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Mechanical Performance of Sisal Fibre-Modified Self Compacting Concrete: A Comprehensive Study

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ABSTRACT

To promote sustainable development, there is a need to explore alternative materials to help lower construction cost and also to increase the toughness of concrete, Sisal fibre could be used as an additive in concrete. Sisal fibre is extracted from the leaves of the *Agave sisalana* plant, is a natural fibre that does not require extensive chemical processing. This study focuses on examining the impact of sisal fibre on the strength properties of self-compacting concrete (SCC). The preliminary properties of the materials, as well as the rheological properties of SCC which includes L-box, V-funnel, T50, and slump flow tests, were analyzed to assess the concrete's workability. The study evaluated the compressive and split tensile strength at different sisal fibre dosages, 0.0 (control), 0.25, 0.5, 0.75, and 1 % by volume with a mix ratio of 1:2.91:1.05 and a water-cement ratio of 0.35. The test results were analyzed using Design Expert software (version 13, 2021). Predictive models were developed for compressive and split tensile strength. The models showed R^2 values of 94.49 % for compressive strength and 88.24 % for split tensile strength, indicating a strong correlation. In addition, the difference between adjusted and predicted R^2 values was less than 20 %, further supporting this. The optimal results yielded a compressive strength of 17.31 N/mm² and tensile strength of 4.39 N/mm² at 0.25 % sisal fibre content after 28 days of curing. Based on these findings, it can be concluded that 0.25 % sisal fibre content could be used to produce lightweight concrete structures.

Keywords: *Self-compacting concrete. Sisal Fibre. Response Surface Methods. Compressive strength. Split Tensile Strength. Design Expert Software*

1. Introduction

Self-Compacting Concrete (SCC) has made a big impact on the construction industry because it can flow and spread on its own without breaking apart. This makes it easier to fill complex moulds and areas with lots of reinforcement without needing machines to shake it into place. However, despite these benefits, SCC can still be brittle and has low strength when pulled, which can cause cracks and reduce how long it lasts in certain situations [1]. Cracks in hardened concrete is a common issue in the construction industry. These cracks can compromise the durability and structural integrity of concrete and also when it propagates deeper into the concrete can lead to serious corrosion to the reinforcement. Fibres, however, have been shown to possess the ability to fill and heal cracks. To improve SCC, fibres are added to make it stronger and last longer. Fibre Reinforced Self-Compacting Concrete (FRSCC) includes fibres that help stop cracks and improve the concrete's strength. Natural fibres are also being studied as eco-friendly options for reinforcing SCC [2]. There is a lack of research on the use of sisal fibre in self-compacting concrete using response surface methodology (RSM). Therefore, this study tends to fill the gap existed in the literature.

According to [3] natural fibres like coconut, sisal, and bamboo in SCC, showing they can improve its strength while being eco-friendly. The study found these fibres boosted tensile and flexural strength, but too much fibre reduced workability. Using a mix of different fibres also improved SCC's strength and toughness.

Sisal fibres are strong and have good tensile strength, making them useful in many industries. They resist saltwater, are biodegradable, and eco-friendly. In construction, sisal fibres improve the strength of concrete and plaster. They are also used in making durable carpets, paper, and cardboard. Sisal's strength and versatility make it valuable for many uses. A recent study showed that adding sisal fibre to concrete improves its compressive and flexural strength [4]. A study carried out by [[2] aimed to improve the tensile strength of self-compacting concrete by adding different fibres, including sisal. Self-compacting concrete flows easily without mechanical vibration, making it ideal for areas with dense reinforcement. This study tested sisal fibre-reinforced concrete at different percentages (0.25 % to 1.5 %) to examine its fresh and hardened properties. Compressive, tensile, and flexural tests were done on cubes, cylinders, and beams after curing for 7, 14, and 28 days.

According to [5] adding various fibres affects the strength and behavior of self-compacting concrete (SCC) after cracking. Concrete mixes were tested with steel, polypropylene, and hybrid fibres at different volumes (0.5 %, 1.0 %, and 1.5 %). The research found that steel and hybrid fibres improved compressive, tensile, and flexural strengths of SCC. Steel fibres showed the highest increase in tensile strength, while hybrid fibres balanced improvements in both pre-cracking and post-cracking phases.

A study by [6] explores how waste laterite can be used as coarse aggregate in sustainable self-compacting concrete (LSCC). Thirteen different mixes, were used with factors like laterite (LA: 10-50 %) and sisal fibre (SF: 0.25-1.25 %) were tested for properties such as flow and strength. Analysis of variance was used to analyze and optimize the results. The best mix contained 0.76 % sisal fibre and 26.8 % laterite, which signifies a good strength and flow with minimal error.

Sisal Fibre Extraction: Sisal leaves are dark green, straight, and fleshy. To extract the fibres, the leaves are crushed and manually separated using a smooth stick. The fibres are then thoroughly washed with water to remove dust and waste, and air-dried [7].

