IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 22, Issue 3 Ser. 1 (May. – June. 2025), PP 18-26
www.iosrjournals.org

Prediction Of Tensile Strength Of Chopped Carbon Fibre Reinforced Polymer (CCFRP) Concrete

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Abstract
This paper experimentally investigates the workability; split tensile strength of chopped carbon fibre reinforced polymer (CCFRP) concrete and formulation of a prediction model for split tensile strength of CCFRP concrete. The concrete consists of water, Portland cement (PC), river sand (RS), granite chippings (GC) and CCFRP of 10mm length, ranging from 0% - 2.5% by weight of cement to reinforce the concrete. 2 unreinforced, 15 trial, and 15 control mix ratios were designed. For every mix ratio, 3-concrete cylindrical specimens measuring 150 mm in diameter and 300 mm in length were produced, allowed to cure for 7, 14, 21, and 28 days respectively at room temperature in water tanks. Specimens were subjected to split tensile strength test. Results obtained from the trial mix ratios were utilized to develop the regression model for predicting the split tensile strength of CCFRP concrete and the results determined from the control mixes were employed in validating the model. Addition of CCFRP to the concrete decreased the workability of concrete. Split tensile strength of CCFRP concrete increased with increasing fibre content up to optimum fibre content of 1%, with strength value of 8.40N/mm^2 (65.46% improvement) was observed at mix ratio 1:1.5:3.5:0.01 (PC:RS:GC:CCFRP) at water-cement ratio of 0.55. The F-statistic was used to test the model's adequacy at 95% confidence level showed that F-computed (1.1743) was lesser than F-critical (2.4837). In conclusion, the developed model is appropriate for predicting the split tensile strength of CCFRP concrete and the inclusion of CCFRP in concrete production is welcomed in improving the split tensile strength of Portland cement concrete.

Keywords: *Concrete, CCFRP, Workability, Split Tensile Strength, Osadebe Model, Prediction*

Date of Submission: 25-04-2025 Date of Acceptance: 05-05-2025

I. Introduction

The construction industry is facing significant challenges, including the need for more sustainable and resilient construction material (Rajak et al., 2019). Concrete is one of the most commonly used constructional materials, largely due to its characteristics that can be altered to meet the needs of various applications (Najafiyan et al., 2013). Concrete's widespread use is ascribed to its inexpensive and accessible constituents, simple production method, and versatility for construction and infrastructure projects (Brandt, 2008), for this reason, concrete is ideal for a variety of uses. However, concrete's inherent low tensile strength, brittleness, post-cracking capacity, ductility, flexural and impact strength impose limitations on structural design and long-term durability (Rajak et al., 2019; Kizilkanat, 2015; Lee et al., 2016; Plague et al., 2017). Fibres have become more widely used in concrete to enhance pre- and post-cracking behaviour. Concrete has been enhanced in terms of durability and mechanical properties by the use of various fibre kinds and materials. Numerous independent research studies have demonstrated how fibres can enhance the physical, mechanical and durability properties of concrete (Yakhlaf et al., 2013). To reduce structural cracking and increase the lifespan of structures, the addition of fibres reduces the possibility of spalling and scabbing failures, prevents crack propagation, and extends the softening region in the concrete matrix (Li et al., 2021). Among the different types of fibres used in concrete based composites, carbon fibres offer distinct advantages and economical benefit as it is readily available as waste product from the aerospace industry and coal, it is 2 to 5 times more rigid than the other fibres (Tabatabaei et al., 2013). Carbon fibres are relatively new and insufficiently explored admixtures in concrete technology. Carbon fibre is a carbon filament consisting of carbon atoms bound together with polymer resin with the means of heat under certain pressure. Carbon fibre is one kind of non-metallic fibrous material with high strength, high modulus, resistance to high temperature, resistance to acid and alkali corrosion and good conductivity; it possesses fine performance of carbon as well as the flexibility of fibre (Askar et al., 2022;

