/_c$)%	Tensile Strength (N/mm^2)
0	6.4
0.25	5.6
0.5	7.1
0.75	7.5
1.0	8.6
1.5	9.2
2.0	9.6
3.0	9.8

Nadgouda [9] used 3%, 5%, and 7% (by weight of cement) of coconut fibre in the concrete mix. It was observed that the tensile strength of concrete goes on decreasing with an increase in the fibre content of the concrete mix.

4.3 Flexural Strength

Siddiqui [4]] replaced cement by fly ash with different percentages 35%, 45% and 55% by mass. San fiber added in different percentages 0.25%, 0.50% and 0.75% in concrete mixture. It was reported that addition of san fiber increased the flexural strength of fly ash concrete. This increase is about 5% at 0.25% fiber content while at 0.75% fiber content the increase is about 10%. The addition of twines of natural san fiber enhanced the load carrying capacity and ductility.

Kshatriya [8] reported that sugarcane bagasse improved slightly (3.5%) the flexural strength. It was observed that when the raw jute is added in concrete by 1% weight of cement then the flexural strength of concrete cube increased by 1% and by adding modified jute flexural strength increase by 4%.

Nadgouda [9] used 3%, 5%, and 7% (by weight of cement) of coconut fibre in the concrete mix. The main purpose of including fibers in concrete is to increase the flexural strength of concrete which makes the concrete work more efficiently as a flexural member. From the Fig.6 that shows the variation of the flexural strength of concrete with the change in the fibers content, it was found that the 28th day flexural strength of concrete goes on increasing with an increase in the fiber content of the concrete mix [9]

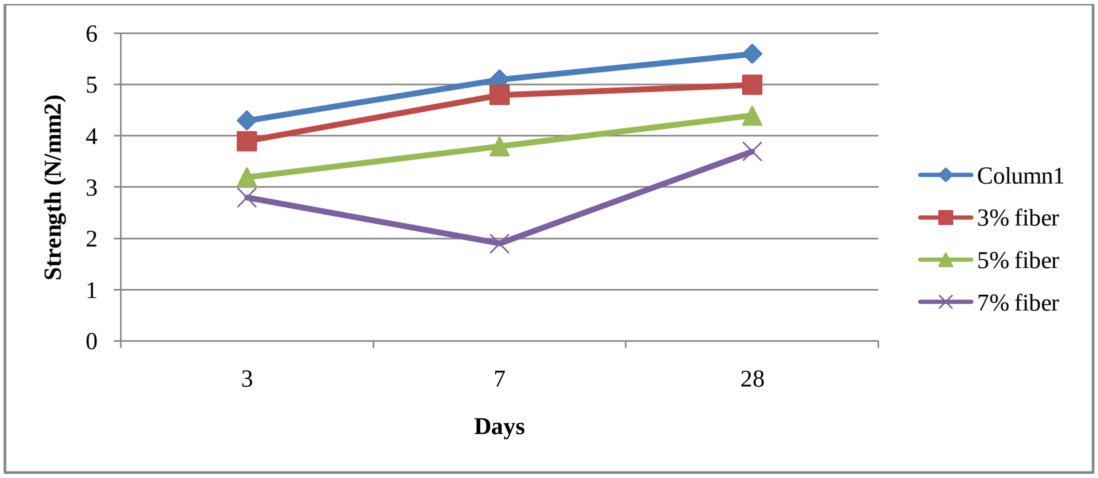


Fig.8 Flexural strength at different fiber percentages [9]

Reis and Ferreira [10-11] reported that coconut fiber reinforcement improved the flexural properties of epoxy polymer concrete and this improvement is more than the glass and carbon fiber reinforced concrete. The Coconut fiber increased the flexural strength by about 25% as compared to referral unreinforced concrete.

Savastano*et al*., [12] reported that the modulus of rupture of coir fiber reinforced composite was 18% more than that of referral at same w/c ratio. It is also reported that composite made with Eucalyptus pulp has 16.5% higher modulus of rupture as compared to referenced concrete.

V. DURABILITY PROPERTIES OF NATURAL FIBER CONCRETE

5.1 Water Absorption

Awang et al. [13] used polypropylene fibre and kenaf fibre with different percentage 0.25% and 0.40% of total volume of concrete. Class F fly ash was also added in certain mixes with 0% and 30% as cement replacement. It was founded that PFA25 and PFA40 resulted in the lowest percentage of water absorption due to the reason of polypropylene is a hydrophobic type of fibre which does not absorb water.

