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Variability Analysis of Compressive and Flexural Performance of Coconut Fibre Reinforced Self-Compacting Concrete

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Abstract: Self-compacting concrete (SCC) is a high-performance material that flows freely and consolidates without segregation or bleeding. Though several studies have been carried out on the properties of SCC, none has checked the effectiveness of coconut fibre in SCC. Therefore, this study investigated the effectiveness of incorporating coconut fibre into SCC to improve its strength and toughness. Four mixtures were considered, the first having no inclusion of fibre while the remaining three had coconut fibre inclusions of 0.2%, 0.4%, and 0.6% by weight of cement. The samples were tested for their workability, passing ability compressive and flexural strengths. Analysis of Variance was used to determine if there was any statistical difference between the mean values of the compressive and flexural strengths of the concrete or if the values were similar. The addition of coconut fibre reduced the workability and passing ability of the concrete, but all mixes met the SCC specification. The CFRSCC with 0.2% had the highest compressive and flexural strengths. Only the compressive strength of 0.6% incorporation of fibre significantly differs from the strength of all other fibre incorporation in the SCC. The study concluded that adding 0.2% coconut fibre to SCC can increase its strength. The use of natural fibres like coconut can enhance the properties of concrete and could be an alternative to synthetic fibres, especially in regions where natural fibres are locally available and cost-effective.

1. Introduction

Reinforced concrete structures have been seeing a rise in demand recently because of a surge in building projects. Due to this explosion in construction, concrete reinforcement and formwork are becoming extremely dense and complex; therefore, problems occur due to materials that are not readily available nearby, particular performance characteristics, individual preferences, local expertise, and price [1]. As a consequence of this, Self-Compacting Concrete (SCC), which supplies concrete that is of a higher quality and has a higher degree of durability, gains popularity.

SCC is an innovative form of concrete with outstanding performance that flows readily and consolidates under its weight without segregation or bleeding [2]. It stands for one of the most cutting-edge and exceptional concrete technologies researched and applied over the previous ten years. A significant development in concrete engineering, self-compacting concrete is currently regarded as having better working and performance characteristics [3].