Chukwu and Cheeseman, 2020; Rajak et al., 2019; Yongxiang, et al., 2009). Carbon fibre is incredibly light and durable and frequently utilized in industries requiring high stiffness (rigidity) and strength-to-weight ratios such as in sporting, underwater equipment, automobiles, aerospace, civil engineering and a expanding number of consumer and technical applications (Rajak et al., 2019; Kudo et al., 2023; Nguyen et al., 2020; Geier et al., 2019). Their potential use in machine foundations, impact resistance structures, blasts shelters, electrical and electronics industries, in thin pre-cast products like roofing elements, tiles, curtain walls, cladding, panels, shaped beam sections, repairing and retrofitting materials are some of their unique advantages. Chopped carbon fibre reinforced polymer (CCFRP) is one of these new materials which are cut from different kinds of carbon fibre roving. It offers superior properties such as high strength-to-weight ratio, high tensile strength, excellent corrosion and abrasion resistance, good conductivity, resilience to high temperatures and the ability to be easily tailored to specific design requirements (Askar et al., 2023; Chukwu and Cheeseman, 2020; Rajak et al., 2019). These unique properties make CCFRP well-suited for use as one of the main solutions to increase tensile, toughness and bending resistance of concrete by inhibiting the initiation, and propagation of cracks (George et al. 2021; Deng, 2020; Safiuddin, 2018).

Askar et al. (2023) experimentally investigated the effects of CCFRP fibre on mechanical properties of concrete. They concluded that the addition of CCFRP significantly reduced workability, 0.25% CCFRP enhanced the early age compressive strength by 17% for normal strength concrete (NSC) and 18% for low strength concrete (LSC) while the 28-day-old samples were enhanced by 6% and 10% for NSC and LSC respectively. NSC and LSC 28-day-old tensile strength were drastically improved by 44% and 17% respectively by the addition of 0.25% CCFRP. As a result, CCFRP concrete has excellent tensile and flexural qualities; this cutting-edge material is highly useful for constructing unique structures including roofing sheets, panels, tiles, and curtain walls.

Mello et al. (2014) carried out a study on carbon fibre reinforced concrete utilizing M30 grade concrete and carbon fibre lengths varying in percentage of carbon fibre content (0.20% to 0.50%). It was revealed that the unreinforced concrete exhibited a tensile strength of 3.75 MPa, a flexural strength of 6.46 MPa, and a compressive strength of 42.8 MPa after 28 days. The addition of carbon fibres improved the strength properties of the concrete, the tensile strength increased by 11%, the flexural strength by 45%, and the compressive strength by 2%.

Prashant *et al*. (2015) worked on incorporating CCFRP into concrete in order to modify and enhanced the final product. They demonstrated that on fibre dose rates of 0.25%, 0.5%, 0.75%, and 1.0% by volume of cement in order to modify and enhance the effects of carbon fibre reinforced concrete, it was revealed that revealed that at 0.25% CCFRP, compressive, tensile and flexural strength values improved by 8.3%, 13.2% and 13.1% respectively. At 0.5% CCFRP, percentage improvement of 12.7%, 23.7% and 29.5% were obtained accordingly. Meanwhile the 0.75% CCFRP concrete gave improvement readings 22.8%, 31.6% and 3.1% correspondingly. Finally, the 1% CCFRP concrete generated compressive, tensile and flexural strength improvement of 38.4%, 42.1% and 52.5% respectively. Therefore, optimum dosage of CCFRP was recorded at 1%.

Kulikova and Sliusar (2022) experimentally investigated the effects of CCFRP on concrete with varying length ranges between 3 and 9 mm, the results revealed a favourable increase of 1.5% and 16% in compressive and flexural strength, respectively.

A significant barrier in the general literature reviews of CCFRP concrete is the narrow range in variation of the carbon fibre contents, which may result in ambiguous findings and the absence of formulated predictive models for strength of CCFRP concrete. This study utilizes 32 distinct design mix ratios with a wide range of carbon fibre variations ranging from 0 – 2.5% and presented a formulated model based on the Osadebe regression model to predict the tensile strength property of CCFRP concrete.

II. Materials And Methods

Materials

The following is a list of the materials used to make CCFRP concrete:

Cement: General purpose 3X 42.5N Grade Portland Limestone cement manufactured by Dangote Nigeria Limited was used in this study. This Portland cement conformed to the requirements of BS EN 2013, BS EN 2016, ASTM C150. Cement was purchased from Ichie Dosco Cont. Agency, a cement dealer company along Alakahia, East-West Road, Port Harcourt, Rivers State, Nigeria. Fig. 1a shows the cement.