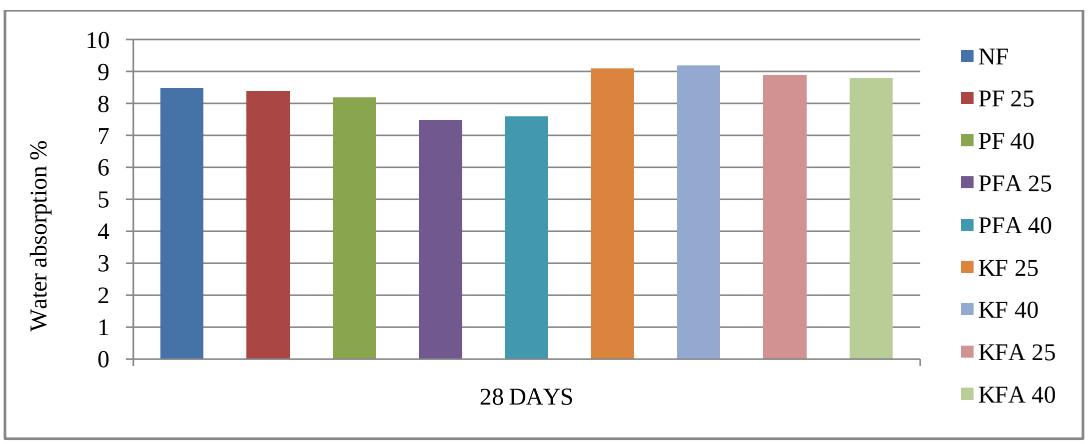


Figure 9 Water Absorption with different fiber at different ratio [13]

Sam and Sheeja [14] used coir fibre in normal concrete. Concrete reinforced with different percentage of coir fibres had shown lesser and normally equal to the normal concrete. The minimum water absorption rate was found on 1% fibre content by weight of cement on both the lengths. While increase in the content of the fibre from 1% to more, it is clearly seen that, the water absorption rate is being increased.

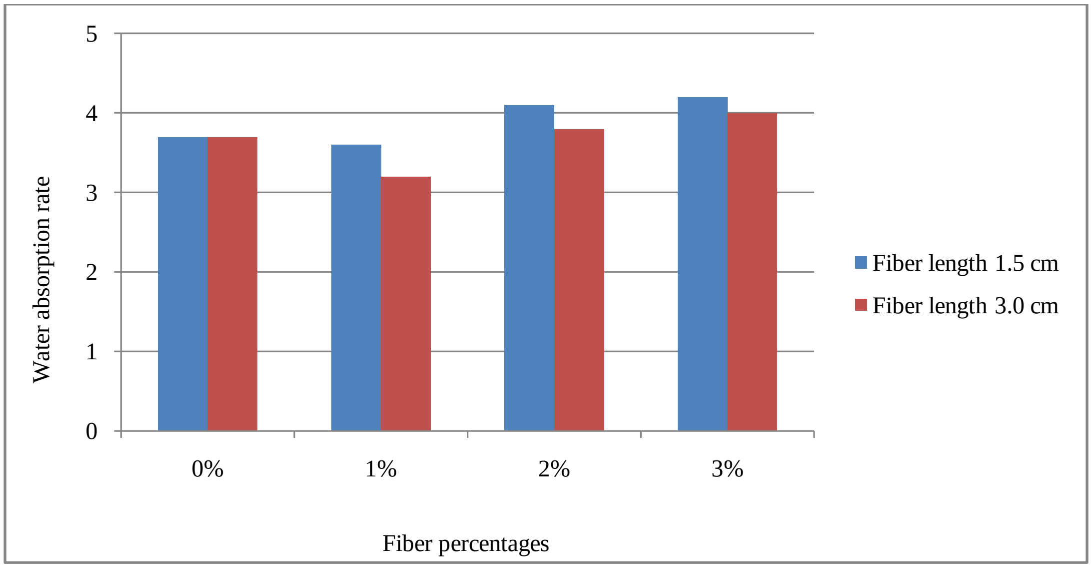


Figure 10 Water absorption of concrete reinforced with Different % of coir fibre [14]

Awang and Muhammad [15] used synthetic and natural fibres consisting of AR-glass (GF), polypropylene (PF), steel (SF), kenaf (KF) and oil palm (OPF) fibre. Two percentages of fibres included in each fibrous specimen at 0.25% and 0.40% of the total volume fraction. It was concluded that 0.40% containing of glass fiber resulted in the highest rate of water absorption while containing of 0.40% steel fiber recorded the lowest percentage among all specimens. The percentage rate of water absorption for all kind of fibre lightweight foamed concrete is presented in Fig.11.