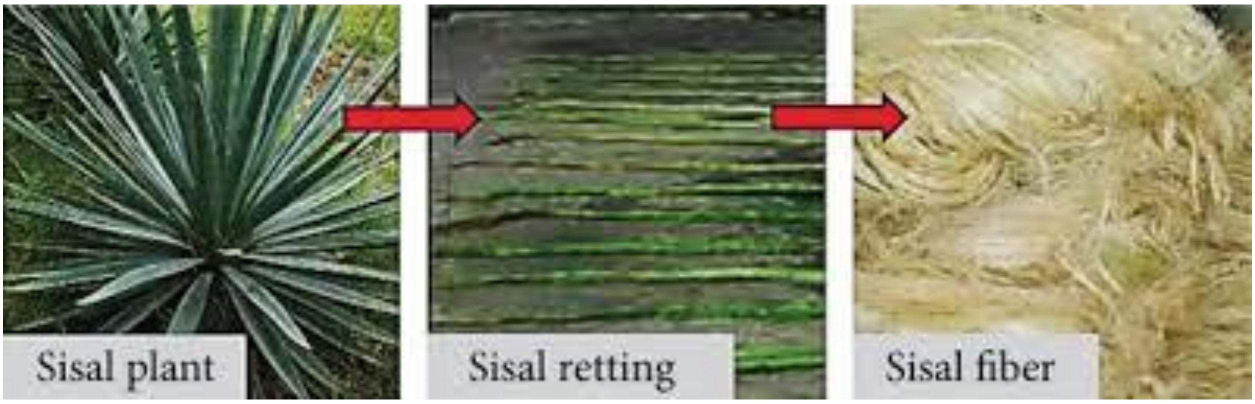


Figure 1: Sisal Fibre Extraction Process

Treatment of Sisal Fibre: Various chemicals like hemicelluloses, lignin, and pectin are used to treat the fibres. Ammonium treatment involves extrusion, and other treatments use chemicals like NaOH, $Ca(OH)_2$, and sodium silicate. Sisal fibres absorb a lot of water, which affects their performance in concrete. The treatment improves fibre cohesion in composites, although untreated fibres showed more flow. Sisal's stiffness depends on its cellulose content [7].

This study aims at improving the mechanical performance of SCC and employed response surface method for the development of mathematical prediction models and optimized the Sisal fibre content at various curing age to produce light weight self-compacting concrete.

2. Materials and Methods

2.1 Material

Cement: Portland limestone cement of grade 42.5N was used and sourced from a nearby dealer in Sabon Gari market. Quality control and standard tests were done on the cement. The physical properties of cement were examined and has a specific gravity of 3.18, standard consistency of 29 %, initial and final setting times of 89 minutes and 172 minutes respectively.

Aggregates: Fine aggregate was locally collected behind Drama Village at ABU Zaria. It has a specific gravity of 2.63, a water absorption rate of 4.17 %, and its particle sizes falls within Zone II of the aggregate distribution curve. While the coarse aggregate with 20 mm maximum nominal size was obtained from a nearby quarry opposite the Nigerian College of Aviation Technology in Samaru, Zaria. It has an aggregate crushing value of 23.10 %, impact value of 20.34 %, and a specific gravity of 2.85.

Water: Portable pipe-borne water from Civil Engineering Department, Ahmadu Bello University was used.

Superplasticizer: The superplasticizer utilized is Conplast SP430 SRV, which was obtained from the Samaru Market in Zaria.

Sisal fibre: The sisal fibre was sourced from Panteka Tudun Wada in Kaduna. To enhance its properties, the fibre was thoroughly dried to minimize moisture content, ensuring better performance in the final application. This step is crucial, as reduced moisture can improve the fibre's durability and bonding characteristics when incorporated into various materials. Some of the properties of sisal fibre are presented in Table 1.

Table 1: Properties of Sisal Fibre

Diameter(mm)	Specific gravity	Length(mm)	Color	Tensile strength (N/mm^2)	Water absorption (%)
0.13	0.22	5	Pale yellow	10.60	14

2.2 Methods

2.2.1 Production of Self-Compacting Concrete

The production of self-compacting concrete (SCC) followed the method by [16]. The materials used were Portland limestone cement of grade 42.5N, sand, gravel, water, and superplasticizer to improve workability. The mix proportions were based on BS EN 206-1:2013 standards. First, the dry ingredients, cement, sand, and gravel were mixed for 2 to 3 minutes. Then, water and the superplasticizer were added, and the mixture was stirred for another 3 to 5 minutes until smooth. Afterward, fresh properties of SCC were done to check the concrete's workability. The SCC was then poured into moulds, left to set for 24 hours, it was demoulded placed in a curing tank and cured for 7, 14, and 28 days to ensure its strength properties was achieved.