Fine aggregate: Fine aggregate (river sharp sand) was used for this study. It was obtained from the New Calabar River, Choba Port Harcourt, Nigeria and was used to produce concrete specimens throughout the experimental phase of this study. It was clean, well graded with a specific gravity of 2.68. It was washed and sundried for two weeks to remove the moisture content which could lead to increase in the water content of the mix. The grading and properties were carried out to the requirements of ASTM C136, ASTM C33, ASTM

C127. The particle size distribution of the fine aggregate as shown in Fig. 3, illustrates that the river sand used was well graded and is classified as zone 2 based on the grading limits for fine aggregates. The maximum size of fine aggregate was 5mm.

Coarse aggregate: Coarse aggregate (granite chippings) was used in this study. It passed through the 25mm sieve and retained on 4.75mm test sieve. This conformed to the specification of ASTM C127, ASTM C33-99a, and ASTM C136. The granite chippings was sourced from Ishiagu, Ivo Local Government Area of Ebonyi state and purchased from a dealer at Obiri-Ikwerre flyover, East-West Road, Port Harcourt, Rivers State, Nigeria. The aggregate was thoroughly washed and sun-dried for two weeks to remove dirts. It was of high quality having maximum of 20mm. The grain size distribution of the aggregate is presented in Fig. 4.

Water: Potable water available in the University of Port Harcourt, Choba campus was used in all the experiments. The water seemed clean, fresh, colourless, odourless, and tasteless. This conformed to the requirements of ASTM C 1602, BS EN 1008.

Chopped Carbon Fibre Reinforced Polymer (CCFRP): CCFRP with short fibre length of 10mm was used as reinforcement in this study as shown in Fig. 1b. The fibre is not discontinuous fibre due to the fibre length more than 1mm. The CCFRP was ordered from Yixing Zhongfu Carbon Fibre Products Co. LTD and has the following properties: filament diameter (6-8 μm), carbon content (≥93%), tensile strength (3530-4200MPa), tensile modulus (230-245GPa), gel content (0.8-1.3%), volume density (1.78g/cm^3), elongation at break (1.82%), moisture content (1≤%), fixed length rate (90%). Table 1 shows the CCFRP properties.

Superplasticizer (Conplast SP430): Conplast SP430 is a sulphonated naphthalene polymer based chemical admixtures, a product of Fosroc. It was purchased from Purechem Manufacturing Limited, Lagos Nigeria. Conplast SP430 was purchased and supplied as a brown solution which instantly disperses in water, with specific gravity of 1.18 at 22^{o}C + 2^{o}C. In this study, Conplast SP430 was added to concrete at a constant dosage of 1.2% by weight of cement. This admixture is in accordance with ASTM C494. Fig. 1d shows the Conplast SP430 superplasticiser and Table 2 shows the properties.

Table 1. CCFRP properties.

Product		chopped carbon fiber with glue
Specification		YD
Inspection item	Unit	Lot average
Filament diameter	μm	6~8
Carbon content	%	≥93
Tensile strength	MPa	3530~4200
Tensile modulus	GPa	230-245
Gel content	%	0.8~1.3
Volume density	g/cm^3	1.76
Elongation at break	%	1.82
Moisture content	%	1≤
Fixed length rate	%	90

Table 2. Conplast SP430 properties.

Appearance	Brown liquid
Specific gravity (BSEN 934-2)	1.18 @ 22°C + 2°C
Water Soluble Chloride (BSEN 934-2)	Nil
Alkali content (BSEN 934-2)	Typically less than 55g Na_2O equivalent/litre of admixture

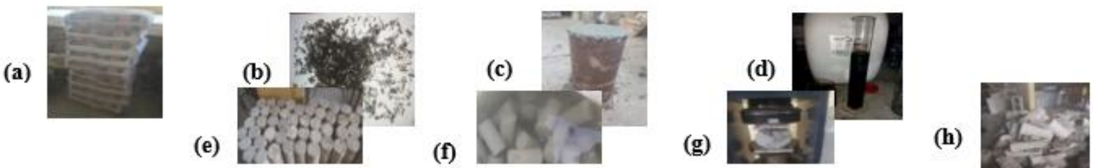

Fig. 1. (a) Dangote 3X 42.5N Portland limestone cement (b) Chopped carbon fibre reinforced polymer (CCFRP) (c) Fresh CCFRP concrete in cylindrical mould (d) Conplast SP 430 superplasticiser (e) Demoulded CCPRP concrete cylindrical specimens (f) CCPRP concrete cylinder specimens in curing tank (g) Split tensile strength test on CCFRP concrete cylindrical specimens (h) Tested CCFRP concrete cylindrical specimens

