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Experimental investigation on the potentials of Sisal Fibres as Reinforcements for Drainage Concrete Cover Plates

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Abstract: With the development of infrastructures in Rwanda, the roads construction has been one of busiest area, and as the country counts thousands hills the design and construction of drainage systems required a great attention. Most of road drainage channels are covered with concrete plates that are reinforced with ordinary steel bars, while others are not covered due to the high cost of reinforced concrete plates. As the majority of these plates are only subjected to light pedestrian loads, they should be reinforced accordingly. This study was intended to check the potentials of sisal fibres from Agave Sisalana' cactus plant which has shown good results in flexural members, as plates reinforcements. At first the quality of ordinary concrete components was checked. Then some of sisal fibres were prepared, manufactured into ropes of 10 mm diameter and then used as replacements of main steel bars in concrete plates before their tensile capacity was checked. Other pieces of sisal fibres of 5 cm length were mixed in concrete mass with different percentages of 0.5%, 1% and 1.5% of concrete volume. Test results showed that the compressive, tensile and flexural strengths for concrete with 1% of sisal fibres were more adequate for M30 concrete and therefore able of sustaining the real loads applied to the drainage concrete cover plates. As the performance of natural sisal fibres depends on fibres treatment methods, length, and type of required concrete, further studies on the use of sisal fibres should consider those factors.

Keywords: Agave sisalana, drainage channel, Reinforced Concrete, Sisal Fibres, Sisal ropes.

1. Introduction

Recently, Rwanda has known the development of infrastructures, and the roads construction has been one of most busy area. Roads are constructed with drainage channels and most of them are being covered with concrete plates along the roads. Others were being left uncovered and becoming dangerous, as well as unsafe zones to the public. The covering of all drainage with concrete plates may be an expensive solution mainly due to the cost of materials, especially that some of them are exported from outside the country, while the local material manufacturing industry was still only growing. As these plates were not subjected to any heavy traffic load, except the one from pedestrians, especially when drainage channels are separated from the roadway by kerbs, there was a need in the strong but cheaper solution. The Fig.1(a), and Fig.(b) show the difference between the covered and uncovered spaces noted on one of the Kigali City roads. Sisal is a natural fiber derived from the long, green leaves of the ‘agave sisalana’ cactus plant, and they are very commonly used in Rwanda (Fig.1,c).



Fig.1: Covered KN 3 Rd (a), Uncovered KN 25 (b), and Agave sisalana’ cactus plant (c)

Until today, sisal fibres have not been under use as construction materials. For extracting sisal fibre, the leaves are crushed between blunt knives and moisture and the fleshy pulp are removed from the fiber (Naveenet al., 2018). The purpose of this study was the assessment of the potentials of sisal fibres as replacements of ordinary steel reinforcements as local materials for the production of safe but affordable drainage concrete plates. Among others, specific objectives were to analyze the rationale of using Reinforcement Steel bars in drainage plates, to identify strength performance of sisal fibres, to manufacture and test drainage plates with Sisal Fibres, and to conduct a cost estimation to establish the affordability of the new drainage plate. The use

of natural fibre reinforced composites is now considered as a new perspective in the construction industry (Suryawanshi and Dalvi, 2013). Sisal fiber was found to be a potential reinforcement for polymer composites, with its physical and mechanical behaviors depending on their source, age, and location, but also on their fiber diameter, experimental temperature, gauge length, and strain rate, as well as the manufacturing method (Naveen et al., 2018). Sisal fiber inclusion can effectively reduce the propagation of the cracks in the concrete core (Tan et al., 2017). The use of natural fibres including sisal fibres, among others in structures have been encouraged because they are locally available, cheaper and have some good properties (Sen and Reddy, 2011). Also, good physical properties, mechanical performance, and microstructural characteristics of the composites before and after accelerated and natural aging were evaluated (Tonoli et al., 2011). A significant improvement in the overall performance of the cement based composites was observed though the investigation on the possibility of using cellulose fibres including sisal (Reynaldo, 2011). Another potential application of composites reinforced with sisal fibres material may be the replacement of asbestos cement composite, which has got a negative impact to human and animal health and is prohibited in industrialized countries (Aruna, 2014). The addition of fibres not only can increase the tensile strength to the concrete mixes but also can improve some other engineering properties (Priyankarani and Srichandana, 2015). The use of fiber ropes as a partial replacement of steel bars in concrete beams realized about 75% of the load capacity of the ordinary reinforced beam (Heniegal, 2017). Sisal fibres can be used as admixture and offer good properties especially the compressive, tensile as well as flexural strength of concrete, but they are influenced by the fiber length (Bharath and Srikanth, 2017). A comparative study on conventional concrete and sisal fibre reinforced concrete with varying length has also shown the influence of the fibre length in concrete (Dhumal et al., 2018). Sisal fibres may be even a good earth reinforcement material with potential applications in civil engineering, as it was demonstrated by the assessment of mechanical properties of fiber-reinforced silty clay (Yankai et al., 2014).