It can be used in a variety of scenarios from bulk strong structures to thin parts. It can also be said to be the most innovative breakthrough in concrete technology over the years and the biggest technological advance. Due to its inherent advantages, SCC will eventually replace conventional vibrated concrete as the preferred type of concrete [4,5].
SCC was created for the first time in Japan in 1986 and was intended to fill difficult-to-access complex geometrical shapes and heavily reinforced formwork without requiring external compaction during the process of pouring [6]
The advantages of Self-Compacting Concrete such as rapid rate of concrete placement and ease of flow around congested reinforcement have made it very reliable in concrete design.
Also, the easy flow ability and proper segregation resistance of SCC provide a high level of homogeneity and uniform concrete strength for concrete construction. SCC is different from popular vibrated concrete in that it has high workability and flows through the congested area under its weight, filling the formwork without segregation of its constituent materials with a void-free structure, and can be placed without vibration [4].
Additionally, SCC has some advantages over vibrated concrete in the areas of sufficient flow ability, good passing and filling abilities, segregation resistance, and stability, all of which are made possible by properly balancing the constituent materials and associated admixtures.
Other advantages of SCC are faster Construction time, noiselessness, and improved surface finishing by eliminating patching [7].
Despite the numerous advantages of SCC, the setback is that it requires more binder, chemical admixture, and cement. To enhance SCC production, research is being done to enhance test procedures such as slump flow, V-funnel, L-box, and J rings, quantitatively assess admixtures, and substitute expensive ingredients with less expensive ones [8].
Superplasticizers and powder content increase workability and cohesiveness in SCC but increase shrinkage due to SCC's thermal expansion. To address these problems, cement content is partially replaced with mineral admixtures and fibres to improve the fresh and hardened properties of SCC [9,10]. Therefore, this study looks into the effect of incorporating coconut fibre in SCC.
Given their low cost and accessibility locally, the recent addition of natural fibres to SCC has been the subject of extensive research in the field of construction materials. These natural fibers were incorporated into concrete to produce materials with improved strength and toughness. Out of all natural fibers, the coconut fibers have performed because of their toughness. Research papers on the suggested topic are reviewed as follows:
Muthusamy et al. [11] Investigated the impact of sisal fibre addition on self-compacting concrete's (SCC) fresh mechanical characteristics and the flexural performance of fibre-reinforced RC beams manufactured from industrial wastes such as fly ash and meta kaolin. The test findings show that FA and MK employ a mineral admixture for making SCC. Additionally, it was made clear that sisal fibre enhanced the mechanical qualities of concrete. The study revealed that when compared to conventional RC beams, fibre-reinforced RC beams had a higher ultimate load. When sisal fibre was introduced, it was discovered that the flexural toughness and ductility of concrete significantly increased. The research was conducted by Kamal et al. [12] to enhance the qualities of reused self-compacting concrete (RSCC) by applying demolition debris as coarse aggregates. Glass fibres were utilized to fulfil the intended objectives, with the content of glass fibre ranging from 0.0 to 0.4%. With the aid of the Slump flow, J-ring, and V-funnel tests, 47 concrete mixtures were assessed. Compressive, tensile, and flexural strength tests were conducted along with density calculations. When compared to the control mix, the glass-fibre containing RSCC mixes had compressive strengths that were 24% and 25% higher than those of the mixes with crushed ceramic and broken red break, respectively.
Şahmaran et al.'s [13] research paper examined the fresh and mechanical properties of fly ash-containing mixtures of fibre-reinforced self-compacting concrete with high-volume fly ash. Half of the concrete by weight was supplanted with fly ash debris. All of the mixtures' slump flow diameters were found to be within an acceptable range of 560-700 mm, and the slump flow time was found to be less than 2.9 seconds.

Fediuk et al. [14] created self-compacting concrete by combining rice husk ash with Portland cement, which was thermally treated under different circumstances. Samples containing 10%, 15%, 20%, and 25% rice husk ash had a bulk density decrease of 3.19, 5.18, 5.58, and 6.37%, respectively. This was caused by the ash's pozzolanic action, which caused the matrix to compact and open porosity networks to be blocked. The end strength of self-compacting concrete including ash was equivalent to standard samples, but an increase in the ash concentration resulted in a drop in the early mechanical characteristics.

Rajesh et al. [15] investigated the structural properties of corroded beams made of self-compacting fibre-reinforced concrete (SCC). Initially, SCC samples were made utilizing polypropylene (PF) and glass-chopped fibres (GF). Fresh qualities such as compressive strength and flexural strength were evaluated. In terms of load capacity, stiffness, ductility, and ultimate energy, fibre-reinforced SCC enhanced the structural performance of the corroded beams.

Sharma et al. [16] studied the effects of glass fibre and carbon fibre on SCC. According to their findings, adding glass and carbon fibre to SCC increases compressive strength, but when more fibres are added, the compressive strength decreases. For compressive strength, 0.8% fibre was found to be the ideal amount, with carbon fibre growing by 13.03% and 18.68 with 0.8% carbon fibre while glass fibre grows by 12.33% and 19.49 at 14 and 28 days, respectively. Carbon fibre costs 4.5% less and glass fibre costs 7% less for SCC. Also, because SCC with fibre addition uses 8–9% less cement in concrete, it is an environmentally friendly choice.

Kavitha et al. [17] investigated how Eco bamboo fibres, which partially replaced cement with GGBS and Alccofine, affected the strength behaviour of FRSCC. Improved split tensile, compressive, and flexural behaviours have all been explored with bamboo fibres. By replacing GGBS and alccofine with bamboo fibres, concrete became significantly more flexure-resistant and had higher flexural strength. Strength increased to as high as 6.1 N/mm^2 after 28 days.