Method of Study

The main objective of this paper is to study the tensile strength of chopped carbon fibre reinforced (CCFRP) concrete with a wide range of designed fibre contents up to 2.5%. An experimental study is carried out to investigate concrete reinforced with carbon fibre under slump test and split tensile test. The concrete design mix ratios for the trial and control mixes were achieved using Scheffe's mix design procedure, the concrete test specimens were batched, mixed, cast, compacted, demoulded, cured and tested for split tensile strength test for 7, 14, 21 and 28 days. Result from the trial mixes were used for developed the predictive model. The model was used to predict the control mixes and experimental values and predicted values were compared and analysed. The model was validated using F-statistic at 95% confidence level. The research methodology flowchart is presented in Fig. 2.

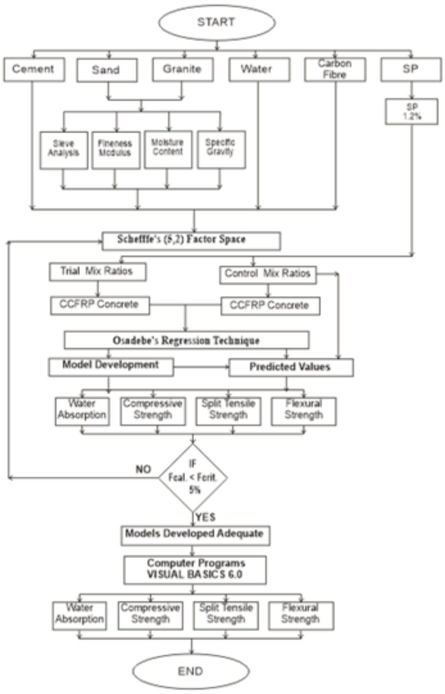

Fig. 2. Research Methodology Flowchart

Design Mix Ratios for Trial and Control Mixes

The concrete design mix ratios were achieved using Scheffe's mix design procedure (Scheffe, 1963) through trial mixes and literature. The method was used to generate mix ratios of the experimental points, for the production of 382 cylinder specimens, these are presented in Table 3 and Table 4 for trial and control mixes respectively.

Table 3. Actual mix design for CCFRP concrete (Trial mix ratios).

Batch label	Responses	Water	Cement	Sand	Granite	CCFRP
TB0	Y_0	0.50	1	1.55	3.63	0.000
TB1	Y_1	0.5	1	1.75	3.01	0.005
TB2	Y_2	0.55	1	1.5	3.5	0.01
TB3	Y_3	0.4	1	1.35	2	0.015
TB4	Y_4	0.6	1	1.5	2.7	0.02
TB5	Y_5	0.45	1	2	3	0.025
TB6	Y_{12}	0.525	1	1.625	2.75	0.0075
TB7	Y_{13}	0.45	1	1.55	3.1	0.01
TB8	Y_{14}	0.55	1	1.625	3.25	0.0125
TB9	Y_{15}	0.475	1	1.875	3.75	0.015
TB10	Y_{23}	0.475	1	1.425	2.35	0.0125
TB11	Y_{24}	0.575	1	1.5	2.5	0.015
TB12	Y_{25}	0.5	1	1.75	3	0.0175
TB13	Y_{34}	0.5	1	1.425	2.85	0.0175
TB14	Y_{35}	0.425	1	1.675	3.35	0.02
TB15	Y_{45}	0.525	1	1.75	3.5	0.0225

Table 4: Actual mix design for CCFRP concrete (Control mix ratios).

