Study of the Properties of Coconut Fiber to explore Suitability to be used in Reinforced Concrete

Khem Raj Joshi[1*], Bharat Mandal[2] and Tarumay Ghoshal[3]

[1]*Department of Civil Engineering, DIT University, Uttarakhand, India*
[2]*Department of Civil Engineering, TU Institute of Engineering, Pulchowk Campus, Nepal*
[3]*Department of Civil Engineering, DIT University, Uttarakhand, India*

***CORRESPONDING AUTHOR:**
Khem Raj Joshi
Email:khemjoshi1978@gmail.com

ISSN : 2382-5359(Online), 1994-1412(Print)

DOI :
https://doi.org/10.3126/njst.v21i2.64634

Date of Submission: Aug 4, 2024

Date of Acceptance: Oct 13,2024

ABSTRACT

Natural fibers have been utilized in construction materials consistent with the concept of sustainability. These fiber sources are abundant in many parts of the world. It is established that the orientation of coconut fiber used in concrete mix, attempts to obtain the highest possible ductility as opposed to normal brittle nature of concrete. The use of these fibers increases tension capacity of that concrete and reduces negative environmental consequences. Therefore, in this study, physical as well as mechanical properties of coconut coir have been evaluated to explore the use of it as favorable concrete reinforcing fiber. It is found that coconut fibers have 0.2 to 0.4 times tensile strength of mild steel. Similarly, its elongation property against mild steel is near about 0.3 times before breaking. The other major property, bonding with concrete is also found comparable to bond of reinforcement with concrete. The non-toxic and environmental friendly properties are particularly additional advantages on the use of such bio composites in concrete.

Keywords: Coconut fiber, mortar, fiber treatment, mechanical characteristics, and durability.

1. Introduction

The current high economic growth has greatly increased the demand for building materials such as concrete, so most countries allocate a significant portion of their budgets to building infrastructure. Concrete, a major building material, is very important for the development of infrastructure such as roads, bridges and buildings. The consumption of concrete worldwide is estimated to be around 23 billion tons per year. This makes cement and concrete one of the most commonly used materials in construction (Huda & Alam 2014; Meyer 2009; Tam *et al.* 2018; Kylili & Fokaides 2017). In fact, it is estimated that the production of concrete accounts for around 8% of the world's carbon dioxide emissions. Therefore, increased use of unconventional, natural, recycled and alternative building and insulation materials supports the sustainability of the built environment (Kylili & Fokaides 2017). Green or alternative materials are increasingly being investigated for their benefits. Using natural fibers in reinforced composites reduces the environmental impact and reliance on traditional materials to make concrete. Moreover, the amount of natural fibers has increased significantly in recent decades. Farmers collect millions of tons of natural fiber each year from a variety of crops such as cotton, abaca, sisal, coconut, jute, hemp, flax and ramie, and livestock such as sheep, goats, camels and alpacas. The use of natural fibers is beneficial for at least five good reasons, including environment protection, cost savings, social responsibility, sustainable development and high-tech performance.

Conventional concrete (CC) often exhibits compressive strength but weak tensile strength. Steel rods are commonly used to correct this failure in conventional concrete, also known as reinforced cement concrete. Fiber reinforced concrete (FRC) is a special type of concrete created when fibers are added to concrete to increase its natural tensile strength (Cosgun 2016; Fediuk 2018; Sekar & Kandasamy 2019; Yin *et al.* 2019). Due to their sustainability, biodegradability, and environmental considerations, natural fibers are now the most commonly used, along with secondary cement components. It is one of the reinforcing materials, but natural fibers also help to reduce CO_2 emissions. Natural fibers are cheaper, stiffer and easier to recycle than synthetic fibers and also available anywhere in the world.

It is well known that properties of concrete can be changed by adding different organic and inorganic material depending on the situation to make it suitable for usage as building material. These properties of conventional concrete: workability, color and time for curing can be altered by changing the constituents. However, researchers often search for traditional materials such as agricultural waste to make concrete environmentally friendly (Alengaram *et al.* 2008; Mannan & Ganapathy 2004; Mannan & Ganapathy 2002; Olanipekun *et al.* 2006). While recycling of such type of building materials, environmental quality will not be degraded further. In this context, coconut fibers can be a wise option.

Coconut cultivation is a popular hobby all over the world, especially in tropical and subtropical regions. According to a recent study (Ohler 1999), over 50 billion coconuts are harvested for coir fiber worldwide. Ripe coconut shells are used to produce coir, a common natural substance used in the manufacturing of durable goods. Coir proving grounds are abundant with coir, which can be used as concrete reinforcement. In addition, it brings income to coconut farmers who benefit from increased demand from the construction industry.

