ORIGINAL PAPER

AnchorageBond Strength Characteristics of Lateritic Concrete with Laterite Aggregates and Palm Kernel Fibres

Authors' contributions

The work was carried out in collaboration among all authors. They all contributed to the research, preparation of the manuscript, read and approved it.

ABSTRACT

Globally, sources of natural aggregate such as sand and quarry dust as fine aggregate, and crushed granite, sandstone, dolomite and basalt as coarse aggregate for concrete are fast getting depleted or exhausted. There is therefore the need to look for alternative sources to replace them. Laterite is abundant in tropical regions of the world and is a potential alternative to conventional concrete aggregates. Palm kernel fibre is also a natural and renewable material that is found to be good fibre reinforcement to improve cracking resistance of concrete. This study assessed the anchorage bond, compressive and tensilestrength properties of concrete using lateritic aggregates mixed with palm kernel fibre(PKF). The compressive, bond and tensile (split cylinder and modulus of rupture) strengths of lateritic concrete were evaluated experimentally through crushing, tensile and anchorage bond tests. The same mix for characteristic strength of 25N/mm^2 concrete, the compressive strength was found to be 7.42N/mm^2 for lateritic concrete without PKF representing 29.68% of the 25N/mm^2 concrete strength. The addition of palm kernel fibre to the lateritic concrete further decreased the compressive strength of the resulting concrete with increasing PKF to 1.90N/mm^2 at 20% palm kernel fibre, causing 74.34% reduction in the compressive strength. The rate of reduction of the compressive strength was sharp initially for small amounts of the palm kernel fibre but approached a constant value at 15% and 20% additions of palm kernel fibre. The tensile strength was 9.59% of the compressive strength showing a similar relationship with the compressive strength of conventional concrete. Also bond strength showed decreasing strength with increasing PKF addition except that the reduction was gradual compared to the compressive strength. Thus 2.31N/mm^2, 2.04N/mm^2, 2.18N/mm^2, 1.87N/mm^2 and 1.27N/mm^2 bond strength for 0%, 5%, 10%, 15% and 20% PKF addition respectively. A pull-out bond failure mechanism was observed to occur at or around the middle of the test discontinuous bar specimens while modulus of rupture observed to correlate with the bond strength value representing 84.79% of the bond strength of the 0% PKF specimen.

Keywords: Lateritic concrete, palm kernel fibre, compressive strength, bond strength, split tensile strength, modulus of rupture.

1.0 INTRODUCTION

Laterite remains one of the widely distributed aggregate types around the world with prevalence in Southeast Asia, South America, Australia, Caribbean and Africa. In Africa, it is most abundant in Sub-Saharan region in countries like Nigeria, Cameroon and Ghana *(Gidigasu, 1976)*. It is one of the most used natural materials across the globe which finds its application in many sectors of human activities such as the production of concrete *(Gidigasu, 1976)*. Lateritic concrete is a type of concrete made from laterite aggregate.The use of lateritic concrete (LATCON) has become increasingly popular in recent years due to the availability of laterite, its low cost and also sustainable properties (Ghana Institution of surveyors, 2023). According to Shuaibu et al., laterite has been employed in different areas of construction such as building foundations, road construction, bridges and culverts, pavements and drainage systems. Its production involves mixing the various materials in proportions to achieve desirable characteristics such as strength, workability and durability. LATCON is different from normal aggregate concrete in terms of its composition and properties. While normal aggregate concrete uses the combination of aggregates (such as gravel or crushed rock), sand, cement and water, lateritic concrete replaces the traditional aggregates with laterite soil aggregates. In terms of properties, lateritic concrete is known for its durability, high resistance to weathering and its high permeability. Nonetheless, it has been found to have a relatively lower strength compared to normal aggregate concrete *(Shuaibu et al., 2015*).

Palm kernel fibre is a natural fibre obtained from the kernel or seed of palm trees.It is a versatile material that has many uses in various household and manufacturing industries. One of the primary uses of palm fibre is in the production of ropes, mats, and other woven products. The strength of the fibre and its durability makes it an ideal material for these applications. Since it is a sustainable and eco-friendly material it is used in many practical applications across various industries such as in the production of biofuels where it can be processed into pellets or briquettes and used as a renewable energy source. Palm fibre possesses unique physical and chemical properties which are useful in various ways. It has been applied as fibre reinforcement to control cracking and shrinkage on concrete (Kankam, 1994, 1997, 1999).

