The Effect of Sisal Juice Extract Admixture on Compressive and Flexural Strength of Cement Concrete

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Abstract-The characteristics of concrete are influenced by the ratio of water to cementitious materials (w/c) used in the mixture. An increase in paste quality will yield higher compressive and flexural strength, lower permeability, increased resistance to weathering, improve the bond between concrete and reinforcement, reduced volume change from drying and wetting, and reduced shrinkage cracking tendencies. Admixtures are used to improve the properties of concrete or mortar. The current study investigates the effect of Sisal Juice Extract (SJE) as an admixture on concrete durability. SJE contains unrefined minerals which can be used as organic retarders to increase the rate of strength development at an early age. A total of 84 concrete cubes were produced in 7 sets of 12 samples each. One set was the control mix which had zero SJE content. The remaining sets had varying dosages of SJ namely 5%, 10%, 15%, 20%, 25%, and 30%. Twelve beam specimens were also cast and subjected to the three-point flexural test. To establish the effect on strength of concrete, compressive strength was tested at 7, 14, 28, and 56 days while flexural strength was tested at 28 days. The highest compressive strength was achieved at 5% dosage beyond which a decrease in strength occurred for all the higher dosages.

Keywords-sisal juice extract; compressive strength; flexural strength

I. INTRODUCTION

Concrete is one of the most commonly used construction materials [1]. The production of concrete is achieved by mixing predetermined proportions of cement and aggregates with water to form a plastic material which transforms to a hard strong and load bearing material when dried [2]. The hardening of concrete is attained through hydration which is an exothermic reaction between cement and water. The addition of water to concrete during mixing enables hydration to take place while the excess quantity forms a slurry with the cement which coats the aggregates in the mix, lubricating them and allowing easy movement during compaction [3]. The first stage of hydration that leads to stiffening is caused by the reaction between water and a chemical constituent of cement called tricalcium silicate (C_3S) [4]. The time taken for concrete to harden after the addition of water to the cement–aggregate mix is referred to as setting time. The last stage occurs over a longer period, called final setting time, and is caused by the reaction of water with calcium silicate (C_2S). It is during this stage that hardening occurs, as a result of the exothermic nature of hydration. The higher the rate of hydration is, the higher the rate of both heat generation and strength development [5-7].

The expansion and contraction of the hardened concrete are associated with the generated heat which causes stresses that lead to microscopic cracks within the concrete structure. This phenomenon causes problems when constructing large concrete structural members such as piers, dams and bridges and generally when concreting structures in hot climates [8, 9]. In order to slow both the rate of hydration and the generation of heat and strength development, admixture materials called retarders may be used as they have the effect of delaying the initial setting time of concrete thereby providing enough time for concrete operations [10, 11]. Retarding admixtures reduce the rate of hydration by blocking cement from reacting with water [12-15]. This happens because the retarding admixtures are mainly based on materials having lignosulfonic acids and their salts, hydroxyl-carboxylic acids and their salts, sugars including their derivatives, inorganic salts such as borates phosphates, and zinc and lead salts. [7, 16-19]. Admixtures come in various forms and are usually imported and expensive to acquire, hence cheaper admixture materials need to be established from locally available sources [20, 21]. The ability

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of retarders to reduce the rate of heat generation and strength development when concreting large structural members also helps to prevent the occurrence of capillary cracks that compromise the durability of concrete structures [22].

In [23], the effects of sugar on the setting time of cement and the compressive strength of concrete were investigated. In all curing periods the compressive strength was found minimum for concrete with 0.3% sugar and maximum for concrete with 0.08% sugar. Only in 0.3% sugar, the compressive strength was found less than the strength found for concrete with 0% sugar. The compressive strengths of all the other sugar percentages were found increased in comparison with plain concrete's. The authors concluded that the concrete compressive strength was maximum for 0.08% sugar in all curing periods among the sugar percentages used. Authors in [24] evaluated the effect of sugar on the compressive strength of concrete. Ordinary Portland Cement-OPC (ACC cement) of 43 grades was used for the cube casting. The cubes having sugar dosages of 0%, 0.06%, 0.08% by weight of cement were cast and the compressive strength of cubes for 7, 21, and 28 days were tested. It was observed that the setting time and workability of concrete increased with the increase in sugar dosage and that there was an increase in the compressive strength of about 16.02% at 28 days compared to ordinary concrete [24]. Authors in [25] studied the effect of sugar on strength and durability of HVFAC concrete with similar results. It was observed that the addition of sugar increased the workability and compressive strength of concrete.

