Original Research Article

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

ABSTRACT

The efforts to discover alternative materials for the production of applicable and usable concrete aside the conventional use of pit or river sand as fine aggregates and crushed rock aggregates as coarse aggregates have been hailed by many as a great move to reduce the over-reliance on traditional aggregate concrete. Lateritic soil is abundant in tropical regions and is a potential alternative to conventional concrete materials. Palm kernel fibre, on the other hand, is also a natural and renewable material that has proven to be useful in many ways. This study assessed the strength properties of lateritic concrete using laterite aggregates and reinforced with palm kernel fibre(PKF). The compressive, bond and tensile (split cylinder and modulus of rupture) strengths of lateritic concrete were evaluated and compared to conventional concrete. The results of this study provide insights into the potential use of lateritic concrete in construction applications.The study showed that lateritic concrete possesses good strength properties although not at same levels as normal aggregate concrete. For the same mix ratio of target strength 25N/mm² for normal aggregate concrete, the compressive strength was found to be low, 7.421N/mm², for the lateritic concrete without PKF representing about 29.68% of the target strength. The addition of palm kernel fibre to the concrete further reduced the compressive strength of the control specimen. For example, the addition of 20% palm kernel fibre caused 74.34% reduction in the compressive strength of the control specimen. 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 the palm kernel fibre. The tensile strength was 9.59% of the compressive strength showing a similar relationship with the compressive strength as in normal aggregate concrete. Also the bond strength had similar rate of reduction trend as the compressive strength with varying additions of the palm kernel fibre, thus, it reduced with increasing addition of the palm kernel fibre content. It ranged between 31% and 97% of the compressive strength as PKF varied from 5 to 20% contents. The rate of reduction was not sharp but gradual. The bond strength for the control specimen of lateritic concrete without PKF was low, 2.31N/mm², which represented about 31% of its corresponding compressive strength. A pull-out bond failure mechanism was observed to occur at or around the middle of the test specimen at the section of the bar discontinuity. The modulus of rupture was observed to correlate with the bond strength value which represented 84.79% of the bond strength for the control specimen.

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

1.0 INTRODUCTION

Laterite remains one of the widely distributed soil 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, Cameroun 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. Lateritic concrete is a type of concrete made from laterite soil.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. It 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.

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 the strength properties of lateritic concrete made with laterite aggregates and with palm kernel fibre reinforcements.The strength properties of concrete are a crucial material property in structural engineering because they directly affect the performance and

Comment [R1]:

The abstract reflects a general description of the research, contains background, simple methods and research objectives. The abstract also displays the results and brief discussion and general conclusions are presented.
INTRODUCTION
has contained the research background and has reflected and described the objectives completely and the problem formulation has been presented

METHODS and MATERIALS
It reflects the research methodology specific to the frame of reference for this research. Research has implemented concrete steps regarding the bond strength characteristics of lateritic concrete anchorages with laterite aggregate and palm kernel fiber. These characteristics are important for establishing the basis for initial research.

The materials used are also appropriate. Mixing each material used refers to experimental standards regarding the production of concrete mixtures in accordance with British Standard BS EN 12390-1. This standard is important for determining the aggregate used and the quality standards used.

RESULTS AND DISCUSSION
The results shown in this study are appropriate. There is a study of the slump, density and compressive strength of normal concrete and the test concrete has shown well. The use of LATCON also greatly influences the compressive strength of the sampled concrete.
The bond strength and compressive strength of concrete have an impact on the studies taken with the percentage of concrete bond value which results in the material used having a very significant influence.

CONCLUSION
The conclusion has answered the purpose. The mixture ratio produces compressive strength, flexural strength and tensile strength of laterite split concrete which has a higher ratio than the compressive capacity of normal concrete
The physical properties of normal concrete and experimental concrete follow a good trend so that the concrete mixture using this sample aggregate is good for follow-up.

Best regards,

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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, a necessity for loads transfer between different structural components depend 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 Sodium Hydroxide(NaOH) solution to enhance their binding property, and dried thoroughly. 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

(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, which for conventional aggregate concrete, has a target strength of 25N/mm² for a water/cement ratio of about 0.45. A strength of 25N/mm² was therefore used as reference strength of conventional concrete for comparative analysis with the lateritic concrete. The study material, PKF, was added in varying quantities relative to the amount of cement and the amounts of the PKF were varied 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 for 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. The laterite contained high fine particles content with about 6.9%(from Table-1) passing 0.075mm standard sieve (from the particle size distribution test performed). The fine particles tended to require more water in order to produce a workable concrete mix and hence the high w/c ratio.