2.2.2 Test on the Fresh Properties of Self-Compacting Concrete

To assess the fresh properties of self-compacting concrete (SCC), three tests were conducted that is the Slump flow test which was carried out in accordance with [23] and measured the concrete's consistency. The concrete was poured into a conical mold and the height difference after removing the mold was measured and recorded. The V-Funnel Test, which was conducted according to [21], measured concrete flowability. The SCC was placed in a V-shaped funnel, and the time it took to flow out was recorded, according to [18] the value falls within the range 6-12 seconds. Finally, the L-Box Test and T50 test were conducted according to BS 206, evaluates the concrete’s passing ability. SCC was poured into the vertical section, and the time and height ratio between sections were measured to determine its ability to flow without obstruction.

2.2.3 Test on the Hardened Properties of Self-Compacting Concrete

To determine the hardened properties of self-compacting concrete (SCC) with sisal fibre, two tests were performed. The compressive strength test which was carried out in accordance with [22]. Concrete cubes of 150 x 150 x 150 mm were cast, cured, and tested by applying a gradual load until failure. Equation (1) was used to calculate the compressive strength of each tested cube sample.

Compressive strength = $\frac{\boldsymbol{Failure\ load(N)}}{\boldsymbol{Area\ of cubes(mm2)}}$ (1)

The Split Tensile Strength Test was conducted in accordance with [20]. Cylindrical specimens of 100x200mm were cast, cured, and placed horizontally in an Avery Denison testing machine. A load was applied until the specimen split in half, and the split tensile strength (*Ft*) was calculated using Equation 2. Both tests measured the concrete's ability to handle compression and tension.

$$Split\ tensile\ strength = \frac{2P}{\pi LD} \quad (2)$$

Where P is the maximum load at failure, L is the length of the specimen, and D is the diameter of the specimen.

2.2.4 Response Surface Methodology

Response Surface Methodology (RSM) combines mathematical and statistics to optimize processes. In this study, RSM was used to analyze the effects of curing age and sisal fibre content on the compressive and split tensile strength of self-compacting concrete (SCC). The response (Y) depends on independent variables (*f1, f2, fk), β* is the error as shown in Equation (3), and transformed into coded variables in Equation (4). Factorial design was used to handle interactions between variables, represented by a quadratic model in Equation (5).

$$Y = f(f1, f2, \dots \dots \dots \dots, fk) + \beta_0 \quad (3)$$

$$\eta = f(x1, x2 \dots \dots \dots, xk_n) \quad (4)$$

$$Y = \beta_0 + \sum_i \beta_i x_i + \sum_j \beta_{ii} x_j^2 + \sum_{ij} \sum_j \beta_{ij} x_i x_j + € \quad (5)$$

From equation 5 above, Y represent the response variable, β_0 is a constant, $\beta_i\ \beta_{ii}\ \beta_{ij}$ are coefficients of linear influence and double interactions x_i, x_j are the independent factors and € is the error. The experiment involved two factors that is curing age having three levels (7, 14, 28 days) and sisal fibre content with five dosages (0.0, 0.25, 0.50, 0.75 and 1.0%). This gave 15 number of experimental combinations. When the data was input into the software, three replicates was obtained in order to reduce type II error and achieved a power of design of more than 80%, led to 45 observations. Compressive strength tests were performed on 150 mm cubes, and split tensile tests were done on 100 mm x 200 mm cylinders. Design Expert software (Version 13, 2021) was used for the analysis and optimization.

Mathematical models were generated to predict the SCC strength properties, optimizing compressive and split tensile strength through RSM based on data from these tests. The results helped predict and enhance the performance of SCC reinforced with sisal fibre.

3. Results and Discussions

3.1 Workability of fresh SCC

The results of the fresh SCC modified with Sisal fibre are summarized graphically in Figure 2, 3, 4, and 5.