Batch label	Responses	Water	Cement	Sand	Granite	CCFRP
CB0	Y0	0.50	1	1.62	3.04	0.00
CB1	Y1	0.5075	1	1.5825	2.915	0.01325
CB2	Y2	0.4975	1	1.5875	2.925	0.01575
CB3	Y3	0.5175	1	1.635	3.02	0.015
CB4	Y4	0.5	1	1.5875	2.925	0.0175
CB5	Y5	0.4875	1	1.65	3.3	0.01625
CB6	Y12	0.475	1	1.65	3.05	0.01375
CB7	Y13	0.52	1	1.52	2.64	0.012
CB8	Y14	0.5125	1	1.6875	2.875	0.0125
CB9	Y15	0.53	1	1.52	2.84	0.014
CB10	Y23	0.5	1	1.62	3.04	0.015
CB11	Y24	0.505	1	1.595	2.89	0.0155
CB12	Y25	0.51	1	1.595	2.99	0.0165
CB13	Y34	0.4825	1	1.6375	3.075	0.015
CB14	Y35	0.475	1	1.7125	3.425	0.02125
CB15	Y45	0.5275	1	1.6625	2.875	0.01625

Osadebe Regression Technique Design Method

According to Osadebe (2011), the response of a five-component concrete mixture can be approximated by a polynomial function given by Eq. (1).

$$Y = \alpha_1 Z_1 + \alpha_2 Z_2 + \alpha_3 Z_3 + \alpha_4 Z_4 + \alpha_5 Z_5 + \alpha_{12} Z_1 Z_2 + \alpha_{1s} Z_1 Z_3 + \alpha_{14} Z_1 Z_4 + \alpha_{15} Z_1 Z_5 + \alpha_{23} Z_2 Z_3 + \alpha_{24} Z_2 Z_4 + \alpha_{25} Z_2 Z_5 + \alpha_{34} Z_3 Z_4 + \alpha_{35} Z_3 Z_5 + \alpha_{45} Z_4 Z_5 \quad (1)$$

Where Y is the response function corresponding to an ith observation point. $Z_i,\ Z_j$ are predictors while α_i *and* α_{ij} are the coefficients of the polynomial function. The polynomial function was used to predict the split tensile property of CCFRP concrete in this study.

CCFRP Concrete Cylinder Production and Testing

A mathematical model based on Osadebe's regression theory was created using fifteen (15) trial mix ratios of three samples each at 28 days. Concrete was batched based on weight. First, a homogenous mixture of river sand and cement was achieved by thorough mixing. After that, the homogenous material of sand and cement was mixed further and granite added. The dry composite of Portland cement, sand and granite was well mixed before water and superplasticizer were added. The CCFRP was then gradually included in such a manner as to uniformly disperse it within the composite in order to achieve a homogenous fresh CCFRP concrete. The fresh concrete was tested for slump and poured into prototype cylinder moulds of diameter (D), 150mm and length (L), 300mm. They were compacted in 3 layers of 35 strokes using a tampering rod, left for 24 hours at room temperature to set, demoulded and allowed to cure by water immersion method for 7, 14, 21 and 28 days.

The split tensile test was carried out on the cured cylinder specimens in according to ASTM C496-96. Concrete cylindrical moulds of diameter (D), 150mm and length (L) of 300mm were used for casting the concrete cylindrical specimens. 384 concrete cylindrical test specimens were produced for 7, 14, 21 and 28 days of curing ages, from the Trial and Control mix ratios and the unreinforced concrete mix ratio samples. The test consists of applying a compressive line load along the opposite generators of a concrete cylinder placed with its axis horizontal between the compressive platens. As a result to the compression loading a fairly uniform tensile stress is developed over nearly 2/3 of the loaded diameter as obtained from an elastic analysis. Three (3) specimens were tested at each curing age for split tensile strength at experimental point after removal from water, and the average split tensile strength value was taken as the split tensile strength of concrete. The concrete cylinder for split tensile strength test was loaded in a way that made the specimen to fail due to induced split tensile stresses in the test specimen as displayed in Fig. 3. The load increased gradually until splitting occurred at a constant rate within the range of 0.140 to 0.350 N/mm^2 per second. The maximum load at failure in compression was recorded. The split tensile strength (f_{st}) is determined using Eq. (2).

$$f_{st} = \frac{2P_f}{\pi DL} \qquad (2)$$

Where, $f_{st} = Split\ Tensile\ strength,\ (\mathrm{N}/mm^2)$; $P_f = Load\ at\ failure,\ (N)$; $L = Height\ of\ the\ cylindrical\ specimen, (mm)$; $D = diameter\ of\ cylindrical\ specimen, (mm)$