The potentials of sisal fibres as reinforcements in reinforced concrete plate members are rarely discussed in the current literature, and this is the scope of the presented study.

2. Research Methods and Materials

After the *extraction*, using scissors, some dried sisals fibres were cut into small pieces of 50mm length to be casted with concrete, while others were used into ropes of 10 mm diameter for use as replacement of steel reinforcements for beam. The following Fig.2 shows the process of cutting sisal fibres into smaller pieces and roping, as well as the concrete mixing with sisal fibres.



Figure 2: Cutting and roping of sisal fibres and mixing with sisal fibres

The *materials components for concrete* were locally collected and other bought from the local market: the used aggregates were collected at the local construction company, Real contractors, while the Ordinary Portland Cement (OPC) of 42.5 Grade from Twiga Cement manufacturing available in local market. The used aggregates had the following properties: Coarse aggregates (CA) nominal size: 20mm, CA specific gravity: 2.66; Fine aggregates (FA) zone: Zone II, and FA specific gravity: 2.61.

The formwork fabrication: The formwork for drainage concrete plates was made referring to the dimensions of drainage concrete plates, which were: 140x50x10cm or 100x50x10cm for pedestrians' way. The sizes of beam's formwork are 60x15x15cm. All dimensions are taken from the interior of the formwork (see Fig.3).



Figure 3: Beam and slab Formwork

During the **Mixing** of all designed concrete materials namely, cement, aggregates, water and sisal fibres of 50 mm length composing 0.5 %, 1% and 1.5 %, of concrete weight. The following quantities were calculated using the concrete mix design procedure recommended by IS 10262-2009, while M30 Concrete mix was selected as suitable by strength requirements for road concrete plates.

- ✓ Water content= 186kg; Water cement ratio= 0.45; Cement content = 413.3 kg
- ✓ Volume of concrete = 1 m³; Volume of cement = 0.1312 m³; Volume of water = 0.186 m³ Volume of aggregates = 0.6828 m³; Volume of fine aggregates = 0.2595 m³;
Volume of coarse aggregates = 0.4233 m³;
- ✓ Weight of fine aggregates = 677 kg ; Weight of coarse aggregates = 1126 kg

From the above quantities, the materials mix ratios fixed as follows:

Water: cement: Fine Aggregates: Coarse Aggregates = 0.45; 1: 1.64; 1: 2.72

The testing moulds had respectively the following dimensions: for compressive strength testing: 150x150x150 and 100x100x100 mm, for split tensile: 300x150 mm, for flexural testing: 600x150x150 mm. The following ***tests of concrete components and concrete samples*** were done: aggregates sieve analysis and concrete slump tests, tensile strength of sisal fibres ropes, the compressive strength test with different sisal fiber content (the first cubes were controlling cubes with no sisal fibres content; the other cubes contained the sisal fibres in the following percentages: 0.5%, 1% and 1.5% of total volume of a cube), the split tensile test on cylinders with and without sisal fibres, and the flexural strength test on beams reinforced with ordinary steels of 10mm diameter and others reinforced with sisal fibres ropes (also of 10mm diameter) as steel reinforcements. The cubes, beams and cylinders to be tested were put in a dry place for 24 hours and then the curing took 7 and 28 days. All tests were conducted using three samples and following the procedures as required by Indian standards. The results presented in Figs. 6 – 8 are averages from the three tested samples.

The cost estimation for normal concrete plate reinforced with steel bars and concrete plate reinforced with sisal fibres and ropes, was carried out to compare their affordability. The unit

cost estimation was used. In general the only difference was between the cost of ordinary steel reinforcement and the one for sisal fibres in the local market.

3. Results and Discussion

This section presents all results from the study and discusses them against available standards or previous results. The results from *Sieve Analysis* of the coarse and fine aggregates are presented in Fig. 4 and Fig.5, respectively.