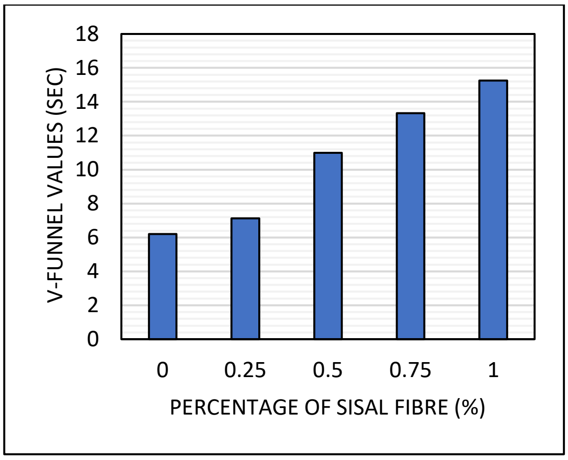


Figure 2: L-Box against % of Sisal Fibre

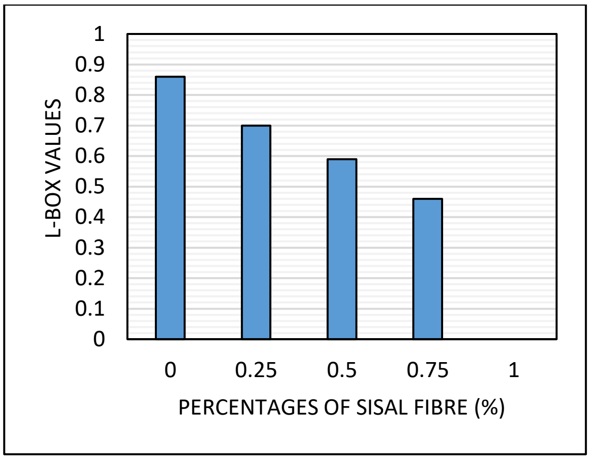


Figure 3: V-Funnel against % of sisal fibre

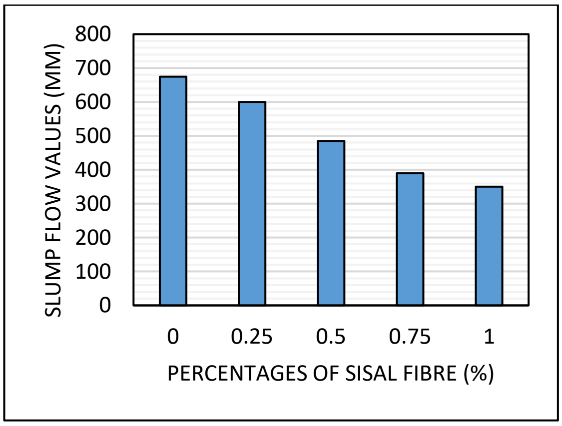


Figure 4: Slump Flow against % of Sisal Fibre

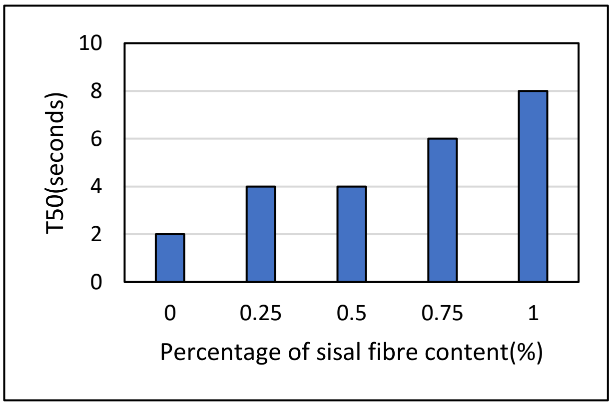


Figure 5: Plot of T50 against % of Sisal fibre content

It was observed that addition of Sisal fibre increased the value of V-funnel and T50, and decreased the slump and L-box value. At 0.25 % fibre, the workability slightly decreases Figures: 2, 3, 4, and 5. at 0 % Sisal fibre, the concrete shows excellent workability, as noted by Patil *et al*., (2024)[6], flowing but remains steady, this is in consistent with the findings of [7]. At 0.5 %, the flowability reduces noticeably, and at 0.75 %, it becomes thick with poor flow, especially around obstacles. By 1.0 %, the SCC becomes very thick, failing in the L-Box test. Overall, increasing sisal fibre content reduces workability, particularly at higher dosage of sisal fibre content (0.75 and 1.0 %), as also observed by [6]. It was also observed in the case of (T50) the workability reduces by adding sisal fibre into the self-compacting concrete mix. Studies by [8] confirm similar findings, where increasing natural fibres like sisal fibre leads to slower flow rates due to the concrete becoming thicker and harder to flow. [10]) also observed reduced workability with higher fibre percentages.

3.2 Compressive Strength of SCC with Sisal Fibre

The results for the compressive strength of SCC at various sisal fibre dosages are presented in Figure 6.