Waste materials can be used to produce new products or can be used as admixtures so that natural resources are used more efficiently and the environment is protected from waste deposits [26]. Kenya, like many other countries, grows sisal in large quantities for extraction of fiber but the remains after extraction are not fully utilized. The objective of this paper is to study the potential of utilizing SJE that is generated from sisal waste as an economical admixture. Statistical assessment on compressive strength, flexural strength, and setting time has been conducted in order to investigate the effectiveness of SJE as an admixture. In addition, the utilization of the sisal waste will address the environmental pollution by making good use of sisal fiber waste material

II. MATERIALS AND METHODS

A. Materials

1) Cement

OPC class 53 conforming to KEBS SRN 103 was used in the production of the concrete for all mixes.

2) Fine and Coarse Aggregates

Natural river sand obtained from local suppliers was used as fine aggregates. Coarse aggregates originated from crushed stone type of nominal size of 10/20 mm. Their properties can be seen in Table I.

3) Sisal Juice

The SJ used for the experiment was obtained from sisal leaves harvested from a local single plantation to ensure the use of a single species. The juice was extracted by squeezing the leaves in a cleaned improvised machine that allowed collection in a container.

TABLE I. PROPERTIES OF FINE AND COARSE AGGREGATES

Properties	River sand	Coarse aggregates
Fineness modulus	2.70	4.82
Silt content	0.5	-
Specific gravity	2.48	2.50
Water absorption (%)	2.1	3.10

4) Water

Water conforming to the requirements for concreting and curing as per IS: 456-20009 was used.

B. Test Methods

The preparation of specimens was done by measuring the required proportions of fine and coarse aggregates and cement and thereafter mixing was done in dry state before the addition of water and SJ. Water was mixed with different dosages of SJ before addition to the concrete mix. A homogenous mix was achieved through thorough mixing of the concrete ingredients. Two concrete mixes were produced. Mix "A" was produced without any addition of SJE while mix "B" had different dosages of SJE. Batched concrete mixes were prepared by replacement of 5%, 10%, 15%, 20%, 25% and 30% water with SJE in six sets as shown in Table II.

TABLE II. DETAILS OF MIX PROPORTIONS CLASS 25 CONCRETE

	Mix A (OPC)	Mix B (OPC + SJ)					
Mix Set	1	2	3	4	5	6	7
Dosage (%)	0	5	10	15	20	25	30

TABLE III. CONCRETE SPECIMEN DETAILS

	No. of cubes (specimen size: (150×150×150mm)	No. of beams (specimen size: (150×150×530mm)
Mix A	12	2
Mix B	72	10

1) Sisal Juice PH Test

The PH value of the fresh SJ was tested in the laboratory using the universal PH scale. SJE was subjected to chemical analysis using XRF technology (X-Ray Florescence spectra analysis).

2) Compressive Strength Test

Concrete specimens were compacted into a detachable mould with dimensions of 150×150×150mm. The specimens were demoulded after 24 hours and were immersed in water to cure. A total of 84 cubes were cast, and they were cured for 7, 14, 28, and 56 days. Compressive strength tests were conducted after the respective curing days. A compression machine was used in the laboratory, in accordance with BS EN 12390.

3) Flexural Strength Test

The test was carried out to determine the strength of concrete according to BS EN: 12390-5: 2009. The specimens for various SJ dosages were prepared and cast in moulds measuring 150×150×530mm and were cured for 28 days. A total of 12 beams were tested using the three point flexural test method. The beam specimens were placed between two supports in the universal testing machine and load was applied at the center until failure occurred.