The key strength properties of concrete are its compressive strength, tensile strength, flexural strength and bond strength *(Neville, 2011)*. Several studies have been undertaken to investigate the strength characteristics of different LATCON types and have made findings about their strength properties.*Akpokodje et al. (2021)* in an investigation conducted found that although the compressive strength of lateritic concrete is comparable with traditional concrete, it possesses relatively lower compressive strength. Another study by *Tsado et al. (2013)* determined the effect of using different types of aggregates on the compressive strength of lateritic concrete. The results revealed that using crushed granite as a coarse aggregate resulted in higher compressive strength compared to using laterite as a coarse aggregate. As an effort to provide an extensive knowledge on lateritic concrete, this current study was designed to assess theanchorage bond, tensile and compressive strength properties of lateritic concrete made with laterite aggregates and mixed with palm kernel fibre (PKF) reinforcement to improve cracking resistance.The strength properties of concrete are a crucial material property in structural engineering because they directly affect the performance and safety of structures (*Kenzie, 2004*). The compressive, tensile and flexural stresses, and the ability of the concrete to bond with reinforcement bars or other surfaces, which is a necessity for loads transfer between different structural components depends on the strength components of the concrete.

2.0 MATERIALS AND METHODS

2.1 Materials

Concrete for the tests was prepared using ordinary Portland cement (Class CEM 42.5R), sieved laterite soil as fine aggregates (nominal size range of 0.075mm – 3.35mm), sieved laterite soil aggregates as coarse aggregates (nominal size range of 6.7mm – 14mm) and palm kernel fibre (PKF). All the materials (fig-1(b)) used were locally obtained around the Kumasi- Ayeduase enclave in Ghana. Potable water was used for mixing the concrete.

(a) **(b)**

Fig-1: (a) Laterite soil (b) Cement, Fine aggregates, Coarse aggregates and Palm kernel fibre

2.2 Preparation of Materials

(a) Aggregates

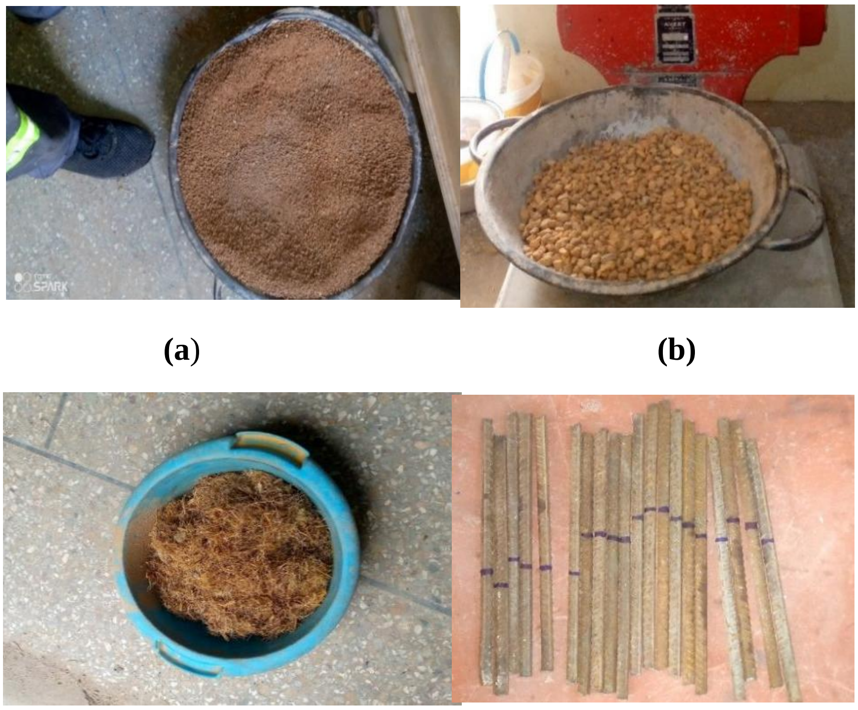
A bulk some of the laterite soil (fig-1(a)) was batched and dried and subsequently sieved through standard sieve sizes for the fine aggregates and coarse aggregates. In order to depict standard size ranges of sand for concrete works, the fine aggregates (fig-2(a)) portion was obtained by sieving through sieve sizes 75 microns and 3.35mm sieves. Thus the fine aggregates for the mix had sizes between 0.075mm and 3.35mm. On the other hand, coarse aggregates (fig-2(b)) used had sizes between 6.7mm and 14mm. This implies that they were obtained by sieving the laterite sample through 14mm and 6.7mm sieves. It can be stated hence from the above that, aggregate sizes between 3.35mm and 6.7mm and also sizes above 14mm did not form part of the concrete mix.