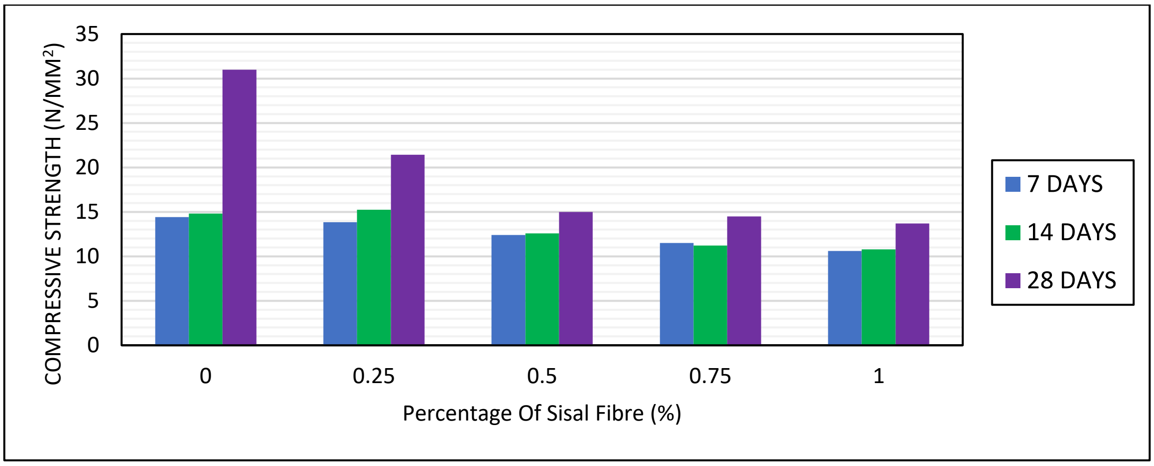


Figure 6: Compressive Strength of SCC against Sisal Fibre Content

The compressive strength results show that concrete without sisal fibre (0 %) has the highest strength, especially at 28 days. Adding sisal fibre lowers the strength, with a small decrease at 0.25 %, but higher fibre content causes a significant drop. Moreover, the target strength was achieved at 0.25 % Sisal fibre content. So, 0.25 % Sisal fibre content can be used in the production of lightweight concrete. A study by [11] also found that natural fibres like sisal reduce compressive strength, especially at higher amounts. Similarly, 12] noted that while fibres improve other properties, they weaken compressive strength when used in large quantities. The same reason was reported by [13], linking this to disruption of the concrete matrix.

3.3 Split Tensile Strength of SCC with Sisal Fibre

The results for the split tensile strength of SCC at various sisal fibre dosages are shown in Figure 7.

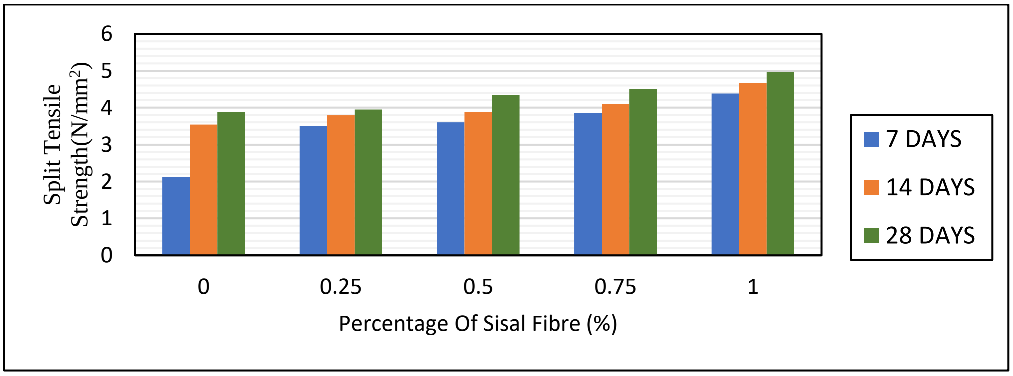


Figure 7: Split Tensile Strength of SCC against Percentage of Sisal Fibre

The results from Figure 7 show that adding sisal fibre improves the split tensile strength of SCC, with the highest strength at 1 % fibre content. The split tensile strength increases steadily from 0.5 % to 1 % fibre, making this range ideal for applications needing higher tensile strength. The control mix (0 % fibre) has much lower tensile strength, making it less suitable for such uses. Moreover, [11] also found that natural fibres like sisal improve split tensile strength in concrete. Similarly, [14] and [15] reported that sisal fibres enhance tensile performance by bridging cracks and resisting tensile forces.

3.4 Analysis of Variance (ANOVA)

Analysis of variance was used to analyse how various factors (the input or independent variables) affect the responses (the output or variable of interest being measured, by using the one-way analysis of variance. The analysis of variance checks if the factors have a significant impact on the response based on the set confidence level. The set confidence level of 95 % was adopted, meaning that the P-Value (probability level) should be less than 5 % ($p < 0.05$), A p-value less than 0.05 indicates that the model is significant. As can be observed from Table 3 and 4, both the models for compressive and split tensile strength have p-values of < 0.0001, meaning the models for compressive and split tensile strength are highly significant. The F-value measures how much the factors in the model improve the prediction of the response compared to random error for both the compressive and split tensile strength we got 74.24 and 58.52 which indicts that the models are statistically significant and there is only 0.01 % chance that f value could occur due to noise.