4) Setting Time of Cement Mortar

The setting time of cement mortar made with replacement of water with SJ by 0%, 5%, 10%, 15%, 20%, 25% and 30% were obtained in accordance with BS EN 196-3:1995.

III. Results and Discussion

A. Chemical Analysis of Sisal Juice Extract

The fresh SJE was subjected to a litmus test giving a PH of 5, which is acidic. The decrease in compressive strength of concrete cubes with increase in the quantity of SJE was caused by the fact that the components of concrete break down during contact with acid [18]. From the results in Table IV, it can be noted that the content of calcium oxide (CaO) is the most predominant element at 35% followed closely by potassium oxide (K_2O). These two ingredients are also found in gypsum which is a mineral used for retarding the setting of cement during manufacture. Other elements found in both gypsum and SJE include magnesium oxide (MgO) and sulphur (S) [27, 28].

TABLE IV. CHEMICAL COMPOSITION OF SISAL JUICE

Element	Percentage by Weight (%)
Calcium oxide (CaO)	35.88
Potassium oxide (K_2O)	32.40
Magnesium oxide (MgO)	13.74
Aluminum oxide (AL_2O_3)	4.19
Silicon dioxide (SiO_2)	4.08
Iron (Fe)	3.55
Sulphur (S)	2.95
Phosphorous pentoxide (P_2O_5)	1.48
Chlorine (Cl)	1.00
Zinc (Zn)	0.62
Manganese (Mn	0.38
Titanium (Ti)	0.23
Strontium(Sr)	0.11

B. Effects of SJE on Compressive Strength

TABLE V. EFFECT OF SISAL JUICE ON COMPRESSIVE STRENGTH

Mean strength (N/mm)								
		Percentage						
		0%	5%	10%	15%	20%	25%	30%
Days	7	17.02	20.18	16.74	15.63	11.86	12.43	9.76
	14	22.10	24.87	20.85	19.55	17.29	14.97	11.92
	28	25.00	26.08	21.97	22.79	20.27	18.07	17.96
	56	28.90	30.47	25.03	23.38	21.21	19.53	18.69

The test results in Table V indicate an increase in strength between control and cement with 5% of SJ but beyond 5%, the strength decreased steadily. The steady decrease in compressive strength can be attributed to the fact that SJE is acidic and an increase of SJE breaks down the components of concrete during contact as shown in [18]. The results in Figure 1 point out a strength gain trend with 5% dosage attracting the highest compressive strength while 30% SJE gained the least strength at all ages. In Figure 2, the compressive strength difference between the control mix and 5% SJ dosage is 4.32%. The results show that there is a low rate of decrease in strength between 10% and 15% of SJ dosage but beyond 15% to 25% SJ, the rate increases. This result is in line with the results demonstrated in [23].

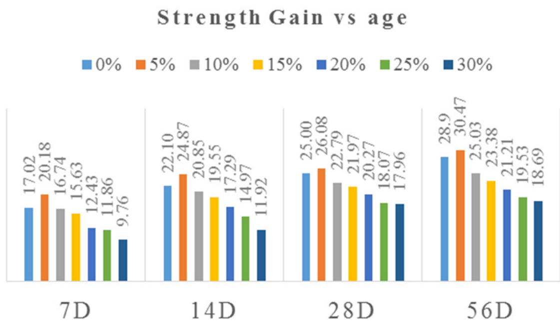

Fig. 1. Strength of concrete at different ages.

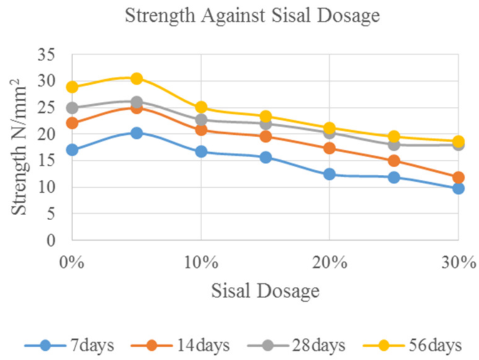

Fig. 2. Effects of SJ dosage on concrete's strength.