(b) Palm Kernel Fibre

PKF (fig-2(c)) used in the study was obtained from local food restaurants around the Kwame Nkrumah University of Science and Technology, Kumasi campus. The fibres were collected in bulk and soaked in boiling water for 30 minutes to remove and displace the oil content. This was done for several times until no or very little smidgen of oil could be traced and spread out under the scotching sun for complete drying. The fibres were then treated with 4% Sodium Hydroxide (NaOH) solution to enhance their binding property, and dried thoroughly(Sayakulu and Soloi, 2022). The dried PKF was separated and cut into tiny pieces averaging a length of about 5mm and average diameters of 0.5mm before being used for a mix.

(c) Steel Reinforcement Rods

Deformed ribbed reinforcing bars (fig-2(d)) of size 11mm were used for the bond strength study. Deformed ribbed reinforcing bars are well known to achieve stronger bonding with concrete than smooth rebars. The rebars were cut into smaller pieces of 25cm long and wiped with a cotton rag to remove dirt/dust and rust particles before use in order to enhance bond.



(a) **(b)**

(c) **(d)**

Fig-2: (a) Fine aggregates (b) Coarse aggregates (c) PKF (d) Steel reinforcement

2.3 Study Variables

With reference to the primary objective of the research, the experimental procedure involved the use of one concrete type, thus, ordinary lateritic concrete which has only laterite as its aggregate components. The mix ratio was 1:2:4 with water/cement ratio of about 0.45which for conventional aggregate concrete has a target strength of 25N/mm². Hence, a strength of 25N/mm² was therefore used as reference strength of conventional concrete for comparative analysis with the lateritic concrete. The PKF added was in varying quantities relative to the amount of cement as follows: 0%, 5%, 10%, 15% and 20% of the required cement amount for each given volumetric mix. Consequently, a concrete with identification CS-PKF-000 means 'concrete specimen with PKF content of 0%' and CS-PKF-005 would mean 'concrete specimen with 5% PKF'. The amounts of the constituent materials of the concrete; the cement, fine aggregates and coarse aggregates were maintained constant in all mixes. From these, a total of 12 concrete mixes were prepared. The water-cement ratio (w/c) used was 0.98 and was maintained constant for all concrete mixes obtain workable mixes. For conventional concrete, a w/c ratio 0.98 would be regarded excessive and would result in reduced compressive strength. However, the laterite used contained high fine particles content (about 6.9% from Table-1) passing 0.075mm standard sieve. The fine and PKF particles required more water in order to produce a workable concrete mix and hence the high w/c ratio.

2.4 Mix Design, Specimens Preparation and Curing

The production of the concrete mix was in accordance with the British Standards BS EN 12390-1 (2000) and other related codes of practices and specifications that are used in Ghana (GS 1207:2018; IS 10262:2009). The amounts of PKF for different mixes were determined as a percentage of the cement volume. PKF amounts of varying percentages of 0%, 5%, 10%, 15% and 20% of the cement proportion were used for all test. The inner surfaces of the moulds were lubricated with car engine oil to facilitate easy demoulding process after casting in order to ensure the desired shape of the cubes. The required amounts of materials (cement, fine aggregates, coarse aggregates and water) were batched and weighed using the weighing balance. Batched samples were carefully poured into a dry large concrete mixing pan and mixed thoroughly using a shovel and hand trowel to form a uniform paste. The weighed amount of water was added and mixed to form a workable concrete paste. Slump test was conducted to obtain the workability of the lateritic concrete. Cube moulds were filled with the concrete in three layers using a hand trowel for which each layer was tamped 25 times with a tamping rod to ensure adequate compaction of the concrete in the cubes. The surfaces of the moulds were dressed using the hand trowel and the cast cubes were left over for 24 hours after which demoulding was done. Cubes after being demoulded were cured in a water for 28 days (at a temperature 23±2°C) before testing

2.5 Testing methods

2.5.1 Compressive strength

The compressive strength test was conducted in accordance with BS EN 12390-3 standard method for testing concrete compressive strength. For the purposes of this research, the full strength, thus the 28th day compressive strength of the lateritic concrete was used for analysis. The specimens were removed from the water bath and wiped of excess water from the surface and allowed to dry. The dimensions and the masses of the specimens were taken using a meter rule and weighing balance respectively. This was necessary to determine the cross sectional area on which the compressive load was applied. The masses recorded were used for determining the density of the lateritic concrete. The bearing surface of the testing machine on which the specimen was placed was cleaned to ensure a smooth surface was provided. In a test for a specimen, the specimen was placed centrally on the base plate in such a manner that the compressive load was applied to opposite sides of the specimen. The base-plate on which the specimen sat was moved gently to contact the top surface plate. The load was then applied to the point of failure at the rate of 50mm per minute and the maximum load was recorded. The compressive strength was determined as the maximum load per unit cross sectional area of bearing surface.