Hence, coconut fibers due to being economic has been an option to be used in concrete and studies have been done to test such concrete from durability and strength aspects. In this context, studies were conducted on durability of slag mortar that was reinforced with coconut fiber (John *et al.* 2005). Fibers were extracted from aged walls and tested. It was found durability was not affected. In similar study for testing fiber reinforced concrete, mechanical properties of such concrete were tested under dry and wet conditions and found less susceptible to sulphate reactions (Sivaraja *et al.* 2010). Another study confirmed that flexural strength in coconut fiber reinforced concrete was enhanced by 90% (Ng *et al.* 2017). Not only this, tensile strength and modulus of elasticity of coconut fiber reinforced concrete is increased compared to concrete without fiber. Also, such use of organic material will not cause any leaching of harmful substances. Studies also reveal that use of coir fibers in concrete prevents micro cracks, especially coconut coir fiber reduces overall weight of concrete due to being low density in nature (Salain *et al.* 2016). However, those studies further suggested that coir fiber length, higher mixing water content are important parameters to consider while using these fibers in concrete (Bharat *et al.* 2018; Pederneiras *et al.* 2021; Yashwanth *et al.* 2021).

Therefore, the purpose of this study is to identify the properties of coir as a fiber reinforcement that can be used in concrete. Both physical and mechanical properties are targeted here for coconut coir fiber. Also, the aim is to explore the suitability of these type of fibers which may then be used in various constructions that do not always necessarily need steel fibers such as canal lining, secondary minor structures etc.

2. Methodology

Coconut coir is a natural fiber extracted from the husk of a coconut. The unprocessed fiber is manually taken from a coconut after the coir has been removed. The method of expelling coconut coir includes few steps. The mature coconuts are gathered from the trees and cleared out to dry under the sun for some days. The outer hard shell of the coconut is removed employing a cleaver or other sharp device. The brown sinewy layer between the hard shell and the coconut meat is evacuated employing a machine or physically employing a scrubber. The coir fibers are washed altogether to expel any dirt or impurities. The fibers are soaked in water for a number of days to relax those and to make more flexible. The fibers are beaten with a wooden hammer or other device to be partitioned and broken down into little pieces. The strands are spread out to dry within the sun or employing a drying machine until they are totally dry. The dried strands are screened to expel any remaining pollutants or bigger pieces. The coir strands are compressed into bunches for transportation and capacity. Once the coir strands have been prepared, they are prepared to be utilized as a fiber and other reason.

In another way of removing fiber, coconut shell is kept in a tidy space and retted. During the retting process, the coconut shells are buried in moist soil to promote microbial degradation of the softer sections. The shells are then pummeled and cleaned to help readily detach the coir fibers and extract the fibers from the coco peat powder using a sieve. Figure 1 and 2 indicate the fiber extraction process.

Fig.1: Raw Coconut Coir with cell

Fig. 2: Extracted raw coconut coir

From the raw coir around 74% of fiber can be extracted. That indicates that on average, 26% of dust and 74% of fiber remains in coconut coir after the inner hard cell was removed.

In this work, the physical and mechanical characteristics of unprocessed coconut fiber were examined using the accepted measuring practices, which were primarily based on Indian Standards. Following tests were performed: (i) Measurement of Diameter and Length of Fiber, (ii) Bulk Density, (iii) Density, (iii) Water absorption, (iv) Tensile Strength, (v) Bond Strength to concrete.

3. Results and Discussions

(i) Measurement of Diameter and Length of fiber:

Fibre aspect ratio is the ratio of length to diameter of a fibre and is usually expresses as a single number greater than 1. It is an important fiber parameter. Therefore, the fiber diameter was evaluated using a digital thickness gauge and a screw gauge having list count of 0.01mm, and the length was measured with a Vernier caliper. Coir fibers vary in diameter from head to tail. The average fiber diameter of the coir is found 0.4 mm to 0.50 mm. Same dimensions for this type of fibers were used and recommended for coir fibres reinforced concrete (Ali 2011). The average diameter of 20 random samples tested was found 0.45 mm. For calculation length should be at least two times of developing length.

(ii) Bulk Density:

Bulk density is determined by measuring the volume of a known mass of sample in its natural arrangement. The coir is a fibrous material that can be different form therefore bulk density does not mean any value. Therefore, density of the fiber is evaluated in its compressed form. As per the magnitude of compression, the bulk density varies. In average compression by hand, its bulk density was found 189 kg/m^3. Fig. 3 denotes the bulk density measurement.

