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# Bond Strength of Reinforcing Steel Bars locally milled from Scrap Metals in Concrete prepared with Palm Kernel Shell as Coarse Aggregate

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*Abstract*— **Palm kernel shell (PKS) has been explored as partial coarse aggregate in concrete due to the depletion of conventional aggregates for concrete as well as the environmental hazards associated with the mining of these aggregates. Structural concrete is usually reinforced with steel reinforcing bars to augment its tensile capacity. Bond strength of reinforcing steel bars locally milled in Ghana from scrap metals in concrete with PKS as partial coarse aggregate was investigated. Four concrete mixes with varying PKS contents were used in double pull-out prismatic specimens and embedded with 12mm and 16mm diameter steel reinforcing bars. The 28th day compressive strength varied between 8.86N/mm2 and 28.49N/mm2. The slump values reduced with increase in PKS aggregate content. PKS percentage replacement as well bar type, size and geometry all impacted on anchorage bond strength and total slip at failure. Anchorage bond strength was found to be between 2.84N/mm2 and 10.13N/mm2. Total slip displacements between 6.59mm and 13.80mm were recorded. Two types of bond failures, namely, splitting and shear failures were observed.**

*Index Terms*— **Bond Strength, Concrete, Palm Kernel Shell, Steel Reinforcing Bar, Slip**

## I. INTRODUCTION

Concrete has been used since the ancient times and is in continuing usage as the world's most sought after construction material. The depletion of conventional aggregates for concrete as well as the environmental hazards associated with the mining of these aggregates have propelled concrete technologists and researchers to explore the use of palm kernel shell (PKS) as an alternative coarse aggregate material for concrete. PKS as by-product of palm kernel oil extraction waste has enormous economic benefits when used in concrete.

Reinforcing steel bars (rebars) are embedded in concrete primarily to augment concrete's inability to resist tension. The tension that is induced due to flexural tension, direct tension, 'diagonal tension' or environmental effects can efficiently be taken up by reinforcing steel bars. Rebars also improve the ductility of concrete that is generally brittle so that the reinforced concrete can possess the ductility required. Concrete is also advantageously reinforced with rebars which are stronger in compression than concrete for bearing compressive stresses as it is usually done in columns and compression zones of some reinforced concrete elements [1]. The composite action of concrete and rebar depends on the bond stress that develops at the interface of the concrete and the rebar.

Pull-out test is one of the simplest experimental tests used to determine the bond characteristics between rebar and the surrounding concrete. The significant characteristics of the development of bond stress–slip and particularly the maximum bond stress have been reported to be undoubtedly reliant on factors relating to material, geometry and/or loading factors [2–4]. Considering the sizes of the specimens in both the pull-out and the beam test, the pull-out test is very economical. The pull-out test is much faster and simpler to use than the beam test [5]. However, the simple pull-out bond test does not reflect the true bond behaviour at the steel bar – concrete interface in the tensile zone of a beam as the concrete is subjected to compression while the bar is put in tension due to the loading method in a pull-out test. Bond strength obtained from a simple pull-out test therefore tends to be over-estimated. In a double pull-out bond test both concrete and bar are in tension and better simulate the behaviour of a beam tension zone.

Alengaram et al. [6] compared the mechanical and bond properties of palm kernel shell concrete with normal weight concrete. 100mm cubes were used for the compressive strength and 100mm diameter cylindrical pull-out test specimens with 200mm height were used for simple pull-out bond test. Although the bond stress of PKS and cement matrix appeared to be weaker in tension, compared to the crushed granite aggregate and cement matrix, the ultimate experimental bond stress of PKSC was found to be about two times greater than the theoretical values based on the calculations from the British Standard code [7]. Chen et al. [8] conducted an experimental research to investigate the bond behaviour of light weight concrete (LWC) and normal weight concrete (NWC). The experiment was conducted using 150mm cube single pull-out test specimens embedded with 20mm diameter rebar. Concrete strength of 20N/mm$^2$, 40N/mm$^2$ and 60N/mm$^2$ were used for both LWC and NWC. Expanded clay was used as lightweight aggregates for LWC. It was observed that both the ultimate bond stress and the ultimate slip increased as the concrete strength increased. The results also showed that the type of aggregate and the concrete strength affected the bond characteristics.

