Strength characteristics of banana and sisal fiber reinforced composites

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Abstract. The steadily growing demand for various materials of buildings, the availability of natural sources was decreasing. It is necessary to use alternative materials for the construction of buildings. Fibers are of two types. They're natural and artificial fibers where natural fibers are abundant and cheap in manufacturing, eco-friendly and renewable. Natural fibers have less density, low cost and fewer durability when compare to artificial fibers. The composite materials were reinforced by using natural fibers. By adding these natural fibers the properties of concrete in mechanical behavior were improved. Here banana and sisal natural fibers have been employed as reinforcement in composite materials. The abundant source of banana fiber is peduncle and pseudo-stem and sisal fiber is a leaf fiber that is very strong. There were many research works with the adoption of these fibers are in numerous percentages like 0%, 0.5%, 1%, 1.5% and 2% in concrete(M25 grade) and was casted by using Ordinary Portland Cement(53grade). This paper overviews the particulars and results of preceding years research papers and also compares the strength properties of banana fibers and sisal fibers viz tensile, flexural strength (modulus of rupture) and compression strength (cube strength).

Keywords: Banana fiber, Compression strength, Flexural strength, Natural fibers, Sisal fiber, Tensile strength.

1. Introduction
The ecological concerns and the growing environmental awareness of natural fiber composite materials have attracted many researchers and scientists attention, due to their advantages over the other conventional fibers. Composite materials, reinforced with natural fibers are rapidly growing because of its industrial and other applications. The natural fibers are of different types. They are flax, jute, hemp, kenaf, sisal, coir, banana, kapok, sisal, palm, henequen and many others[1]. Natural fibers are utilized in constructions due to their non-abrasive, non-toxic, light weight, biodegradable properties and low cost. The most purpose of utilizing natural fibers is to reduce the environmental impact of non-biodegradable in composite materials [2]. By adding these natural fibers in the concrete, it reduce the air void content, minimize the formation of cracks and also increase the durability of the concrete structures.
Banana fiber is one amongst the agricultural waste materials i.e., these fibers are the waste materials of banana cultivation. The large source of banana fiber is peduncle(stalk) and pseudo-stem (lingo-cellulosic fiber)[3]. The pseudo-stem is cylindrical in shape, where the leaf stalk bases are in clustered aggregation. Banana fiber is the best among other fibers and has good mechanical properties. The specific strength properties of banana fibers are better than other conventional fibers. Banana fibers have light weight, fire resistance quality, high strength, smaller elongation, biodegradability, great potentialities and robust moisture absorption quality. Banana fibers are also utilized for manufacturing paper bags, crafts, filter paper lamp stands, decorative items, composite stuffs, greeting cards, pen stands, rope and mats etc.. The life span of banana fibers is about 100 years and it’s the strongest of all other long fibers. Banana fibers can be folded 3,000 times[4].

The sisal plant could be a variety of shrub(perennial) that grows in the tropical zone and subtropical zone of the globe. Sisal fiber is a leaf fiber extracted from the plant Agave sisalana and these are extensively cultivated among the world. Agave sisalana(American aloe) plant is grown in hard soil where any other normal plants cannot be cultivated. The average temperature ranges between 28°C to 20°C and the average annual rainfall ranges between 1500 mm to 600 mm. Agave sisalana plants are grown in high temperatures and prolong droughts where the normal plants cannot be grown. Approximately after decortications only 5% of sisal leaf is employed and remaining95% of leaf residue is often used for fertilizer productions, animal feed and generation of bio energy[5]. The fibers with no impurities and no damages are visually selected for the drying process. The moisture and dust are not absorbed by sisal fibers as they are anti-static [6]. Sisal fibers won’t wear and tear effortlessly and thus requires minimum maintenance. At the minimum length of the fiber, the compressive strength is seen to be maximum but after 1 percentage addition of sisal fiber, the compressive strength starts to be reduce[7]. The intent of the study is to determine the optimum percentage of banana and sisal fibers to be added in the concrete which might be useful for the future research works.

2. Composition and properties of natural fibers

2.1. Properties of fibers

The banana fibers are acquired from banana cultivation fields. By using a cutting machine, the uniform length of the fibers is acquired. The properties like mechanical and physical properties of Banana fibers were firm in various natural form [8]. The chemicals that are used for sisal fiber treatment in concrete are hemi celluloses, lignin, pectin, ashes[9]. The chemical treatment of sisal was done by using the extrusion method. The fiber specimen of concrete were used of three major roles using untreated sisal fiber, by using chemical agent of (Na OH) treated fiber and also by using chemical agent of Na OH-clay sisal fiber treatment[10]. The water absorption of natural fiber is relatively high in sisal. The sisal fiber process for making a specimen is operated hot by compression moulding[11]. The colour of sisal fiber was white and the pH was 6.90 when treated with 5% solution. The portable water with pH of 7 was used during the experiments [12].