C. Flexural Strength Test

The test was conducted in accordance with BS EN 12390:2009 by using the three point load system. Beams, with a size of 150×150×550mm were used (Figure 3).

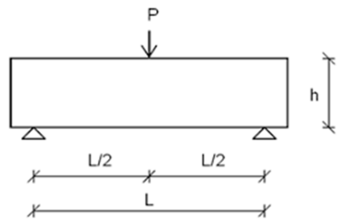

Fig. 3. Three point load system.

The results for flexural strength of SJE concrete are plotted against various percentages of SJE dosage. In Figure 4, it can be seen that when SJE dosage is increased, a significant increase in flexural strength is obtained. The predominant increase in flexural strength is found at 20% SJE dosage. The percentage of increase in flexural strength is 18% compared to control concrete. There was a slight decrease in flexural strength at 25% and 30% dosage.

TABLE VI. FLEXURAL STRENGTH TEST RESULTS

SJ dosage	S/No	Load (N)	Flexural strength (N/mm^2)	Avg.
0%	Specimen 1	32.21	4.29	4.3
	Specimen 2	32.40	4.32	
5%	Specimen 1	33.00	4.40	4.4
	Specimen 2	33.00	4.40	
10%	Specimen 1	33.75	4.50	4.6
	Specimen 2	34.88	4.65	
15%	Specimen 1	36.00	4.80	4.9
	Specimen 2	36.75	4.90	
20%	Specimen 1	39.98	5.33	5.1
	Specimen 2	36.98	4.93	
25%	Specimen 1	37.95	5.06	4.9
	Specimen 2	36.00	4.80	
30%	Specimen 1	31.50	4.20	4.5
	Specimen 2	36.00	4.80	

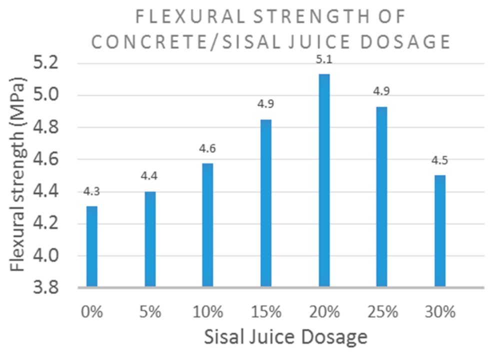

Fig. 4. Flexural strength of concrete at different SJ dosages.

The outcomes demonstrated that beam flexural performance increased rapidly by the addition of SJ, up to 20% and then it decreased slightly which is in line with results presented in [29]. Furthermore, diagonal cracks were observed on all the beams, including the control. Ultimate collapse occurred by concrete crushing within the compression zone for all the beams.

Fig. 5. Ultimate collapse of a concrete beam.

D. Comparison between Flexural and Compressive Strength

Table VI shows the relationship between the flexural and the compressive strength of concrete with SJE.

TABLE VII. FLEXURAL AND COMPRESSIVE STRENGTH COMPARISON AT 28 DAYS

Sisal dosage (%)	Flexural strength (N/mm^2)	Compressive strength (N/mm^2)
0	4.3	25.00
5	4.4	26.08
10	4.6	21.97
15	4.9	22.79
20	5.1	20.27
25	4.9	18.07
30	4.5	17.96

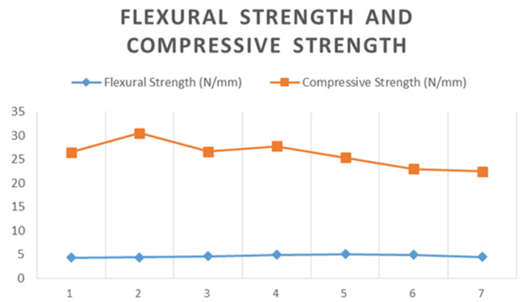

Fig. 6. Comparison between flexural and compressive strength at different sisal dosages.

Flexural strength must be between 10 to 20% of compressive strength depending on the type, size and volume of coarse aggregates used, see Table VIII.