Table 3: ANOVA of Response Variance (Compressive Strength of SCC with Sisal Fibre)

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	**1023.60**	**5**	**204.72**	**74.24**	**< 0.0001**	**Significant**
A-curing age	324.72	1	324.72	117.76	< 0.0001	
B-sisal fibre	468.53	1	468.53	169.91	< 0.0001	
AB	173.61	1	173.61	62.96	< 0.0001	
A^2	31.71	1	31.71	11.50	0.0016	
B^2	37.49	1	37.49	13.60	0.0007	
Residual	107.54	39	2.76			
Lack of Fit	107.54	9	11.95			
Pure Error	0.0000	30	0.0000			
Cor Total	1131.14	44				

Table 4: ANOVA on the Response Variable (Split Tensile Strength of SCC with Sisal Fibre)

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	**16.16**	**5**	**3.23**	**58.52**	**< 0.0001**	**Significant**
A-curing age	5.29	1	5.29	95.82	< 0.0001	
B-sisal fibre	9.51	1	9.51	172.16	< 0.0001	
AB	0.5112	1	0.5112	9.26	0.0042	
A^2	0.4838	1	0.4838	8.76	0.0052	
B^2	0.0035	1	0.0035	0.0626	0.8038	
Residual	2.15	39	0.0552			
Lack of Fit	2.15	9	0.2393			
Pure Error	0.0000	30	0.0000			
Cor Total	18.31	44				

3.5 Mathematical Models

Models were developed based on the influence of the independent variables (curing age and Sisal fibre content) on the responses (compressive and split tensile strength). Below is the mathematical model formed after removing the insignificant terms from the model?

$$f_c = 12.71 + 3.29A - 4.60B - 3.34AB \quad (6)$$

$$f_S = 4.17 + 0.4200A + 0.6559B \tag{7}$$

From the equations (6) and (7), f_c and f_S represent the compressive and split tensile of the self- compacting concrete with sisal fibre, 12.71 and 4.17 represent the base compressive and split tensile strength which means the SCC without any sisal fibre content in it.$+3.29A$ and $+0.4200A$ indicates that for every unit increase in curing age, the compressive and split tensile strength increases by 3.29 N/mm² and 0.4200 N/mm². This indicates that curing age positively influences the strength. The value $-4.60B$ indicates that for every unit increase in sisal fibre content, the compressive strength decreases by 4.60 N/mm². This suggests that adding sisal fibre slightly reduces compressive strength and $+0.6559B$ indicates that for every unit increase in sisal fibre content, the split tensile strength increases by 0.6559 N/mm². This suggests that sisal fibre has a positive effect on the tensile strength of the concrete. Finally, $-3.34AB$, this shows interaction term between `A` and `B` it implies that the combined effect of curing age and fibre content has a negative influence on compressive strength. The strength decreases further when both variables are considered together. The degree of correlation values was used to evaluate the adequacy and quality of the established model. Table 5 shows the coefficients of determination for the responses investigated.

Table 5: Coefficients of Determination (Compressive and Split tensile Strength of SCC with Sisal Fibre)

Response	R^2	Adjusted R^2	Predicted R^2	AP
Compressive Strength of SCC with Sisal Fibre, F_c	0.9049	0.892	0.8662	29.0832
Split tensile Strength of SCC with Sisal Fibre, F_s	0.8824	0.8673	0.8377	25.0741

From Table 5, it was observed that the difference between the predicted and the adjusted R^2 values is less than 0.2 (20%) which signifies a strong correlation, and the Adequate Precision value measure the signal to noise ratio. To accept the desirability of a model, the AP value should be greater than four (4). From the above responses that is compressive and split tensile strength, the AP values are greater than 4, this can be used to navigate the design space.

3.6 Effects of Factors on Compressive and Split tensile strength of Self-Compacting Concrete with Sisal Fibre

Figures 8 to 11 shows the 2D and 3D plot of the interactions between the factors and responses of the self-compacting concrete with sisal fibre

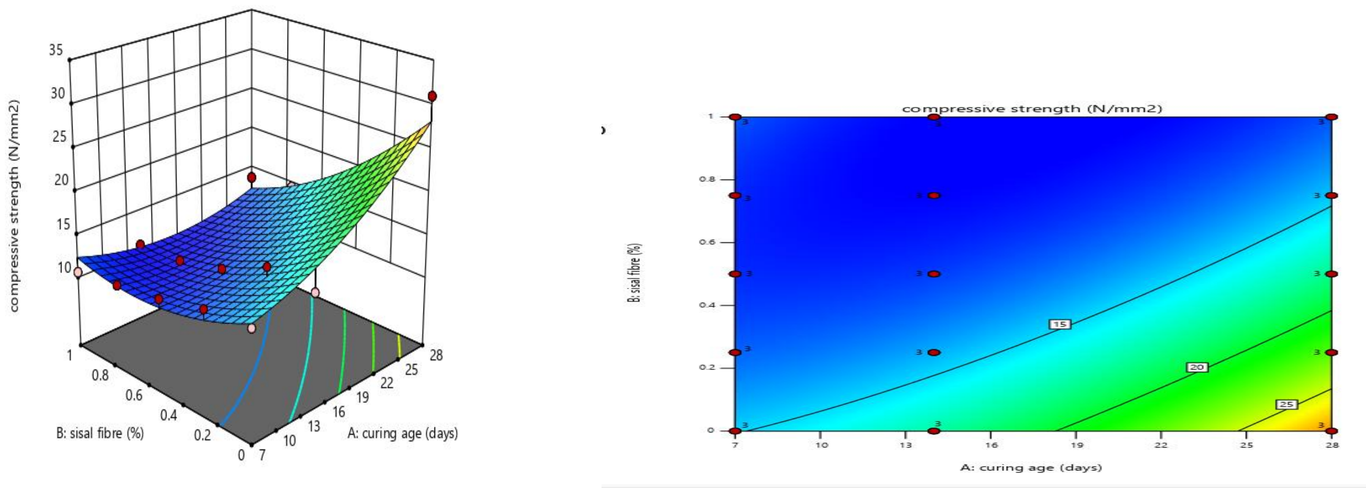
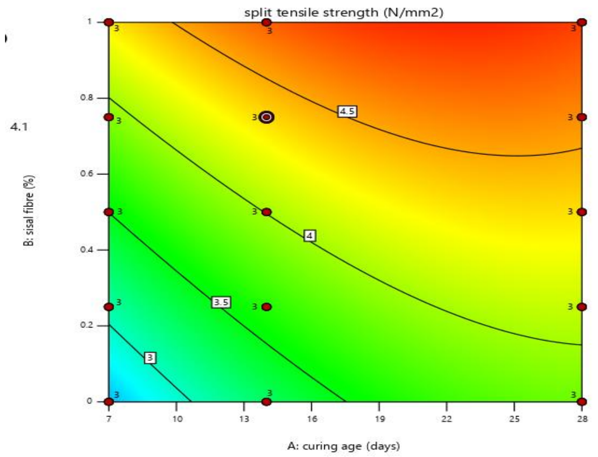