Figure 1a. Pseudo-stem of the banana tree [13]Figure 1b. Banana fiber [14]
2.2. Physical properties of fibers
The physical properties of sisal and banana fiber varied greatly. The density of 1.45 g/cm³, the average length of 300 mm, the average diameter of 0.12 mm and water absorption of 76.7 % are the physical properties of sisal fiber. Similarly, banana fiber has a density of 950-7 50 kg/m³, length of 2000 to 5000 mm, the diameter of 0.080 to 0.250 mm and water absorption of 60 %. The aspect ratio (l/d) for banana fiber is 1.5\textsuperscript{[15, 16]}.

2.3 Chemical properties of fibers
Sisal and banana fibers were majorly composed of the same chemicals except a few. The similar chemicals in both the fibers were hemicellulose, lignin and cellulose. The sisal fiber was composed of 12 % hemicellulose, 9.9 % lignin and 65 % cellulose whereas banana fiber was composed of 6-9 % hemicellulose 5-10 % lignin and 60-65 % cellulose. In addition to these chemicals, sisal fiber has waxes of about 2%. Similarly, in banana fiber, there were 1-3 % ash, 3-6 % extractives and 3-5% pectin\textsuperscript{[17]}.

2.4 Mechanical properties of fibers
Similarly, mechanical properties also varied for both the fibers. Young's modulus of 9-38 Gpa, elongation of 18.2 %, the average tensile strength of 1090 N/mm² were the mechanical properties of sisal fiber. Young's modulus of 27-32 Gpa, failure strain of 1-3 %, the average tensile strength of 529-914 N/mm² were the mechanical properties of banana fiber\textsuperscript{[5, 15]}.

3. Overview of various researches
Sisal fibers of 0.5%, 1%, 1.5% and 2% were added in M25 and M20 mixes. The specimens were tested for their compressive strength(cube strength), the strength of concrete in tensile and modulus of rupture(flexural strength). Both in M20 and M25 mix design, the cube strength and the strength of concrete in tensile was increased by adding 1% - 1.5% of sisal fiber respectively\textsuperscript{[22]}. Sisal fibers of 0.5%, 1%, 1.5% and the lengths of about 5mm, 10mm, 20mm were added in M30 grade of concrete. Here 43 grade of ordinary Portland cement (OPC) was used to calculate the strength of concrete in tensile, cube strength and flexural strength. The compressive strength at 0.5% fiber content of SFRSCC with the aspect ratio of 33, gave the maximum value and at addition of 0.5%, 1%, 1.5% sisal fiber, the higher value of impact strength. By adding 0.5% fiber, the flexural strength of SFRSCC is\textsuperscript{[23]}. Addition of 0.6% sisal fiber in beam structure was added to observe the strength of concrete in tensile, compressive strength(cube strength) and flexural strength (modulus of rupture) of the specimen. By adding sisal fibers in volume of 0.6%, it resulted in enhanced tensile, modulus of rupture and at the volume of 12%, 20% and 50%, it resulted in enhanced the cube strength\textsuperscript{[24]}. Sisal fibers of different percentages 1.5%, 2% were added. The M30 concrete beam undergone torsional loading test, at 2% fiber with aspect ratio 100 and the minimum torsional load was observed. By adding 1.5% of sisal in concrete, the torsional loading started reducing \textsuperscript{[25]}. 
The fiber length 30 mm gives maximum strength of concrete in tensile meanwhile the fiber length 40 mm gave the maximum impact strength. Incorporation of 40% untreated fibers provides an increase of 20% of the strength of concrete in tensile and the incorporation of 34% untreated fibers provided an increase in impact strength[26]. Banana fiber of 0, 0.5, 1, 1.5 and 2 percentages were added to calculate the mechanical properties like tensile strength, modulus of rupture and impact strength. By adding 0.5% of banana fiber the flexural strength was found to be maximum[27]. In accordance with ASTM D790 and ASTM D638 the mechanical properties of the specimens were analyzed using tensile strength and modulus of rupture. Volume of banana fibers of 40%, 50% and 60% were used to study the tensile and flexural strengths. The composites with 50% and 60% of banana fiber gave the maximum tensile strength and the maximum flexural strength [28].

4. Result and discussion

4.1 Compressive Strength Test

The compression strength (cube strength) of concrete is that the strength of hardened concrete measured by the compression test. The compression strength of the concrete could be a measure of the concrete’s ability to resist loads which tends to compress it. This was measured by crushing the concrete specimens in the compression testing machine[29].