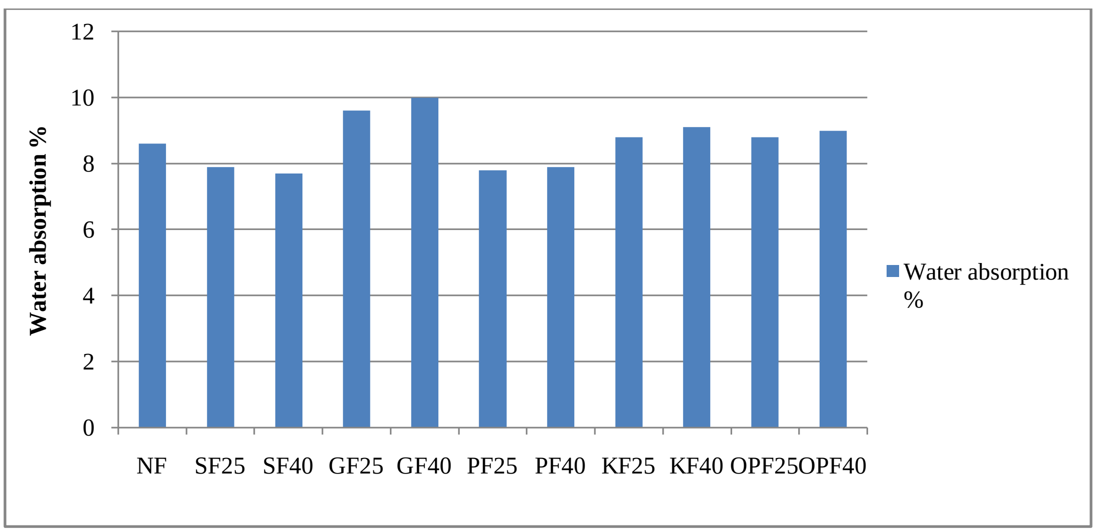


Figure 11 Water Absorption with different fiber at different ratio [15]

5.2 Sulpher Attack test

Sam and Sheeja [14] used coir fiber in concrete of 1.5cm and 3.0cm length at different percentage 0%, 1%, 2% and 3% by weight of cement for determining the resistance of concrete to the sulphate. The cubes were immersed in a 5% sodium sulphate solution for 28 and 56 days.The effect of sulphate attack on the properties of concrete was identified in terms of strength loss and it can be observed from Table 8. It was concluded that the optimum percentage and length of coir fibre are 1% and 3cm respectively.

Table 8: Loss in strength after Immersion in sodium sulphate solution [14]

Percentage of coir fibre	Percentage in strength reduction			
	Fiber length 1.5 cm		Fiber length 3.0 cm	
	28 days	56 days	28 days	56 days
0	4.14	6.03	4.14	6.03
1	1.94	2.2	1.71	2.05
2	2.01	2.8	1.82	2.6
3	2.12	3.4	2.09	3.4

5.3 Acid Attack test

Sam and Sheeja [14] used coir fiber in concrete of 1.5cm and 3.0cm length at different percentage 0%, 1%, 2% and 3% by weight of cement. The cubes were immersed in sulphuric acid solution for 28 days and 56 days. It can be observed from Table 9 that there was a slight reduction in strength when concrete content 1% fiber. It was concluded that optimum percentage and length of coir fiber was 1% and 3.0cm respectively.

Table 9 Loss in strength after immersion in sulphuric acid [14]

% of coir fiber	Strength Reduction			
	Fiber length 1.5 cm		Fiber length3.0 cm	
	28days	56days	28days	56days
0	23.7	36.98	23.7	36.98
1	21.4	26.86	13.49	24.41
2	24.69	31.13	16.79	27.22
3	29.7	35.13	19.9	32.41

VI. DUCTILE PROPERTIES OF NATURAL FIBER CONCRETE

6.1 Impact Strength

Ramakrishn and Sundarajan [2] reported that the impact resistance of natural fiber reinforced cement mortar slabs is 3 to 18 times higher than that of plain cement mortar slabs. It was reported that the residual impact strength ratio (IRS) of natural fiber reinforced slab specimen’s ranges between1.9 to 3.9. It was concluded that natural fibers enhanced the impact resistance of concrete and exhibited response comparable to the glass fiber.