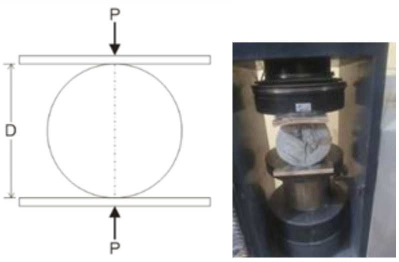

FIG 3

III. Results And Discussion

The result of the sieve analysis test for the fine and coarse aggregates are presented in Fig. 4 and Fig. 5 respectively. The results from the analysis of the river sand, gave a coefficient of uniformity (Cu) value of 7.27 and a coefficient of curvature (Cc) value of 1.02. Therefore, the river sand can be categorized as a well-graded, since Cc=1-3, as stipulated under the Unified Soil Classification System (USCS). The granite chippings recorded a Cu value of 2.88 and a Cc value of 1.35. This also shows that the granite is well graded.

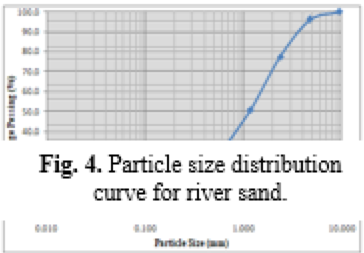

Fig. 4. Particle size distribution curve for river sand.

3.2

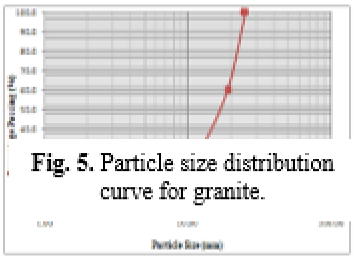

Fig. 5. Particle size distribution curve for granite.

Results of Slump Test on CCFRP Concrete

The result of the slump test on CCFRP concrete clearly show that the slump decreases with increasing CCFRP content in the mix ratios (both for the trial and control mixes) as depicted in Fig. 6 and Fig. 7 respectively. The relationship between slump and fibre content is relatively linear. For the trial mixes, the slump decreased from 27.3% to 87.5% as the CCFRP content increased from 0.5% (TB1) to 2.5% (TB5) when compared with the unreinforced concrete specimen (TB0). Similarly, for the control mixes, the slump decreased from 48.3% to 85.1% w.r.t the unreinforced concrete (CB0) as the CCFRP content increased from 1.2% (CB7) to 2.125% (CC14). These findings are in line with previous studies by Askar et al. (2023) and Garces et al. (2005), who reported that the addition of carbon fibres to concrete leads to an increase in air content and porosity, resulting in a lower slump and reduced workability.

The relationship between slump and the percentage of CCFRP content (V_f) in the mixes can be mathematically expressed as linear regression models, as shown in Eqs. (3) and (4) for the trial mixes and control mixes respectively. The goodness-of-fit for these regression models, as indicated by the R-squared values, were 0.96 and 0.98 respectively tor trial and control mixes. The values demonstrated the strong correlation between CCFRP content and slump behaviour. The results of the slump test on CCFRP concrete clearly highlight the significant impact of fibre content on the workability and dispensability of the fresh concrete mixture. The inverse relationship between CCFRP content and slump value, as well as the linear regression models developed, provide valuable insights into the influence of CCFRP on the rheological properties of the concrete, which is an important consideration in the mix design and implementation of this composite material.

$$\text{Slump (Trial Mixes)} = 83.1506 - 30.8627V_f \quad (3)$$

$$\text{Slump (Control Mixes)} = 87.45917 - 32.7384V_f \quad (4)$$

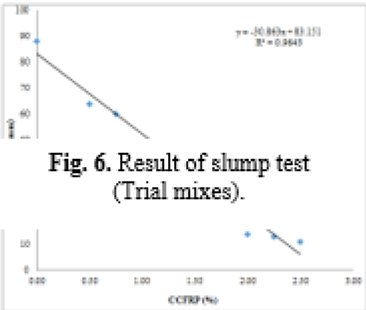

Fig. 6. Result of slump test (Trial mixes).