Al-Hadithi et al. [18] investigated the response of PET fibre-infused self-compacting concrete (SCC) slabs to impact stresses. In their research, there were eight SCC mixers with various plastic fibre content ratios (0.25%, 0.50%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75%, and 2.0%). PET fibres have improved the energy absorption capacity and resistance to impact load of slabs incorporating SCC, leading to more uses for this kind of concrete in environmentally friendly structures.

Odeyemi et al. [3] examined how rubber crumb (RC) and polyethylene terephthalate (PET) interacted when used as coarse particles in SCC. SCC was tested for slump flow, slump height, flowability, density, and compressive strength for a target compressive strength of 20 N/mm^2 when granite was replaced by RC and PET at varying percentages of 10, 20, and 30%. The results were all within the EFNAC [19] acceptable range. As RC and PET were added, the concrete's density decreased until it reached a 20% increase, at which point it started to rise. As the percentage incorporation of PET and RC rose, the SCC’s compressive strength increased.

Akinpelu et al.’s [20] study centred on determining the splitting tensile strength of SCC. The splitting tensile strength and compressive strength of similar grades of vibrated concrete (VC) and self-compacting concrete (SCC) were found to be experimentally and analytically related. The analytical study demonstrated that the same analytical model could be used for both types of concrete because there was no statistically significant difference in the results. The experimental results showed that the ratio of the splitting tensile to compressive strengths for VC and SCC decreased with increasing compressive strengths.

None of the reviewed studies checked the effectiveness of coconut fibre in SCC. Therefore, this study aims to evaluate the effectiveness of coconut fibre-reinforced self-compacting concrete (CFRSCC).

2. Materials and Methods

This section shows the materials and tests procedure used in the production of the CFRSCC. CFRSCC mixes were produced using locally available river sand (fine aggregate), coarse aggregate, Coconut Fibre, Stone dust, and superplasticizer (SP). Limestone Portland cement, Dangote brand, of grade 42.5R conforming to BS 8500-2 [21] was used. Coarse aggregate that passed through the 20 mm sieve size was used in the production of the concretes and conforming to ACI Committee 363 [22].

A locally available river sand conforming to ASTM D7928-17 [23] with a maximum size of 4.00 mm was used in the production of the concretes. The high-performance superplasticizer (SP) CONPLAST SP430, a reputable brand based on polycarboxylic ether from Fosroc constructive solutions, was employed. It aids in enhancing and preserving the novel properties of the coconut fibre-reinforced self-compacting concrete.
For this study, brown coconut fibres were employed. It was purchased from local coconut sellers in Ilorin, Nigeria. It was painstakingly removed from the outer layer of the coconut fruit. The fibres were well-cleaned to get rid of any pollutants that were stuck to them, and then they were allowed to air dry for a few days at room temperature. After that, the fibres were trimmed to lengths of about 25 mm. Potable water was used in all the concrete mixes. The same water was used for curing the specimens in conformity with BS EN 12620 [24].
Mix proportions for grade 20 SCC as reported by Akinpelu et al.[20] was adopted for this study. Details of this mix proportion are shown in Table 1.

Table 1 Mix proportion

Materials	Fibre % per weight of Cement	Cement (kg)	Granite dust (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water/ binder	Superplasticizer
SCC 1(20)	0	450	135	960	813	0.5	1.5 L/100 kg of cement
CFSCC 1(20)	0.2	450	135	960	813	0.5	1.5 L/100 kg of cement
CFSCC 2(20)	0.4	450	135	960	813	0.5	1.5 L/100 kg of cement
CFSCC 3(20)	0.6	450	135	960	813	0.5	1.5 L/100 kg of cement