Siddiqui [4] replaced cement by fly ash with different percentages 35%, 45% and 55% by mass. San fiber added in different percentages 0.25%, 0.50% and 0.75% in concrete mixture. It was reported that addition of san fiber significantly enhanced the impact strength which increased with the fiber content (0.30 to 0.90%). The increase in impact strength was observed 1 to 3 times at 28 days and 1.5 to 3.5 times at 91 days. It was reported that the addition of san fiber significantly enhanced the impact strength and it increased with the fiber content (0.25 to 0.75%). The increase in impact strength was 2-3 times, 1.5-2.0 times and 1.0-1.5 times in fly ash concrete with fly ash content 35, 45 and 55% respectively.

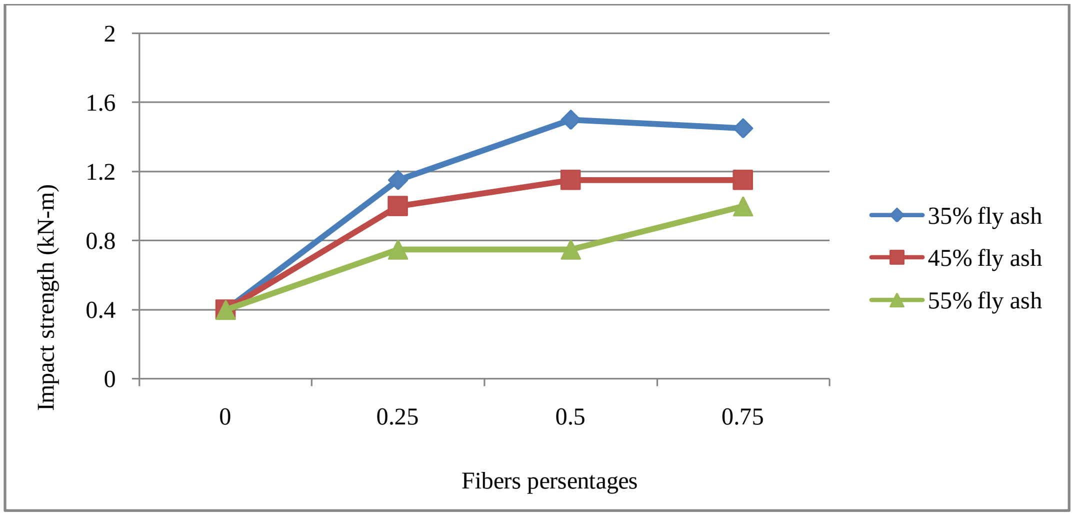


Figure 12 Effect of san fibers on the impact strength of fly ash concrete

6.2 Fracture Toughness

Siddiqui [16] included san fibers (0.30 - 0.90%) in fly ash concrete (fly ash content 30-50%) and reported that the fracture toughness of concrete matrix increased with fiber content. The maximum increase in fracture toughness was found at fiber content of 0.9%. The increase was about 7.2, 4.9 and 3.7 times for concrete matrix with fly ash content 30, 40 and 50% respectively at 28 days. At 91 days, the respective changes were 4.9, 3.8 and 2.6 times.

Savastano et al. [17] reported that toughening in the natural fiber reinforced composites occurs largely because of crack bridging. It is also reported that the intrinsic toughness of the natural fiber cement composites reinforced with sisal, banana and eucalyptus fibers was between 1.2 and 1.4 MPa.

7. Summary

The construction industry is extremely conservative, and so the most likely development route is the use of the new materials in nonstructural applications or in ones where the consequences of failure are not too severe. Experiments and demonstration projects around the world have shown that natural fiber enhancement is a viable and cost effective alternative to conventional building materials. Properties of natural fiber reinforced concretes are improved compressive strength, tensile and bending strength, greater ductility and greater resistance to cracking and hence improved impact strength and toughness. Slump is decreasing with the addition of fibers. More the fiber-cement ratio more is the decrease in slump due to absorbency of water by fibers. Hence the use of proper super plasticizer which does not affect other properties except workability is recommended for higher fiber-cement ratios. Natural fiber being low in density reduces the overall weight of the fiber reinforced concrete thus it can be used as a structural light weight concrete. The addition of fibers increased compressive strength compared to plain concrete. By reinforcing the concrete with fibers which are freely available, we can reduce the environmental waste.

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