2.5.2 Bond strength

The double pull-out test was used to determine the bond strength. The test was conducted in accordance with ASTM 2015-E488-15 standard method on concrete prisms of dimensions 100mm×100mm×300mm. Discontinuous steel bars of diameter 11mm and length 25cm (each) were used. The bars were inserted centrally through the opposite sides of the prisms to meet at the centre which was 150mm from each end of the prism, to simulate anchorage bond type of test. The prisms after 28 days of curing were removed from the water bath, cleaned, dried and painted with emulsion paint. The purpose of the painting was for easy identification of cracks that would be developed at failure points when the pull-out force was applied. The jaws of the machine were adjusted to grip the reinforcing bars firmly. A pull-out force was then applied to pull the reinforcing bars at opposite ends until a point of failure where cracks developed. The maximum load was recorded and used to determine the bond stress. The bond stress f_b was calculated using the following equation:

$$f_b = \frac{Pu}{\pi DL} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where; f_b= bond stress (N/mm²)

P_u= Maximum load (N)

D= Diameter of the reinforcing bar (D)

L= embedment length of bar =150mm.

2.5.3 Split Tensile Strength

The split tensile test was conducted according to the BS EN 12390-6 test method on cylindrical specimen of diameter 100mm and height 300mm. A brass metal cage for containing the specimen was arranged and the specimen placed for testing. The arrangement was such that the cylinder until applied load was centrally distributed along the length of the cylinder. Load was then applied to the point of failure where the concrete splits in tension. The split tensile strength was calculated using equation 2:

$$f_{spt} = \frac{2P}{\pi LD} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where f_{spt}= splitting tensile strength (N/mm²); P= maximum applied load(N); L= Length of test cylinder (mm); and D= diameter of specimen(mm).

2.5.4 Modulus of Rupture

This is also referred to as the flexural tensile strength test. It was assessed on control beams of size 100mm×100mm× 500mm as recommended by the BS 12390-1. Specimens were marked out into sections in order to locate the centre of the beam. Metal strips were supported on the metal plates and the specimen placed for testing. The metal strips served as simply supported ends to the specimen. The specimen was subjected to single central point loading in accordance with the BS EN 12390-5 using the Universal Flexural Testing Machine. At the point of failure, the beam specimen broke into two halves. The maximum load at the failure region was recorded as the failure load. The modulus of rupture was determined as in equation 3:

$$f_{ct} = \frac{3PL}{2bd^2} \quad \text{...(3)}$$

where f_{ct}= flexural tensile strength of lateritic concrete specimen (N/mm^2); P = maximum appliedload (N), L = span of the test beam (mm), b is the width(mm) and d is the depth of the cross section of the beam (mm).

3.0 RESULTS AND DISCUSSIONS

From Fig-3 and Table-1, the gradation results indicated that the laterite soil was well graded. The laterite sample therefore passed gradation requirements for producing a quality LATCON. Well graded aggregates are essential for producing high-quality concrete that is strong, durable, and easy to work with.

Table 1-Particle size distribution of the Laterite soil

Sieve Size(mm)	Weight Retained (g)	Percentage retained (%)	Cumulative Percentage retained(%)	Percentage Finer(%)
37.5	0	0	0.00	100.00
25.4	73	7.3	7.30	92.70
19	33	3.3	10.60	89.40
14	35	3.5	14.10	85.90
10	58	5.8	19.90	80.10
6.7	171	17.1	37.00	63.00
4.75	117	11.7	48.70	51.30
2	228	22.8	71.50	28.50
1	109	10.9	82.40	17.60
0.6	53	5.3	87.70	12.30
0.425	23	2.3	90.00	10.00
0.3	13	1.3	91.30	8.70
0.075	18	1.8	93.10	6.90
Pan	69	6.9	100.00	0.00
TOTAL:	1000			