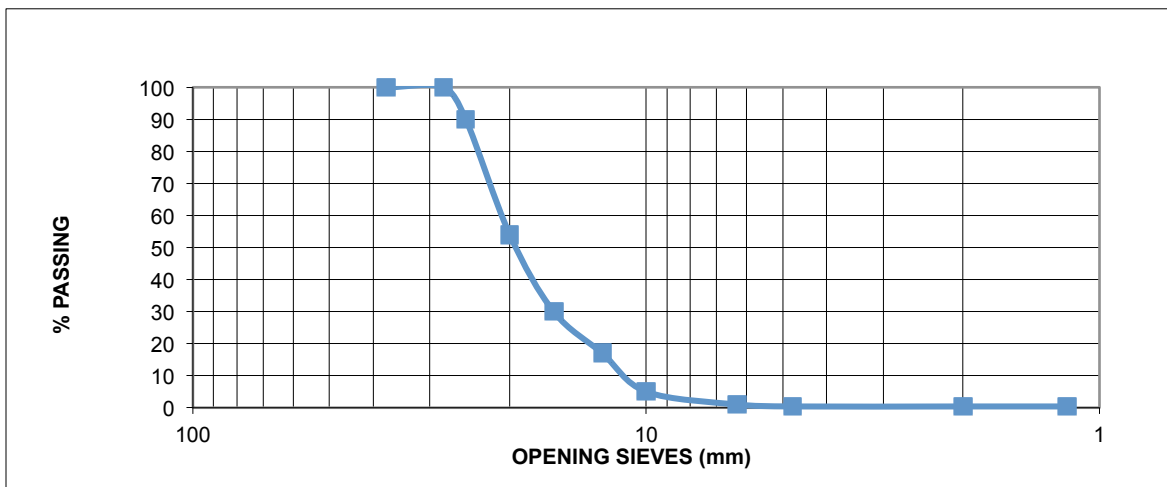


Figure 4: Sieve Analysis of Coarse Aggregate

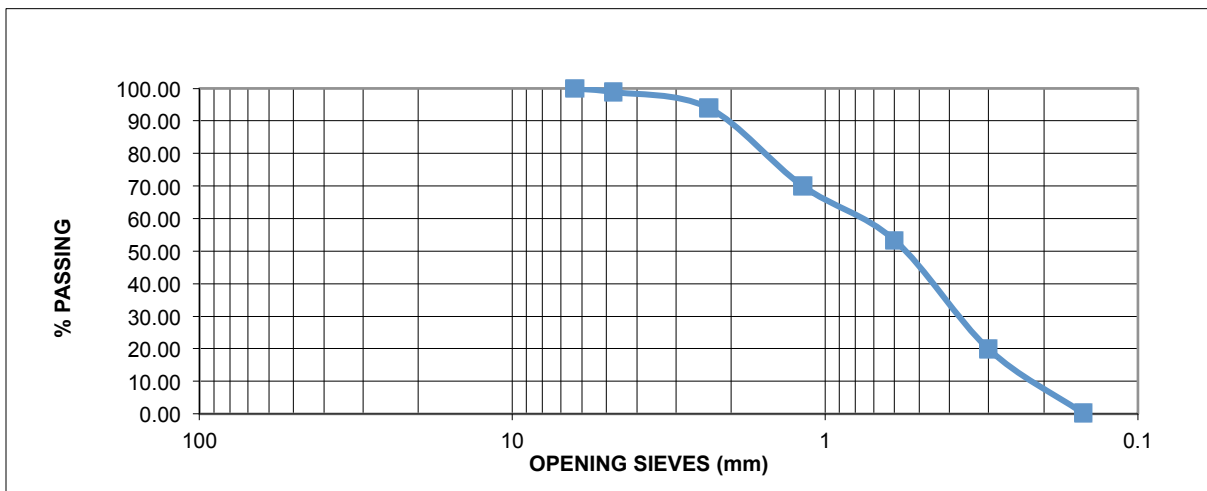


Figure 5: Sieve Analysis of Fine Aggregate

For CA, the total Cumulative % of refusal = 701.8, then the fineness modulus = Total Cum% Retained /100 = 701.8/100 = 7.018. For FA, Total Cumulative % of refusal = 263.57 and the fineness modulus = Total Cum% Retained /100 = 263.57/100 = 2.64. According to IS 383-1970, the medium sand should have the fineness modulus ranging between 2.6 and 2.9, while for the zone II, the fineness modulus should range between 3.37 and 2.1. This indicates that the fine aggregates used in this study was medium sand and was from the Zone II. The fineness modulus of coarse aggregates was found equal to 7.018, and was in the range of 5.5 - 8.0 recommended by the same standard.