Calculation:

Diameter of Vessel=6.4 cm, Height of Vessel =25.5 cm, Mass of Fibre =154.5 gm,

Volume of vessel = $(\pi d^2 h)/4$ =819.917 cm^3

Density =Mass /Volume = 0.189 gm/ cm^3

Fig. 3: Bulk Density Measurement by using cylindrical vessel

Fig. 4: Density Measurement using water replacement method

(iii) Density

A standard water displacement method is used to find out density of the fiber. The least count of the balance used for weighing was 1 gm. The density of fiber was found 0.84 gm/cc, that is 16% lighter than water. Being the denser material comparison to other similar fiber, its durability in wet soil is much longer than other organic materials. Fig. 4 is showing density measurement. The results are consistent with the findings in Chauhan & Arya, 2018.

Calculation:

Weight of empty pycnometer = (W1) =227.10 gm., Weight of pycnometer + dry sample = (W2) =252.6 gm., Weight of fiber =W5= W2-W1=25.5 gm, Volume of empty pycnometer = (V1) =1000 cm^3, Volumn of water filled pycnometer= (V2) = 1000 cm^3,Volumn of water replace by fibre from pycnometer =(V3)= 30 cm^3, Volume of fibre = Volume of replaced water = (V4)= 30 cm^3, Density (D)= W5 / V4 = 0.84 gm / cm^3

(iii) Water absorption

One of the most crucial tests on a fiber is its moisture content, which has an impact on the material's physical properties drying at 100 ^oC. Therefore, coir fiber was put in oven at a temperature of 50 ^oC for 24 hrs to evaporate any moisture contained in the fiber. The oven dried fiber were put in water for 24 hrs and weighted. The water observation of coir fiber was found 15% in average. Therefore, in average 15% of more water is required if we use fiber in concrete. This test has been recommended by Mittal & Chaudhary 2018; Pandey *et al.* 2016 for evaluation of effects while using coir fiber in reinforced concrete.

Calculation

Moisture Content = (Wet Weight - Dry Weight) / Dry Weight × 100%.

Weight of dry weight of sample W1= 85 gm, Weight of 24 hr. wet weight of sample W2=97.85, Moisture content = (W2-W1)/W1*100 % = 15.12 %

(iv) Tensile Strength

It is very challenging to test a thin fiber's tensile strength. It cannot be clamped in a metal jaw or wedge shaped jaw. As a result, the breaking strength of the fiber is measured by clamping both ends by high strength yarn. Tensile strength is assessed at room temperature under typical conditions. Figure 5 and 6 represent tensile strength measurement.

Fig. 5: Tensile strength testing of fiber

Fig. 6: Measurement of length

A dry fiber's tensile strength was discovered to range from 53.06 N/mm^2 to 108.79 N/mm^2.The samples that were tested had an average strength of 78.39 N/mm^2 (Table 1) The values were found in consistence with the similar study made by Nagarajaiah *et al.* 2024; Widnyana *et al.* 2020. On other words, the breaking loads of fiber were found ranging from 7.70 N to 18.87 N. A fiber in average breaks at a force of 12.8 N. A coconut fiber's tensile strength is roughly one third that of the mild steel's yield strength. Evaluation of fiber elongation took place during the tensile strength test. Elongation was found to be 8% on average. The fact that there is very little variation in the elongation of the samples tested. Using the average strength and elongation as a basis, the average elasticity modulus would be 979.88 N/mm^2. The spring balance of least count 5 gm was used to measure breaking load.

The tensile strength (σ) was calculated by using Equation 1. Where F is force to failure (N), A is a cross sectional area fracture plane normal to fiber axis (m^2).

$$\sigma = F/A \quad \text{………………. Eq.1}$$

Table 1: Tensile strength observation values

Sample Length (mm)	Diameter (mm)	Area (mm2)	Force (kg)	Force (N)	Stress (N/mm2)	Average Stress (N/mm2)
50	0.45	0.1590	1.068	10.477	65.91	78.39
50	0.5	0.1963	1.658	16.265	82.88	
50	0.47	0.1734	1.923	18.865	108.79	
50	0.40	0.1256	1.092	10.713	85.29	
50	0.43	0.1451	0.785	7.701	53.06	
50	0.45	0.159	1.500	14.715	92.57	
50	0.46	0.166	1.507	14.784	89.00	
50	0.47	0.173	1.489	14.607	84.24	
50	0.52	0.212	0.987	9.682	45.62	
50	0.49	0.188	1.505	14.764	78.33	
50	0.41	0.132	1.062	10.418	78.95	
50	0.48	0.181	1.402	13.754	76.04	

(v) Bond Strength to concrete.