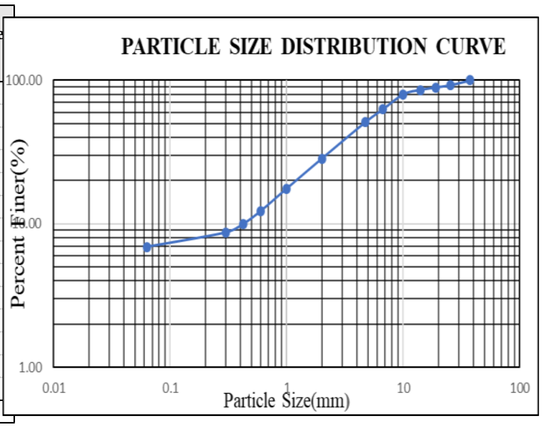


Figure-3: Particle Size Distribution of the Laterite

3.1 Slump

The general range of slump values for the different mixes fell within 10mm – 15mm for w/c ratio of 0.98. This range describes a stiff concrete. Despite the low slump values, the concrete was workable for use. This is similar to what *Ogunbode and Apreh. (2012)* found that LATCON has very good workability. The values however decreased as the PKF content increased. This is attributed to the fact that PKF absorbs part of the mixing water used *(Ikpambese et al., 2016)* resulting in stiffer concrete being produced. Also 0.98 w/c ratio conventionally is very high for normal aggregate concrete mixes and indicates the use of high amount of water which eventually results in flowable concrete. However, this was not the case and this appears to be a clear distinction between LATCON and normal aggregate concrete. The same w/c may not directly apply for the same workability in producing the two concretes. The laterite particles have high water affinity than conventional fine and coarse aggregates.

3.2 Density

The density of the lateritic concrete ranged from 2.14 g/cm^3 to 2.5g/cm^3. It was seen that irrespective of the amount of the addition of the PKF, it did not have significant effect on the density. There was little variation between the density of the control specimens and the densities of the specimens containing the PKF. At 20% of PKF addition, the density obtained slightly approximated the value for the control specimen. This range is similar to the typical range of values for conventional concrete which is 2.3 g/cm^3-2.5g/cm^3. This signifies that LATCON although may not share some similar properties with conventional concrete, the density of the two concrete types may still show the same trend. Nonetheless, how PKF would affect the density of conventional concrete has not been established here.

3.3 Compressive strength

The compressive strength of the control specimen was 7.42 N/mm^2. This represented 29.68% of the target strength for conventional concrete for the mix ratio. Aggregates of laterite soils are smooth rounded rather than angular and rough as can be described in crushed rock aggregates. Smooth, rounded particles slide over each other more easily than rough and angular particles causing a weaker bond between the cement paste and the aggregates which consequently reduces the strength. This is similar to *Tsado et al., (2013)* findings in a study of the structural strengths of laterized concrete. As discovered by the author, the compressive strength decreased with increase in laterite aggregates as replacement for crushed rock aggregates. From the ongoing discussion, for LATCON made with only laterite aggregates, the strength is expected to be lower than LATCON which is produced from partial usage of laterite soil as coarse aggregates. The low compressive strength obtained is therefore tantamount to the properties of the laterite aggregates. Furthermore, the relatively high w/c of 0.98 to achieve workability of lateritic concrete would lead to much reduced strength compared with conventional concrete with low w/c ratio.

The compressive strength results for varying amounts of PKF were 7.421 N/mm^2,6.552N/mm^2,2.752N/mm^2,1.932N/mm^2 and 1.904 N/mm^2 for PKF contents of 0%, 5%,10%,15% and 20% respectively. The specimen with 20% of PKF had the lowest compressive strength, 1.904 N/mm^2. This implies that specimens with PKF were easily compressed under the applied load. The fibres interfere with bonding in the concrete matrix where they act as stress concentration points and weakens the strength of the concrete. It was also observed that, the compressive strength decreased with increasing PKF (fig-4 and Table-2). At 0%, and 20%, the compressive strength was 7.421 N/mm^2 and 1.904 N/mm^2 respectively. This represented 74.34% reduction in the compressive strength when 20% PKF was added. However, for 15% and 20% additions of the PKF, the compressive strength approached a constant value around 1.9 N/mm^2. This implies that further additions from 20% may not cause a significant reduction the compressive strength. At 5% PKF the compressive strength reduced to 6.55N/mm^2 from the control concrete of 7.421N/mm^2.