Figure 8: 3D Plot for Compressive Strength of SCC with Sisal Fibre

Figure 9: *2D*plot of compressive strength of SCC with sisal fibre



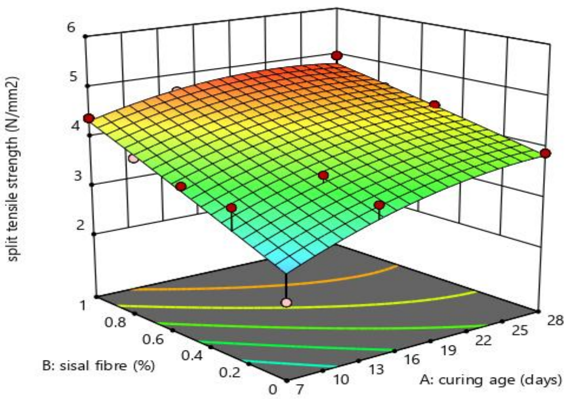
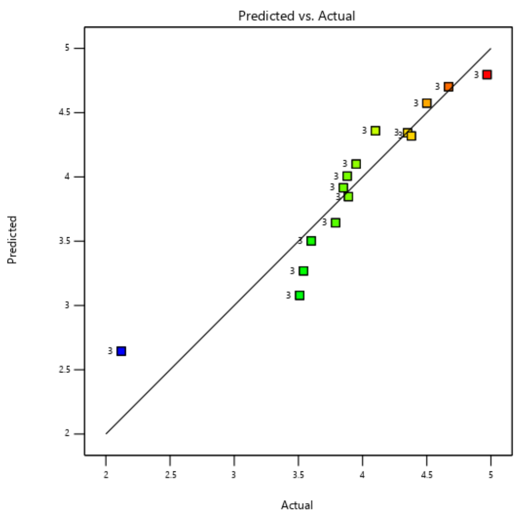


Figure 10: Plot for Split Tensile Strength of SCC with Sisal fibre. Figure 11: Plot for Tensile Strength of SCC with Sisal fibre.

The 2D and 3D plot shows that curing age have a positive influence on compressive strength since it increases significantly with increase in curing age and the sisal fibre content has a negative impact on the compressive strength of the SCC, while the split tensile strength increases with both curing age and sisal fibre content. The combined effect is visible in the smooth rise of the surface, showing that the addition of sisal fibres and longer curing both enhance split tensile strength, though the effect is slightly more moderate compared to compressive strength. The 3D surface plots clearly demonstrate the benefits of optimizing these factors to improve overall concrete performance.

Figure 12 and 13 demonstrates how well the model predicts the actual experimental values. Predicted values (from the statistical model) on the y-axis against the actual values (from experiments) on the x-axis. The closer the points are to the diagonal line; the better the model's predictions match the actual data. The points represent individual data points, and the numbers on the points are likely run numbers or replicate identifiers. If the model is perfect, all the points should fall exactly on the diagonal line (45° line). The closer the points are to this line, the better the model fits the data. In this graph, most points are close to the line, suggesting that the model has predicted compressive strength and split tensile strength quite accurately for most data points. However, there are a few points further from the line, indicating some discrepancy between predicted and actual values in those cases.