Length of a fiber imbedded in concrete, depends upon its tensile strength and bonding to concrete. The bonding strength of fibers was evaluated by casting a M20 concrete cube with insertion of different length of fibers in it. After 28 days curing of concrete, the embedded fibers were pulled in the same manner as in testing of tensile strength. Here 10 mm, 15 mm, 20 mm and 25 mm length was embedded in concrete. All the samples were failed by broken fiber without sleeve out of the concrete. Therefore, development length of the coconut fiber should be less than 10 mm for M20 concrete. Taking the 15 mm as development length for M20 concrete, we did show that the bond strength of concrete is nearly equal to that of ribbed reinforcement. Figure 7 and 8 depict bond strength test. The importance of fiber length in reinforced concrete is mentioned in Ahmad *et al.* 2020; Biswas *et al.* 2011.

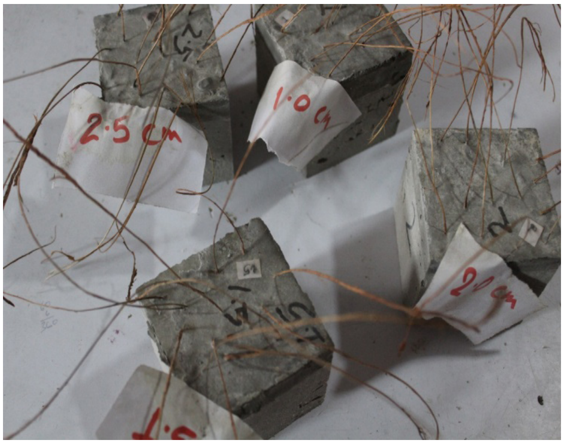

Fig. 7: Sample for bond test


Fig. 8: Bond strength testing

4. Conclusion

After the evaluation of all tests, it can be concluded that the tensile strength of coconut fiber is in average 78.39 MPa with bond strength similar to ribbed reinforcing bar. It can be used as fiber reinforcement in concrete to enhance tensile property of concrete which is also supported by Widnyana *et al.* 2020, Salain *et al.* 2016. The length of 20 mm would be sufficient as fiber reinforcement. Diameter of a coconut fiber varies from 0.4 mm to 0.5 mm (Ali 2011). These fibers can be used as reinforcing for secondary structures where strength and durability aspects are not primarily focused also to make such structures economic and environmental friendly.

5. References

Alengaram, U. J., M. Z. Jumaat, and H. Mahmud, 2008. Ductility behaviour of reinforced palm kernel shell concrete beams. European Journal of Scientific Research 23(3):406-420. DOI: 10.1201/9780203859926.ch41

Ali, M., 2011. Coconut fibre: A versatile material and its applications, Journal of Civil Engineering and Construction Technology Vol. 2(9), pp. 189-197, 2 September, 2011. Available online at http://www.academicjournals.org/jcect ISSN 2141-2634

Ahmad, W., S. H. Farooq, M. Usman, M. Khan, A. Ahmad, F. Aslam, and M. Sufian, 2020. Effect of coconut fiber length and content on properties of high strength concrete. Materials, 13(5), 1075. DOI: 10.3390/ma13051075

Biswas, S., S. Kindo, and A. Patnaik, 2011. Effect of fiber length on mechanical behavior of coir fiber reinforced epoxy composites. Fibers and Polymers, 12, 73-78. DOI: 10.1007/s12221-011-0073-9

Bharat, M., T. Sushant, G. Subid, and T. Aasish, 2018. Mechanical Properties of Concrete with partial replacement of Coarse aggregates by Coconut Shells and reinforced with Coconut Fibre. Journal of Building Materials and Structures 5(2):227-238. DOI: 10.34118/jbms.v5i2.61

Chauhan, N., and N. Arya, 2018. Coconut fiber: A natural versatile material. International Journal of Chemical Studies, 6(6), 555-561.

Cosgun, T., 2016. An experimental study of RC beams with varying concrete strength classes externally strengthened with CFRP composites. Journal of Engineered Fibers and Fabrics
DOI: 10.1177/155892501601100302

Fediuk, R., 2018. Reducing permeability of fiber concrete using composite binders. Special Topics and Reviews in Porous Media: An International Journal 9(1).
DOI: 10.1615/SpecialTopicsRevPorousMedia.v9.i1.100

Huda, S. B., and M. S. Alam, 2014. Mechanical behavior of three generations of 100% repeated recycled coarse aggregate concrete. Construction and building materials 65:574-582.
DOI: 10.1016/j.conbuildmat.2014.05.010