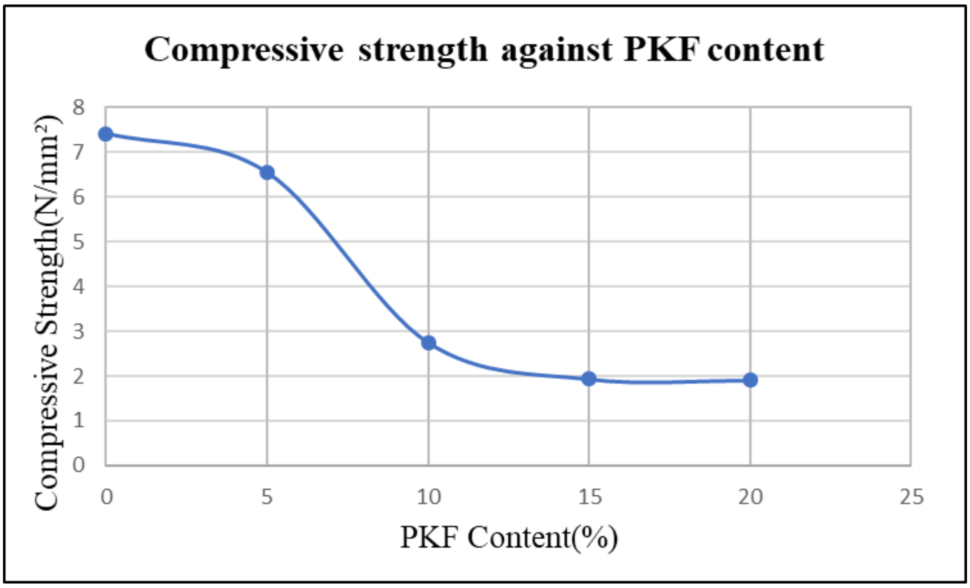


Fig-4 : Variation of compressive strength with PKF Content

3.4 Bond strength

The bond strength of the control specimen was 2.312 N/mm² (Table-2). This represented 31% of its corresponding compressive strength for the same mix ratio. Lateritic aggregates contain clay minerals *(Gidigasu, 1976)* which can reduce the ability of the laterite aggregate to bond with the cement and the steel rod. Moreover, aggregates of laterite are softer and porous making them weak in bonding. The round and smooth surface nature of lateritic aggregates results in weak interlocking between the concrete and steel bars.

3.4.1 Effect of the PKF

The results for the bond strength are shown in Table-2. The bond strength values were 2.31N/mm²,2.04N/mm²,2.18N/mm²,1.87N/mm² and 1.27N/mm² for the PKF contents of 0%, 5%, 10%, 15% and 20% respectively. The bond strength was highest for the control specimens and generally decreased with increase in the addition of the PKF (fig-5 and Table-2). At 0%, the bond strength was 2.31N/mm² and the value decreased to1.27N/mm² upon addition of 20% of PKF. This represents 45% reduction in the bond strength. The rate of reduction also generally increased with increasing PKF content. The bond strength reduced to 12%, 14% and 32% for 5%, 15% and 20% respectively additions of the PKF contents. The general trend can be traced to the change in the mechanical properties of the LATCON as different amounts of PKF are introduced. The PKF has high content of ash *(Ikpambese et al., 2016*)which reduces the bonding characteristics of the concrete and the steel bars.

Table-2: Computations for the bond strength

Prism Identification	PKF Content (%)	Effective embedment depth of rebars, L(mm)	Failure Load,Pu(N)	Idealized area of contact (mm²)	Bond Strength fb,(N/mm²)	Mean Bond Strength fb,(N/mm²)
CS1-PKF-000	0	131	11034	4528.86	2.436	
CS2-PKF-000	0	140	10584	4840.00	2.187	2.312
CS1-PKF-005	5	140	7833	4840.00	1.618	
CS2-PKF-005	5	130	11058	4494.29	2.460	2.039
CS1-PKF-010	10	132	10060	4563.43	2.204	
CS2-PKF-010	10	125	9344	4321.43	2.162	2.183
CS1-PKF-015	15	130	10019	4494.29	2.229	
CS2-PKF-015	15	139	7233	4805.43	1.505	1.867
CS1-PKF-020	20	138	5229	4770.86	1.096	
CS2-PKF-020	20	130	6514	4494.29	1.449	1.273