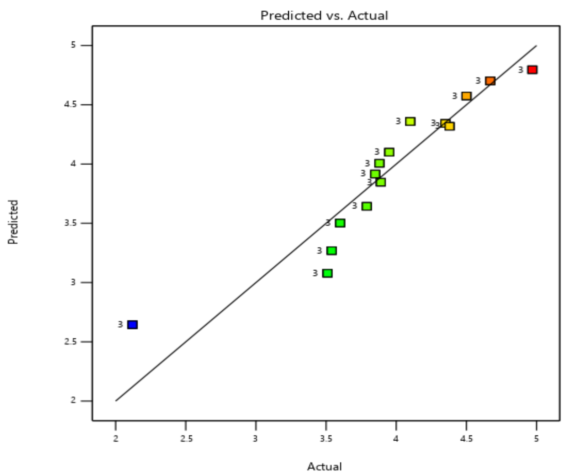


Figure 12 and 13: Plot of predicted against Actual of compressive strength and split tensile strength

3.7 Optimization Result of Self-Compacting Concrete with Sisal Fibre

Table 5 defines the optimization goals and constraints used in the study for optimizing the performance of concrete (compressive strength and split tensile strength) with respect to two key factors: curing age and sisal fibre content. The Curing Age was kept within a specified range (7–28 days) and the Sisal Fibre was maximize within the range of 0 % to 1 %. The goal was to maximize the compressive strength within the provided range (10.6–31 N/mm²) and the Split Tensile Strength was maximized within the range (2.12–4.97 N/mm²). The Lower Limit/Upper Limit columns specify the range of values within which the optimization needs to occur. For instance, curing age ranges from 7 to 28 days, and sisal fibre content ranges from 0 to 1 %. Lower Weight/Upper Weight determines how much emphasis is given to hitting the lower or upper bound during optimization. Both values are set to 1, meaning equal importance is given to staying within the defined range. Importance defines the relative importance of each variable in the optimization process. A value of 3 indicates that all factors and responses (curing age, sisal fibre, compressive strength, and split tensile strength) have equal and moderate importance in the overall optimization.

Table 5: Multi-Objective Optimization Parameters

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: curing age	is in range	7	28	1	1	3
B: sisal fibre	Maximize	0	1	1	1	3
compressive strength	Maximize	10.6	31	1	1	3
split tensile strength	Maximize	2.12	4.97	1	1	3

Table 6 presents the optimization results from the multi-objective optimization process defined. It shows different combinations of curing age, sisal fibre content, and the resulting compressive and split tensile strength, along with a desirability value. The optimization process has found several sets of parameters (curing age and sisal fibre content) that result in varying compressive and split tensile strengths. Most optimal results occur with 28 days of curing age, showing higher strengths with the highest desirability value of 0.523 which occurs for multiple entries, suggesting a balanced optimization between compressive strength, split tensile strength, and sisal fibre content. In the first result (desirability = 0.523), a curing age of 28 days and sisal fibre content of 0.547% yields a compressive strength of 17.313 N/mm² and split tensile strength of 4.387 N/mm². 7-Day Curing: Entries 10 and 11 show results for 7 days of curing, with much lower compressive strength (12.374 N/mm²) but relatively high split tensile strength (4.319 N/mm²), indicating that longer curing is crucial for maximizing compressive strength.

Table 6: Optimization Results of Strength Parameters Considered

Number	curing age	sisal fibre	Compressive strength	Split tensile strength	Desirability	
1	**28.000**	**0.547**	**17.313**	**4.387**	**0.523**	**Selected**
2	28.000	0.550	17.256	4.390	0.523	
3	28.000	0.538	17.447	4.378	0.523	
4	28.000	0.555	17.181	4.395	0.523	
5	28.000	0.521	17.709	4.362	0.523	
6	28.000	0.579	16.838	4.417	0.522	
7	28.000	0.473	18.468	4.317	0.520	
8	28.000	0.441	19.002	4.286	0.517	
9	28.000	0.389	19.914	4.236	0.509	
10	7.000	1.000	12.374	4.319	0.406	
11	7.401	1.000	12.219	4.347	0.396	

4. Conclusions

Based on the above study, the following conclusions can be withdrawn:

I. The materials used in the production of the self-compacting concrete with sisal fibre met the requirement for production of good concrete as specified in the codes used.

II. In the workability test result only the self-compacting concrete with 0 % Sisal fibre content passed the workability specifications, specified by the codes.

III. In the case of the strength properties of the self-compacting concrete, the compressive strength reduces with increase in sisal fibre content, while the split tensile strength increases with increase in sisal fibre content.

IV. The R^2 value for the compressive and split tensile strength of the mathematical model developed are 94.49 % and 88.24 % respectively which are above the specification (80 %).

V. The Optimized value is 0.547 % fibre and 28 days curing age with a compressive strength and split tensile strength of 17.313 N/mm^2 and 4.387 N/mm^2 respectively.

VI. Finally, it was recommended that the use Sisal fibre content should not be more than 0.25 % in the production of lightweight structures.

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