John, V. M., M. A. Cincotto, C. Sjöström, V. Agopyan, and C. T. D. A. Oliveira, 2005. Durability of slag mortar reinforced with coconut fibre. Cement and Concrete Composites 27(5):565-574.
DOI: 10.1016/j.cemconcomp.2004.09.007

Kylili, A., and P. A. Fokaides, 2017. Policy trends for the sustainability assessment of construction materials: A review. Sustainable Cities and Society 35:280-288.
DOI: 10.1016/j.scs.2017.08.013

Pederneiras, M. C., R. Veiga, and J. de Brito, 2021. Physical and mechanical performance of coir fiber-reinforced rendering mortars. Materials 14(4):823.
DOI: 10.3390/ma14040823

Mannan, M. A., and C. Ganapathy, 2002. Engineering properties of concrete with oil palm shell as coarse aggregate. Construction and Building Materials 16(1):29-34.
DOI: 10.1016/S0950-0618(01)00030-7

Mannan, M. A., and C. Ganapathy, 2004. Concrete from an agricultural waste-oil palm shell (OPS). Building and environment 39(4):441-448.
DOI: 10.1016/j.buildenv.2003.10.007

Meyer, C., 2009. The greening of the concrete industry. Cement and concrete composites 31(8):601-605.
DOI: 10.1016/j.cemconcomp.2008.12.010

Mittal, M., and R. Chaudhary, 2018. Experimental study on the water absorption and surface characteristics of alkali treated pineapple leaf fibre and coconut husk fibre. Int. J. Appl. Eng. Res, 13(15), 12237-12243.

Nagarajaiah, M., A. Yadav, S. Prasannakumar, R. R. Mahadevaiah, and P. Hiremath, 2024. Finite Element Study on Coconut Inflorescence Stem Fiber Composite Panels Subjected to Static Loading. Engineering Proceedings, 59(1), 215.
DOI: 10.3390/engproc2023059215

Ng, G. P., G. S. Urgessa, Y. Bayleyegn, and H. A. R. I. A. N. T. O. Hardjasaputra, 2017. Mechanical Properties of Coconut Fiber-Reinforced Concete. Resilient Structures and Sustainable Construction, Valencia, Spain.
DOI: 10.14455/ISEC.res.2017.93

Ohler, J. H., 1999. Modern Coconut Management; Palm Cultivation and Products. Available online: https://practicalactionpublishing.com/book/1431/modern-coconut-management (March 03, 2024).
DOI: 10.3362/9781780445502

Olanipekun, E. A., K. O. Olusola, and O. Ata, 2006. A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates. Building and environment 41(3): 297-301.
DOI: 10.1016/j.buildenv.2005.01.029

Pandey, M. R., S. Pokharel, and N. K. Karn, 2016. Water absorption study of the coconut coir fibre after surface modification by different chemicals for varied duration. In Proceedings of International Conference on Soil and Environment. Bangalore, India (pp. 22-23).

Salain, I. M. A. K., I. N. Sutarja, N. M. A. Wiryasa, and I. M. Jaya, 2016. Mechanical Properties of Coconut Fiber-Reinforced Concrete. In The 6th International Conference of Asian Concrete Federation pp. 21-24.

Sekar, A., and G. Kandasamy, 2019. Study on durability properties of coconut shell concrete with coconut fiber. Buildings 9(5):107.
DOI: 10.3390/buildings9050107

Sivaraja, M., Kandasamy, N. Velmani, and M. S. Pillai, 2010. Study on durability of natural fibre concrete composites using mechanical strength and microstructural properties. Bulletin of Materials Science 33:719-729.
DOI: 10.1007/s12034-011-0149-6

Tam, V. W., M. Soomro, and A. C. J. Evangelista, 2018. A review of recycled aggregate in concrete applications (2000-2017). Construction and Building materials 172:272-292.
DOI: 10.1016/j.conbuildmat.2018.03.240

Widnyana, A., I. G. Rian, I. W. Surata, and T. G. T. Nindhia, 2020. Tensile Properties of coconut Coir single fiber with alkali treatment and reinforcement effect on unsaturated polyester polymer. Materials Today: Proceedings, 22, 300-305.
DOI: 10.1016/j.matpr.2019.08.155

Yashwanth, M. K., 2021. Evaluation of Compressive Strength of Coir Fibre Reinforced Concrete. Turkish Journal of Computer and Mathematics Education (TURCOMAT) 12(10):68-73.

Yin, S., Y. Yu, and M. Na, 2019. Flexural properties of load-holding reinforced concrete beams strengthened with textile-reinforced concrete under a chloride dry-wet cycle. Journal of Engineered Fibers and Fabrics 14.
DOI: 10.1177/1558925019845902