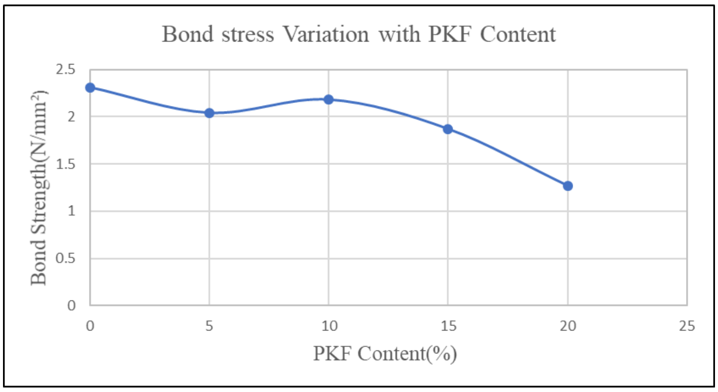


Fig-5: Variation of Bond stress with PKF content

3.4.2 Bond Failure Mechanism

One bond failure mechanism was observed from the testing; transverse anchorage bond cracking of the concrete prism as illustrated in fig-7. From the figure, the cracking occurs at or close to the middle. The transverse cracking at this section is attributed to the discontinuity of the rebar at the midsection of the concrete prism where all the tensile stress in the bar would be transferred to the concrete. The concrete tensile strength was therefore exceeded at this section leading to the transverse crack. At any section along the reinforcingsteel bar(fig-6), the applied load is given by the summation of the tensile stress due to the steel outside the concrete and the tensile stress developed between the concrete and the steel inside the concrete. Therefore:

(i) Equilibrium of forces at any section isrepresented by equation 4:

$P_u = A_s f_{so} = A_s f_{sx} + A_e f_{ctx}$ ……………………………………………..(4)

Where $P_u = f_{so} A_s$ = maximum applied load; A_s = cross sectional area of the steel bar; f_{so} = stress

in reinforcing steel bar at loaded end (and by analogy crack face);f_{sx}= steel stress at section x from loaded end of bar; A_e = area of concrete effectively influencing the reinforcing bar (it is taken as the area of concrete with the reinforcement symmetrical within it); f_{ctx}= tensile

strength of concrete at any point x (Fig 6)

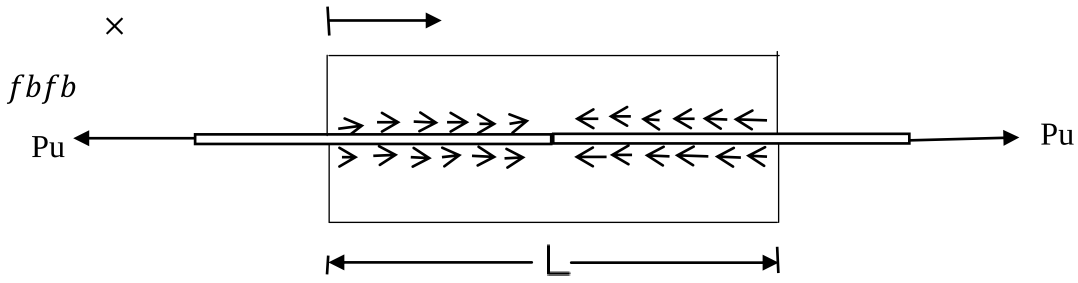


Fig-6: Illustration of the bond mechanism

(ii) Equilibrium of forces on an element of bar dx is given by:

$df_s/dx = f_b u/A_s$ ……………………………………(5a)

where f_b = bond stress between reinforcing bar and surrounding concrete at point x (Fig 6); df_s = change in steel stress over element dx of bar; u is perimeter of bar = πD; D = bar diameter; A_s = area of bar

Integrating equation 5a over an embedment length of L/2 gives:

$$\text{Pu} = \pi D \int_0^{\frac{L}{2}} fb\, dx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5b)$$

$$\text{for } 0 \leq x \leq \frac{L}{2}$$

Therefore:

$P_u = \pi D f_b L/2$

or $f_b = 2P_u/\pi DL$ where the bond stress f_b is assumed to be constant or uniform. L = length of concrete prism.

Similarly, (iii) equilibrium of forces on an element of concrete (dx) is expressed as in equation 6:

$df_{ctx}/dx = f_b u/A_e$ …………………………………………….(6)

As the pull-out force is applied, the resisting tensile stress developed in the section of the steel outside the concrete continues to decrease and approaches zero towards the centre. Bond failure occurs when the resisting tensile force due to the steel outside decreases to zero at $\frac{L}{2}$. In other words, failure occurs when the pull-out force exceeds the bonding between the steel rod and concrete and causes a crack as seen in fig-7. At this point, the maximum applied load would be equal to the tensile stress developed along the steel section inside the concrete. Once the internal crack occurs, chemical adhesion and friction disappear and the bond resistance is offered by mechanical interlock between the steel reinforcement bar and the concrete (*Kankam et al., 2023*).Failure began with a small slightly visible line of crack which was initiated by initial slip, followed by more visible cracks by further slips and finally with total failure. The thickness of the cracks ranged from 1mm-2mm.