The control mix with no coconut fibre was prepared by mixing fine aggregates, coarse aggregates, cement, water, and superplasticizers. They were mixed properly to ensure uniformity. In the case of coconut fibre-reinforced SCC, the coconut fibres were washed, dried, and cut before being mixed with cementitious materials. There were three CFRSCC mixtures used, each with a fibre content of 0.2, 0.4, and 0.6% by weight of cement respectively.
Analysis of Variance (ANOVA) was used to determine if there was any statistical difference between the mean values of the compressive and flexural strengths of the concrete or if the values were similar. The sample population were the SCC samples which were divided into multiple groups with each group containing varying fibre content. The outcome of ANOVA is the 'F-statistic'. This ratio (F-statistic) shows the difference within and between group variance, which ultimately produces a figure which allows a conclusion that the null hypothesis is supported or rejected. If there is a significant difference between the groups, the null hypothesis is not supported, and the F-ratio will be larger. The dependent variables, i.e., the items being measured that are theorized to be affected by the independent variables, are the compressive and flexural strengths. The independent variables which are the fibre contents are the items being measured that may influence the dependent variable. A null hypothesis (H_0) is obtained when there is no difference between the groups or means. Depending on the result of the ANOVA test, the null hypothesis will either be accepted or rejected. In this case, the null hypothesis is stated as H_0 indicating that there is no difference between the different fibre contents on the compressive and flexural strengths. An alternative hypothesis (H_1) is stated when it is theorized

that there is a difference between groups and means. In this case, the alternative hypothesis is stated as H_1 showing that at least one of the different fibre contents significantly differs in the compressive and flexural strengths. Equation 1 was used in testing the statistics.

$$F = \frac{Mean\ square\ for\ the\ fiber\ content\ (within)}{Mean\ square\ error\ (between)} \quad (1)$$

In deciding the outcome of the statistical analysis, If the p-value of the test statistic is less than 0.05 (significance level), then the null hypothesis of no difference is not supported and therefore rejected. In this scenario, a post hoc test will further be carried out to identify the different factors.

2.1 Test methods

The fresh concrete was evaluated for slump flow and passing ability using a slump cone and an L-box apparatus as specified by EFNARC [19].

In evaluating the mechanical properties of the concrete mixes, 3 cubes of size 100 x 100 x100 mm per sample, and 3 beams of dimensions 100 mm x 100 mm x 300 mm were cast and cured in water for 28 days for each of the concrete mixes.

The concrete's compressive strength was evaluated using a Universal Testing Machine (UTM) of 1,000 kN load capacity, manufactured in India after the moulds were removed and the test specimens were allowed to dry for 48 hours before curing. The specimen was loaded gradually at a rate of 140 kg/cm^2 per minute until it failed. The compressive strength procedure was done as specified by BS EN 12390-3 [25].

The flexural strength specimens underwent two-point loading testing in the UTM to produce a pure bending. After 28 days of curing, the maximum load was noted. Where the specimen breaks along the span determines the modulus of rupture. BS EN 12390-5 [26] was followed for the test.

Both the fresh and mechanical properties were determined at the Department of Civil Engineering, Kwara State University, Malete.

3. Results and Discussions

3.1 Fresh Properties

As shown in Fig. 1, all the CFRSCCs showed a significant decrease in slump flow compared to the one without fibre (0% fibre), and the CFRSCC with 0.2 fibre content has the next highest slump flow compared to the other CFRSCCs considered. The result, therefore, justified the hypothesis that the increase in fibre contents decreased the workability of the fresh concrete. The values range from 600 to 690, and all samples produced slump heights that are within the range of 550 to 750 for the SCC slump height that is prescribed by EFNARC [19].

Fig. 2 shows that all CFRSCCs showed a significant decrease in the L-Box when compared to the CFRSCC with a 0.2 fibre content, which has the second-highest L-Box value among all other CFRSCCs taken into consideration. All CFRSCC mixtures considered exceeded the requirements of EFNARC [19] which necessitates a suitable flow that passes through the obstruction and a self-leveling ratio of at least 0.8 to 1.