2.4 Mix Design, Sample 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 dirty car engine oil. This was to facilitate easy demoulding process after casting in order to ensure the desired shape of the cubes was not distorted. 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 bath 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 gradually to the point of failure 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:

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

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:

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

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:

$$f_{ct} = \frac{3PL}{2bd^2} \qquad (3)$$

where f_{ct}= flexural tensile strength of lateritic concrete specimen (N/mm²); 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			

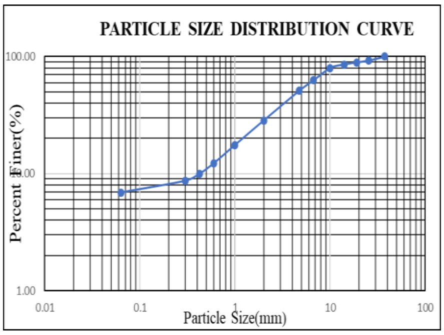

Figure-3: Particle Size Distribution of the Laterite

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/mm²,6.552N/mm²,2.752N/mm²,1.932N/mm² and 1.904 N/mm² 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/mm². 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/mm² and 1.904 N/mm² 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/mm². 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/mm² from the control concrete of 7.421N/mm².

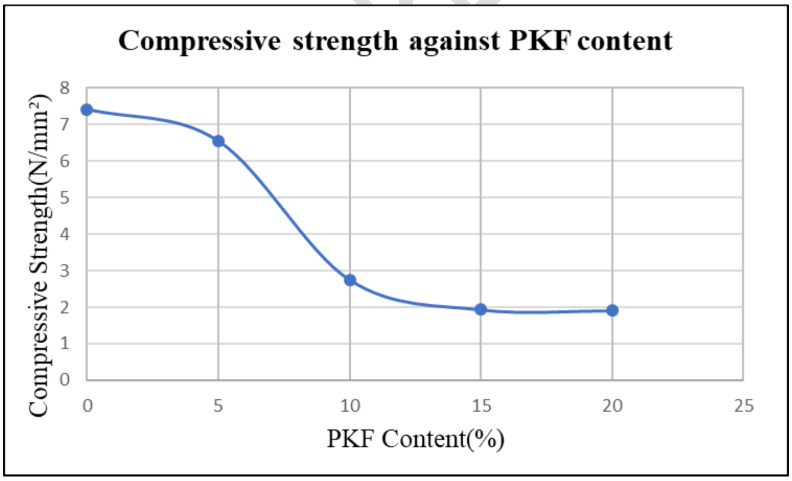

Fig-4: Variation of compressive strength with PKF Content

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

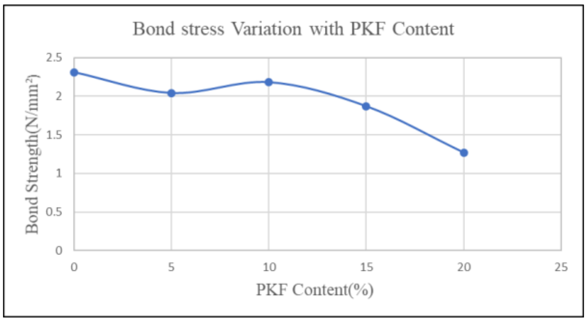

Fig-5: Variation of Bond stress with PKF content

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)

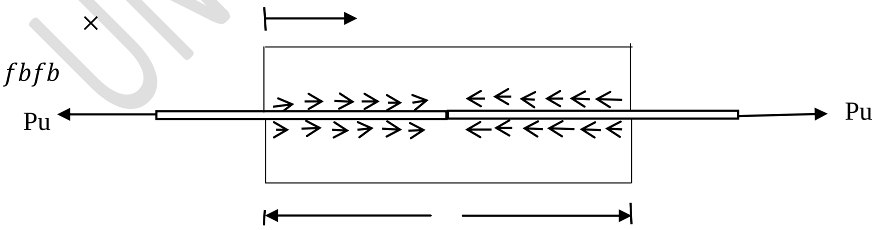

Fig-6: Illustration of the bond mechanism

(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:

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

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

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 Strength to 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

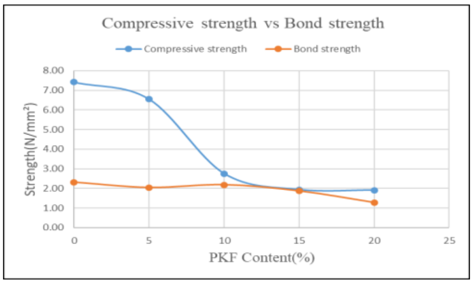

Fig-8: Strength versus PKF Content

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. Test specimens failed by showing minor longitudinal split along the length of the cylinder as showing that LATCON under tensile stress shows similar tensile properties as conventional concrete.

3.6 Modulus of Rupture(MoR)

The MoR results 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 was 27% of the compressive strength and exhibited 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 has shown that lateritic concrete possesses good strength properties and similar trend characteristics as conventional concrete and can be used as a viable alternative to conventional concrete in construction projects. 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 rate of reduction in strength increases with increasing amounts of the palm kernel fibre.
3. The preparation of lateritic concrete of suitable consistency and workability require 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 is about 10% of its compressive strength.

Based on the findings of this study, it is recommended that lateritic concrete can be considered for lightweight and low rise structures such as residential buildings due to its low strength. Palm kernel fibre must not be considered as a reinforcement material for the lateritic concrete as its addition reduces the mechanical strength properties of the concrete.

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