TABLE VIII. ACCEPTABLE RANGE OF FLEXURAL STRENGTH

Sisal dosage (%)	Flexural strength (N/mm^2)	Compressive strength (N/mm^2)	Acceptable range of flexural strength	Remarks on the range of flexural strength
0	4.3	25.00	2.2 to 4.4	Acceptable
5	4.4	26.08	2.6 to 5.2	Acceptable
10	4.6	21.97	2.3 to 4.4	Unacceptable
15	4.9	22.79	2.3 to 4.6	Unacceptable
20	5.1	20.27	2.0 to 4.1	Unacceptable
25	4.9	18.07	1.8 to 3.6	Unacceptable
30	4.5	17.96	1.8 to 3.6	Unacceptable

High flexural strength is essential for stress-bearing restorations, when high pressure/stress is exerted on the material or restoration. From Table VIII, an increase of about 4.32% in compressive strength is witnessed and a significant improvement in flexural toughness is observed in the case of replacing water by 5% SJE. The flexural strength of $4.4N/mm^2$ falls within the required range of 10% to 20% of compressive strength. The appropriate SJ dosage for the production of SJE concrete was found to be 5%. The water replacement by SJE enhanced the flexural strength compared to control mix.

E. Effects of SJE on Setting Time

Figure 7 shows that both the initial setting time and the final setting time increased at an average of 14% and 23% respectively with increase in SJ dosage. According to Table IX, the initial setting time of the cement paste increased with increase in SJ dosage when compared to the reference value. The final setting time also increased exponentially with increase in replacement of water by SJE. This can be attributed to the adsorption of the retarding SJ on the surface of cement particles, forming a protective skin which slows down the process of hydration hence the reason why there is a steady rise of setting time. The layer of retarding admixture around the cement particles acts as a diffusion barrier. Due to this diffusion barrier, it becomes difficult for the water molecules to reach the surface of the un-hydrated cement grains and hence the hydration slows down, and the dormant period (period of relatively inactivity) is lengthened and thus the paste remains plastic for a longer time.

TABLE IX. INITIAL AND FINAL SETTING TIMES OF CEMENT MORTAR WITH VARYING DOSAGES OF SISAL JUICE EXTRACT

SJE dosage (%)	Initial setting time (min)	Percentage increase (%)	Final setting time (tin)	Percentage increase (%)
0	179		334	
5	214	20	467	40
10	234	31	521	56
15	237	32	620	86
20	242	35	893	167
25	265	48	1767	429
30	372	107	1840	451

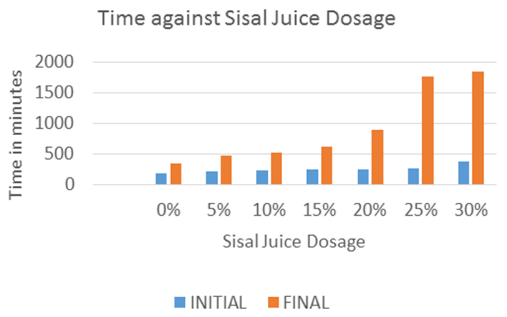

Fig. 7. Effects of SJE on initial and final setting time.

IV. CONCLUSIONS

The following conclusions can be drawn from the experimental study:

- SJE is acidic in nature and contain elements like calcium oxide (CaO) and potassium oxide (K_2O) which are predominant in retarders.
- Early compressive strength development is achieved at all ages with replacement of water by 5% SJE.
- The gradual replacement of water by SJE dosage enhanced flexural strength.
- The optimum water replacement by SJE that achieved high compressive strength and appropriate flexural strength is 5%.
- The replacement of water by SJE retarded the setting time of concrete.

V. RECOMMENDATIONS

The 22.79N/mm^2 concrete strength achieved at 28 days for 15% dosage can be used for low loading retaining wall with low surcharge. The 5% replacement of water by SJE concrete can be used to improve site capacity by increasing formwork rotation and also fasten construction time.

It is hereby suggested that further work on SJE should be carried out at controlled conditions. It is also recommended that prior to the acceptance of SJE as a retarder, the properties of different species of sisal leaves need to be studied.

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