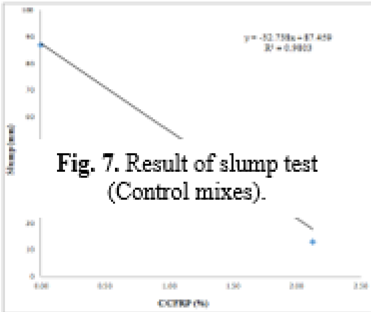

Fig. 7. Result of slump test (Control mixes).

Results of Split Tensile Strength Test

Split tensile strength test result for the trial and control mixes are presented in Fig. 8 and Fig. 9 respectively. For the trial mixes a clear trend was observed. As the CCFRP content in the concrete mix increased, the split tensile strength also increased. At 0% CCFRP content (TY0), the split tensile strength was 2.90 N/mm^2. However, with the addition of CCFRP, the split tensile strength steadily rose, reaching a maximum value of 8.40 N/mm^2 at 1% CCFRP content (TY2). This represents an increment of about 65.46% in split tensile strength compared to the unreinforced concrete mix (TY0). The results corroborate findings from previous studies, such as the work by Yongxiang et al. (2009), Askar et al. (2023) and Sulyman (2016), which showed that the incorporation of carbon fibres can significantly improve the split tensile strength property of concrete. The enhanced performance is attributed to the ability of the carbon fibres to bridge cracks, arrest crack propagation, and enhance the post-cracking behaviour of the concrete matrix (Plague et al., 2017).

Interestingly, the graph also suggested that after reaching the optimal 1% CCFRP content, further increase in fibre dosage did not yield any significant improvements in split tensile strength. This indicates that there is an upper limit to the beneficial effects of CCFRP on split tensile performance (Askar et al., 2023), likely due to factors such as fibre clumping, reduced workability (Askar et al., 2023), and increased porosity at higher fibre contents. The result presented in Fig. 9 for the control mixes show a very similar trend to the trial mixes as in Fig. 8. The split tensile strength increased steadily with CCFRP content, from 2.90 N/mm^2 at 0% CCFRP content (CY0), reaching a maximum of 7.90 N/mm^2 at 1.2% CCFRP (CY7).

Beyond this point, the split tensile strength plateaued and slightly decreased with further increase in CCFRP contents. This corroborates the findings from the trial mixes and suggests that 1-1.2% is the optimal CCFRP content range for maximizing the split tensile performance of this type of concrete, which is in line with observations made by Prashant et al. (2015), Askar et al. (2023) and Kudyakov et al. (2014). The consistency in the results between the trial and control mixes provides confidence in the reliability and reproducibility of the experimental findings. The strong correlation between CCFRP content and split tensile strength demonstrated in both figures highlights the effectiveness of using CCFRP as a reinforcement material to enhance the split tensile properties of concrete, which is in line with the observations made in previous studies cited in the references (Prashant et al., 2015); Askar et al., 2023; Kudyakov et al., 2014).

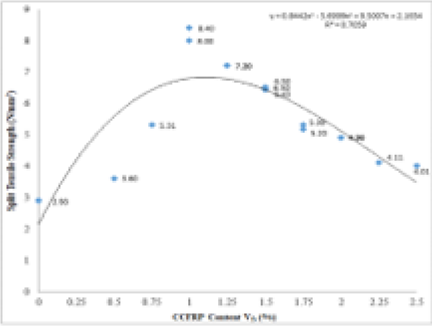

Fig. 8. Split tensile strength vs. CCFRP content V_f (%) at 28 days. (Trial mixes)

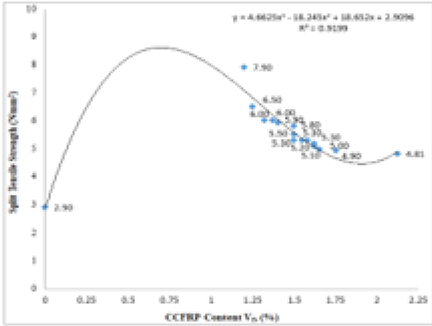

Fig. 9. Flexural strength vs. CCFRP content V_f (%) at 28 days. (Control mixes)