The **tensile strength of sisal ropes** checked in order to establish its tensile capacity with comparison to ordinary reinforcement. Details are presented in the table 1 below.

Table 1: Tensile Strength of sisal ropes

Sample	Diameter(mm)	Cross section Area(mm ²)	Load(N)	Tensile strength (N/mm ²)	Average (N/mm ²)
1	10	78.5	3900	44.6	44.0
2			3600	40.8	
3			4100	46.5	

From the above table, the tensile strength of sisal ropes was found equal to 44.0 N/mm². This established value was in line with results reported in some studies (Aruna, 2014).

The **slump test result** for fresh concrete was found to be 55mm, and the values meet well the applied standards.

The results from mechanical tests for samples with sisal fibres percentage of 0%, 0.5 %, 1% and 1.5 %, tested after 7 and 28 days of curing, are presented in Figs.6 – 8.

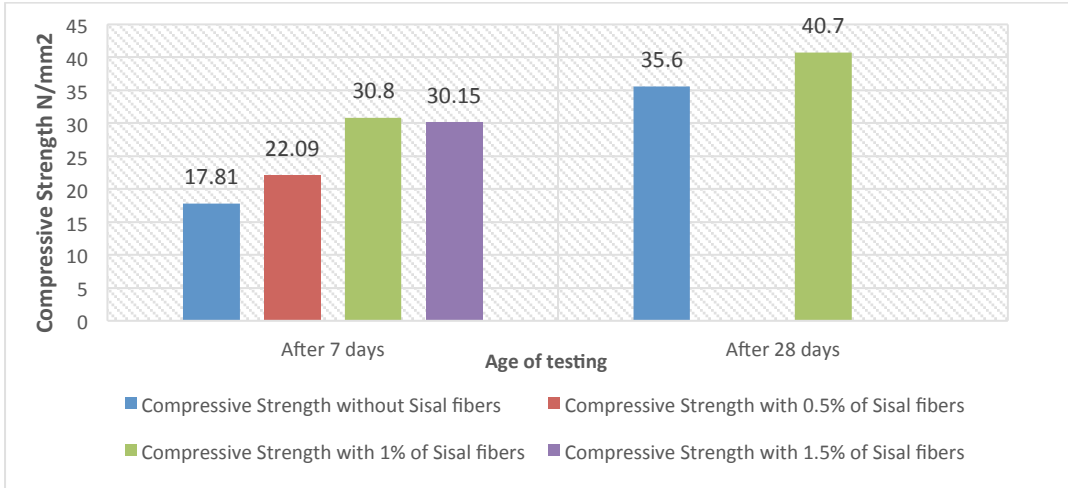


Figure 6: Compressive Strength at 7 and 28 days

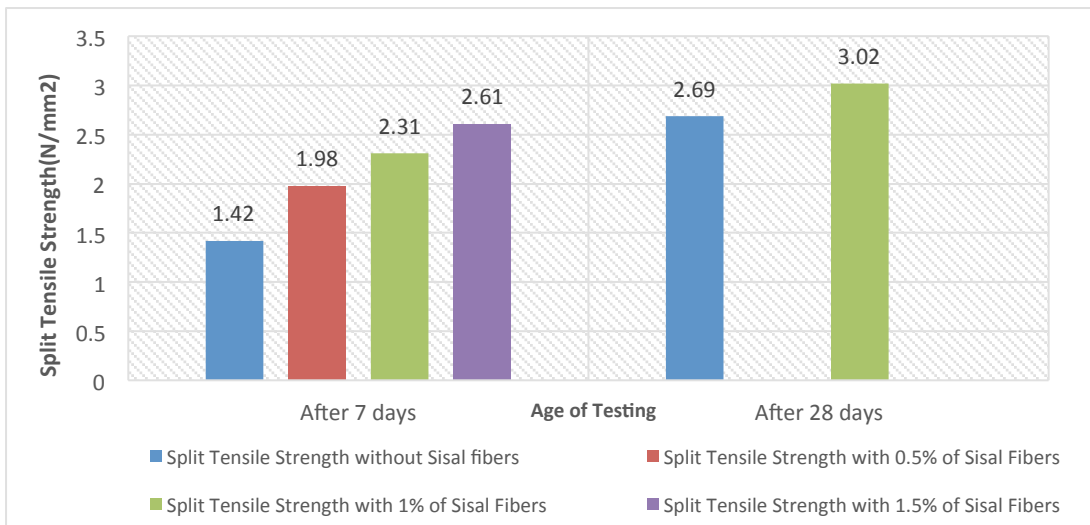


Figure 7: Split Tensile Strength Test Chart

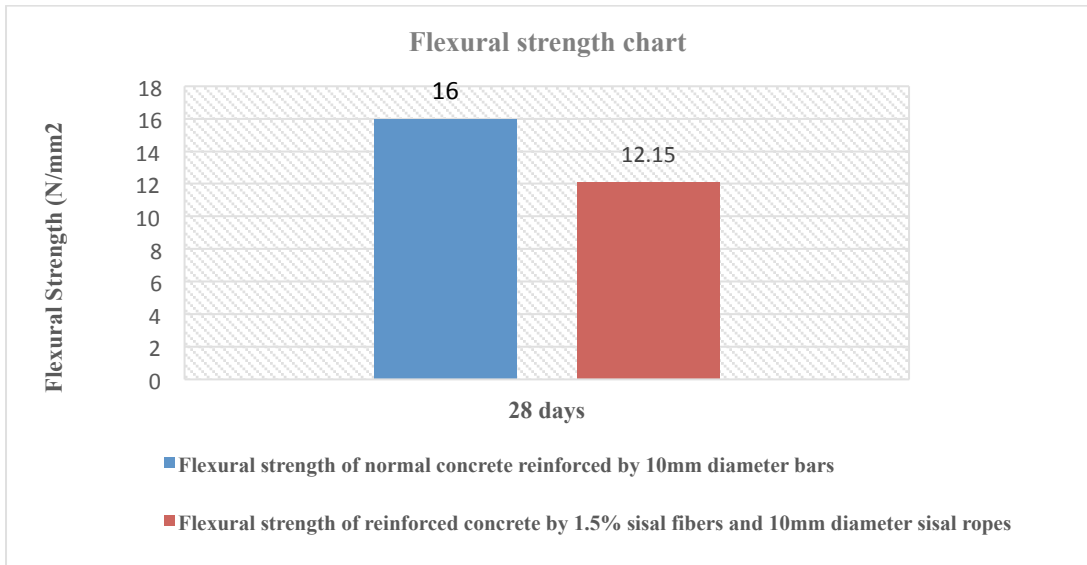


Figure 8: Flexural Strength Test Chart

These mechanical test results are in line with either those from previous studies (Nanak et al., 2013), or those given by standards, as they are summarized in the table 2 presented below.

Table 2: Comparative analysis of concrete plate's strength at 28th day

Properties	Ordinary reinforced concrete plate	Sisal reinforced concrete plate (with 1%)	Min Standard values for M30 (Nanak et al., 2013)
Compression strength	35.6 N/mm ²	40.7 N/mm ²	30N/mm ²
Split tensile strength	2.69 N/mm ²	3.02 N/mm ²	1.9N/mm ²
Flexural strength	16 N/mm ²	12.15 N/mm ²	2.8N/mm ²