When compared to 0.5% and 2%, 1% of banana fiber produced maximum compressive strength. Here the nonreinforced concrete resulted in the compressive strength of 19.78N/mm² and 29.91N/mm² at the end of 7 days and 28 days respectively. By adding 1% of fiber, the highest compressive strength was achieved such as 26.5N/mm² and 35.55N/mm².[7, 22, 30]

When compared to 0.5% and 2%, 1% of sisal fiber produced maximum compressive strength. Here the nonreinforced concrete resulted in the compressive strength of 16.88N/mm² and 32.13 N/mm² at the end of 7 days and 28 days respectively. By adding 1% of fiber, the highest compressive strength was achieved such as 19.41N/mm² and 35.36 N/mm².[30]

4.2 Split Tensile Strength Test

The tensile strength (lastingness) of the concrete was often determined by using a cylinder specimen that splits across vertical diameter [31]. The lastingness principally affects the paste quality and also the interfacial transition zone of the specimen.[32]
When compared to 0.5% and 2%, 1% of banana fiber produced maximum tensile strength. Here the non-reinforced concrete resulted in the tensile strength of 1.83 N/mm² and 3.1 N/mm² at the end of 7 days and 28 days respectively. By adding 1% of fiber, the highest tensile strength was achieved such as 2.95 N/mm² and 3.81 N/mm².

When compared to 0.5% and 2%, 1% of sisal fiber produced maximum tensile strength. Here the non-reinforced concrete resulted in the tensile strength of 2.86 N/mm² and 4.4 N/mm² at the end of 7 days and 28 days respectively. By adding 1% of fiber, the highest tensile strength was achieved such as 4.07 N/mm² and 5.6 N/mm².

4.3 Flexural Strength Test

Flexural strength (modulus of rupture) tests were performed in with ASTM A 370 to know the measurement of flexural properties. According to ASTM standard, specimens are made. At strain rate of 0.5 mm/min the samples are tested. The main advantage of choosing a three-point bend test because for each test it requires only minimum materials and eliminates the accurately determination of centre point deflections in test equipment.[7].
When compared to 0.5% and 2%, 1% of banana fiber produced maximum flexural strength. Here the nonreinforced concrete resulted in the flexural strength of 3.1 N/mm² and 5 N/mm² at the end of 7 days and 28 days respectively. By adding 1% of fiber, the highest flexural strength was achieved such as 4.07 N/mm² and 6.77 N/mm².

When compared to 0.5% and 2%, 1% of sisal fiber produced maximum flexural strength. Here the nonreinforced concrete resulted in the flexural strength of 2.6 N/mm² and 3.94 N/mm² at the end of 7 days and 28 days respectively. By adding 1% - 1.5% of fiber, the highest flexural strength was achieved such as 4.36 N/mm² and 5.12 N/mm².

The strength properties of various mixes showed better results when both banana and sisal fibers were used in a particular specimen. In the presence of both banana fiber and sisal fiber in concrete, the compressive strength, tensile strength (lastingness) and flexural strength (modulus of rupture) were found to be optimum by adding 1% volume of fibers. It was acquired that the sisal fiber reinforced composite was having better tensile (lastingness), compressive and flexural strength in comparison to banana fiber. Mixing of fiber in maximum % (more than 1.5) decreased the strength characteristics and adding minimum % (1 – 1.5) increased the tensile strength (lastingness), flexural strength (modulus of rupture) and compressive strength. Here both the fiber composites were compared with the conventional concrete. The conventional concrete with sisal fiber resulted in more strength properties than the banana fiber composites. From the above study, it was observed that both the sisal fiber reinforced concrete and normal concrete showed better strength at 28 days. The summary of results, by addition of both banana fiber and sisal fiber enhanced the strength properties of concrete. But the sisal fibers in concrete showed better results when compared to banana fibers.

5. Conclusion

The composite materials reinforced by using natural fibers like banana and sisal fibers were reviewed regarding the future expectations in the utilization of natural fibers as are in forcing agent. This review explores the chemical composition, physical and mechanical properties. The properties of banana and sisal fibers are more preferable when compared to other natural fibers. Due to low cost, less density, fewer durability and certain individual properties of banana and sisal fiber reinforced composites, it could have better implementations in different fields of engineering applications. In future generations, the employment of natural fibers will be very desiring because the natural fibers are versatile, abundant, lighter, cheaper, low cost of manufacturing, eco-friendly and superior to other artificial fibers (glass and synthetic fibers). Hence it’s concluded that the natural fiber reinforced composites would be the most cherished technology in the developing world.

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