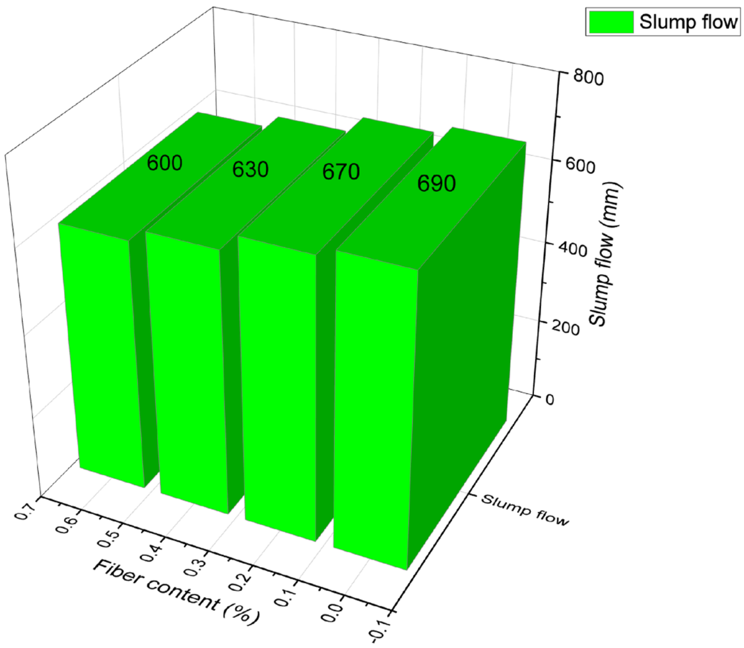

Fig. 1 Slump flow of CFRSCC

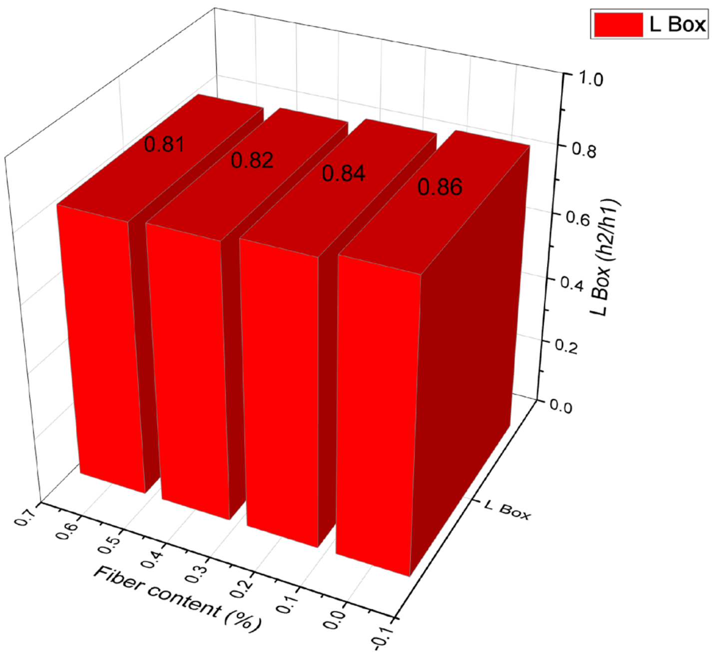

Fig. 2 L-Box of CFRSCC

3.2 Mechanical Properties

In evaluating the mechanical properties of the concrete mixes, the results of the compressive and flexural strengths are shown in Fig. 3.