Fig-7: Bond failure mechanism

3.4.3 Bond strength vs compressive strength

From Table-3, the compressive strength values were comparatively higher than the bond strength values. From fig-8, the trend however was the same for the two parameters. This is expected per *Kazemi and Broujerdium, (2006)* findings that the bond strength of concrete is proportional to the compressive strength. The compressive strength and the bond strength for the control specimen were 7.42N/mm² and 2.31N/mm² respectively. Approximately, this represented 31% of the compressive strength. When 20% PKF was added, the compressive strength and bond strength values obtained were 1.90N/mm² and 1.27N/mm², respectively. The compressive strength decreased by 74.39% of the value control specimen whereas the bond strength decreased by 45% of the value for the control specimen. This implied that the rate of reduction of the compressive strength with PKF addition was higher than the bond strength. Whereas the rate of reduction of the compressive strength was sharp from the control specimen to about 10% addition of PKF where it then appeared constant, the variation of the bond strength was nonetheless gradual throughout.

Table-3: Compressive strength vs Bond strength

PKF content(%)	Compressive strength N/mm²	Bond strength fb,N/mm²	Bond Strengt Compressive strength(%)
0	7.42	2.31	31.15
5	6.55	2.04	31.13
10	2.75	2.18	79.34
15	1.93	1.87	96.65
20	1.90	1.27	66.84

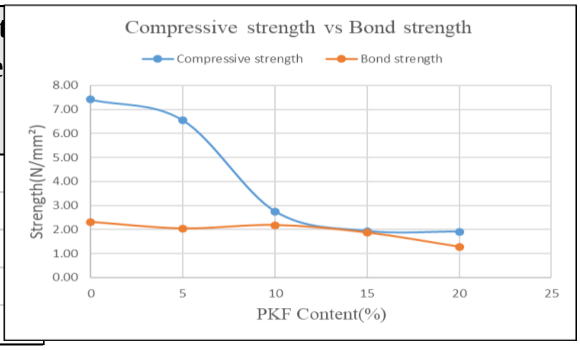


Fig-8: Strength versus PKF Content

3.5 Split Tensile strength (SpS)

The SpS results obtained were 0.786N/mm² and 0.638N/mm² for the control specimens which averages 0.712 N/mm. For same control LATCON mix, the compressive strength was higher than its split tensile strength. The average split tensile strength was 9.59% of the compressive strength. This is in agreement with the generally accepted theory that the tensile strength is about 10% of the compressive strength. Thus LATCON shares similar trend characteristics of compressive strength and tensile strength with conventional aggregate concrete.

The SpS results were however lower than the bond strength results but showed a much closer relationship with the bond strength results representing 30.80% of the bond strength. Thus the tensile strength of LATCON was more strongly correlated with its bond strength than with compressive strength.

3.6 Modulus of Rupture (MoR)

The MoR obtained were 2.071N/mm² and 1.938/mm² for control specimens averaging 2.005 N/mm. Generally, for conventional concrete, higher compressive strength corresponds to high flexural strength. However, the MoR of the concrete from LATCON was 27% of the compressive strength, exhibiting a strong correlation with the bond strength. The average bond strength of the plain LATCON was 2.31N/mm². This was about 15.21% higher than the MoR. Conversely, the MoR represented 84.79% of the bond strength. Cracking and deflection behaviour of concrete structures under flexure and those with minimum flexural reinforcements depends on the flexural tensile strength; the modulus of rupture of the concrete *(Kankam et al., 2023).*

4.0 CONCLUSION

In conclusion, the study shows that lateritic concrete possesses good strength properties. Though lower than the characteristic strength of conventional concrete, the split tensile strength followed the same trend of about 10% of compressive strength. Hence, it could serve as an alternative to conventional concrete for non-load bearing structure elements. The major findings from study are:

1. For the same mix ratio, the compressive strength, flexural strength, and split tensile strength of lateritic concrete made from only laterite aggregates are low compared to strength properties of conventional concrete with the same mix ratio but much higher w/c ratio to achieve adequate workability.
2. The addition of palm kernel fibre to lateritic concrete with only laterite aggregates has a reducing impact on the strength properties. The strength decrease with increasing amounts of the palm kernel fibre.
3. The preparation of lateritic concrete for suitable consistency and workability requires high w/c ratios.
4. The relationship of the strength properties of lateritic concrete are similar to trend in conventional concrete. The tensile strength of lateritic concrete was about 10% of its compressive strength.

Based on the findings of this study, it was recommended that lateritic concrete with PKF addition should not be more than 5% due to its strength decreasing effect on the resulting concrete product.

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