Results of Experimental and Predicted Values and Model Validation

The Osadebe's mathematical model was used to predict the split tensile strength. The predicted values were compared with their control experimental values and the variations were tested for validity. The predicted and the experimental values were tested for adequacy using F-statistic at 5% significance level. The chart for the split tensile strength showing experimental values vs. predicted values is presented in Fig. 10. The result of split tensile strength F-statistic values, for F-computed and F-critical show that the calculated F-value is 1.1743 and this was less than the critical value of 2.4837 as shown in Table 5 using MS Excel data analysis. This proves that the experimental and predicted values coincide at all the experimental points for the control readings, and the model is adequate to predict the split tensile strength of CCFRP concrete. Therefore, the null hypothesis was accepted for the split tensile strength model developed showing that the model is adequate for predicting the split tensile strength of CCFRP concrete. The coefficients of split tensile strength model are presented in Eq. (5) and the obtained coefficient values are now substituted into Eq. (1) to yield the predictive model for the split tensile strength as expressed in by Eq. (6).

$$\alpha_1 = 1064.40, \alpha_2 = 2275.69, \alpha_3 = -962.73, \alpha_4 = -171.97, \alpha_5 = -315052.01, \alpha_{12} = -4683.09Z_1Z_2, \alpha_{13} = 969.64, \alpha_{14} = -12386.55, \alpha_{15} = 288916.5, \alpha_{23} = -3126.48, \alpha_{24} = -2090.05Z_2Z_4, \alpha_{25} = 269032.90, \alpha_{34} = 2152.96, \alpha_{35} = 391965.87, \alpha_{45} = 293164.34 \quad (5)$$

$$F_{st} = 1064.40Z_1 + 2275.69Z_2 - 962.73Z_3 - 171.97Z_4 - 315052.01Z_5 - 4683.09Z_1Z_2 + 969.64Z_1Z_3 - 1176.34Z_1Z_4 + 288916.56Z_1Z_5 - 3126.48Z_2Z_3 - 2090.05Z_2Z_4 + 269032.90Z_2Z_5 + 2152.96Z_3Z_4 + 391965.87Z_3Z_5 + 293164.34Z_4Z_5 \quad (6)$$

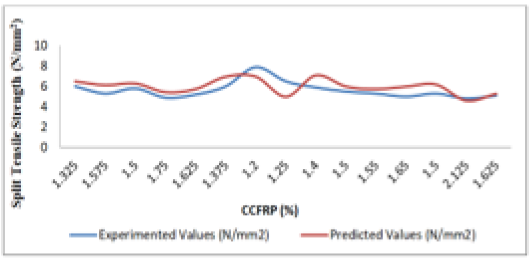

Table 5. F-test results for experimental and predicted split tensile strength

	Experimental Values	Predicted Values
Mean	5.6345	5.9905
Variance	0.6214	0.5291
Observations	15	15
df	14	14
F	1.1743	
P(F<=f) one-tail	0.3840	
F Critical one-tail	2.4837	

IV. Conclusions

(i) When carbon fibre is added to concrete, it became less workable, more difficult to fully compact, and took longer to mix, due to the fact that the water demand to wet the constituent materials increased due to increased surface area by the CCFRP.

(ii) Split tensile strength of CCFRP concrete increased with an increase of fibre content up to a certain percentage, after which increasing fibre content becomes unbeneficial. In this study, this optimum fibre content is found to be 1% with strength effectiveness 65.46 percent.

(iii) The relationship between split tensile strength and fibre content is a third-degree equation. Split tensile strength increased and then reached a maximum strength value of 8.40N/mm^2 at 1% CCFRP content.

(iv) Optimum mix ratio is 1:1.5:3.5:0.01 (PC:RS:GC:CCFRP) at water-cement ratio of 0.55.

(v) The predicted values of split tensile strength of CCFRP concrete were tested for adequacy at 5% level of significance using F-statistic test, the results showed that the calculated F-value was 1.1743, which is less than the critical value (2.4837), showing that the experimental and predicted values are found to coincide at all the experimental points and the model is adequate to predict the split tensile strength of CCFRP concrete.

(vi) The addition of CCFRP in concrete production is very adequate in advancing the split tensile strength of Portland cement concrete.

V. Recommendations

The study recommend the determination of an optimum water reducer admixture that will proffer solution to the loss in slump experienced as fibre content increased, in the production of CCFRP concrete. Further studies are recommended to cover in the area of scanning electron microscopy (SEM) analysis in order to establish the correlation between CCFRP dispersion and its strength properties.

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