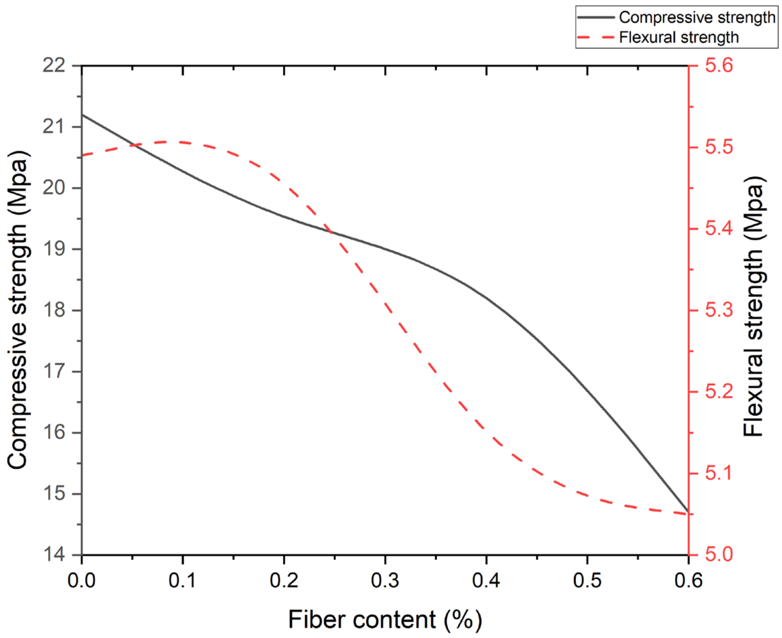

Fig. 3 CFRSCCs' compressive and flexural strengths after 28 days of curing

Fig. 3 depicts the effects of CFRSCCs' compressive and flexural properties at 28 days of curing the concrete. The increase in fibre content reduces the compressive strength of CFRSCC, but the control mixes with 0% coconut fibre showed a noticeable improvement. Comparing various CFRSCCs, the one with 0.2% fibre content has the next-highest compressive strength. When compared to other CFRSCCs and the control mix with 0% fibre content, CFRSCC with a 0.2% fibre content has the maximum flexural strength. This is because the fibres in the 0.2% fibre CFRSCC beams had a bridging effect that kept the beam together after it cracked.
Based on the findings, the CFRSCC with 0.2% fibre exhibits better flexural stiffness than other concrete mixes considered.

3.3 Variability in the compressive and flexural strengths

ANOVA test was used to determine if there is a significant difference in the compressive and Flexural strengths at different mix codes. The result of the test is shown in Table 2.

Table 2 Variability in compressive and flexural strengths

	Test statistic	p-value	Decision
Compressive strength	10.081	0.004*	At least one of the mix codes is significantly different from others
Flexural strength	0.426	0.739	The mix codes are not significantly different from each other

*p-value is significant

Since the test showed that at least one of the mix codes is significantly different from others for the compressive strength, further test is required to identify which of the mix code is significantly different from the other. Tukey's test was employed and presented in Table 3. There are two groupings, with CFSCC3 (20) with 0.6% fibre content being the only mix code in Group 1 while other mix codes are in Group 2. Therefore, only CFSCC3 (20) with 0.6% fibre content is significantly different from other mix codes for compressive strength.

Table 3 The Tukey's test result

Mix code	Fibre Content (%)	1	2
CFSCC3 (20)	0.6	14.7	
CFSCC 2(20)	0.4		18.8
CFSCC 1(20)	0.2		19.3
SCC (20)	0		21.2

4. Conclusion

In this study, coconut fibers (0.2%, 0.4%, and 0.6%) were added to SCC. The results for the coconut fiber reinforced SCC were compared with the control mix design with no Coconut fibre.
The findings were as follows:

i. An increase in coconut fiber contents in SCC decreases the workability of the concrete as the coconut fibre makes a stronger fibre-aggregate interlock and therefore makes it more resistant against SCC flow.

ii. The L-Box result showed the same pattern as the result of slump flow, an increase in fiber contents of SCC reduced the passing-ability of the concrete mix.

iii. The compressive strengths of CFRSCCs decreased with the increase in fiber contents.

iv. CFRSCC with 0.2 % fibre content produced greater compressive strength compared to other CFRSCCs considered.

v. CFRSCC with 0.2% fibre content showed an increase in flexural stiffness compared to other CFRSCCs.

vi. Only the compressive strength of 0.6% incorporation of fibre significantly differs from the strength of all other fibre incorporation in the SCC.

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