For both compressive and tensile strength, the strength values of concrete with and without sisal fibres increases with age (Fig.5, Fig.6), what is in line with standards and show that not only concrete components are adequate, but also the used sisal fibres don't stop the concrete hardening process. From the table 2, it can be concluded that the plates with sisal fibres are stronger under compression and tension than ordinary plates, while ordinary plates are stronger than plates with sisal fibres under flexure. The flexural strength has reduced up to 24.06%, after replacing steel bars with sisal ropes. However the results show that concrete plates reinforced by sisal ropes are stronger enough to withstand footway loadings without failing (Bharath and Srikanth, 2017). The initial decrease and then increase of both compressive and tensile strengths

of concrete samples with sisal fibres up to 1% is confirmed also in different studies (Aruna, 2014; Priyankarani and Srichandana, 2015).

The *cost estimation* showed that plates with sisal fibres were around 1.85 times cheaper than concrete plates with ordinary reinforcement, with the same sizes.

4. Conclusion

Following the earlier set objectives, the study checked first the quality of concrete components and sisal fibres, and established that all of them met standards. Results obtained from compression, split tensile and flexural tests allow concluding that the sisal fibres have a good potentiality to be used as reinforcements in drainage concrete plates up to 1% of concrete volume. The proposed drainage plate with sisal fibres found to be around 1.85 more affordable than the plates with ordinary steel reinforcement. As the performance of natural sisal fibres would depend on treatment methods, fibres length, and type of required concrete, it is recommended that further studies on the use of sisal fibres consider those factors.

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