## II. EXPERIMENTAL METHODS

### A. Materials

The major constituent materials included: palm kernel shell (PKS) and granite as the coarse aggregates, river sand as fine aggregate, ordinary Portland cement and mild steel reinforcing bars. Crushed granite which passed the 14mm test

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sieve was used as coarse aggregates for the control samples and river sand which passed through the 4.75mm sieve was also used as fine aggregate in the normal weight aggregates in this study. Potable water was used to mix the concrete. The PKS aggregate was obtained from a local palm kernel oil producing site. Its nuts had already been removed from the inner face (concave surface) which was fairly smooth without fibres. The outer surface (convex face) was moderately smooth with some amount of fibre. The PKS aggregates passed through the 14mm test sieve but retained on the 10mm test sieve.

The physical properties of the coarse aggregates were determined in accordance with the code requirements for testing coarse aggregates used in concrete [9–11]. These included Aggregate Abrasion Value (AAV), Aggregate Crushing Value (ACV), and Aggregate Impact Value (AIV), specific gravity (Gs) and water absorption. Four concrete mix ratios of 1:1.5:2:0.65 (cement:fine aggregate:coarse aggregate water/cement) with varying PKS coarse aggregate replacements of 0%, 25%, 50% and 100% as shown in Table 1 were used.

Rebars used in this study were selected from five steel manufacturing companies in Ghana, namely Tema Steel (TS), Rider Steel (RS), Ferro Fabrik (FF), United Steel (US) and Sentuo Steel (SS). These steel manufacturing firms mill the deformed mild steel reinforcing bars from scrap metals [12]. Two of the steel producing firms have their initials embossed on their products. United Steel Company's products have the inscription 'USC' while Sentuo Steel has 'STS' engraved on its products. These imprints make their products easily identifiable in the open market. Figure 1 shows inscriptions on US and SS, and geometric properties of rebar surface. The remaining three steel samples have no unique identification marks. Table 2 shows the geometric and physical properties of the steel samples.

*Table 1: Concrete mix proportions*

| Concrete Mix | Granite Content | | PKS Content | | Cement content | Sand content | Water content |
|---|---|---|---|---|---|---|---|
| | % | ($m^3$) | % | ($m^3$) | ($m^3$) | ($m^3$) | (ltr) |
| G-0 | 0 | 0.000 | 100 | 0.0660 | 0.033 | 0.0495 | 21.5 |
| G-50 | 50 | 0.033 | 50 | 0.0660 | 0.033 | 0.0495 | 21.5 |
| G-75 | 75 | 0.495 | 25 | 0.0165 | 0.033 | 0.0495 | 21.5 |
| G-100 | 100 | 0.066 | 0 | 0.0000 | 0.033 | 0.0495 | 21.5 |

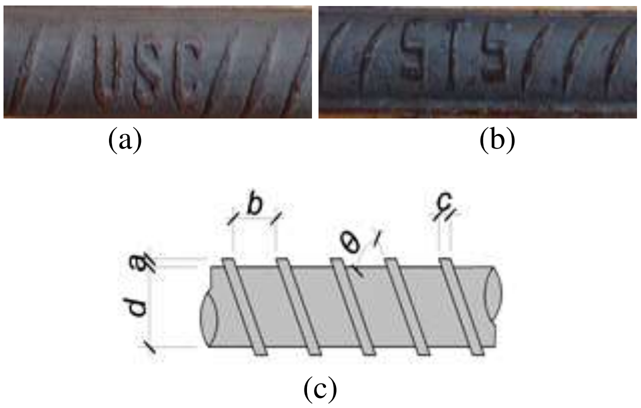



*Figure 1: Physical and geometric properties of rebar surface (a) United Steel (b) Sentuo Steel (c) geometric properties of rebar surface*

*B. Specimens*

120 concrete prismatic double pull-out test specimens of size 150mm x 150mm x 200mm and 12 concrete cubes of ssize 150mm were cast. Different types and sizes of deformed mild steel reinforcing bars (locally milled in Ghana from scrap metals) of length 300mm totaling 240 were concentrically embedded in the prismatic double pull-out specimens. The rebars were made up of 12mm diameter and 16mm diameter bars. Two rebars of the same type and size were embedded in each prismatic concrete specimen. The bars were split and placed end-to-end at midpoint to give two separate embedded lengths in the prismatic concrete. In order to achieve the study objectives, other variables such as mix proportions of granite and PKS in each concrete mix were considered. The double pull-out specimens and the concrete cubes were tested to determine, respectively, anchorage bond strength and compressive strength of each concrete mix proportion. Figure 2 shows the details of the double pull-out specimen.

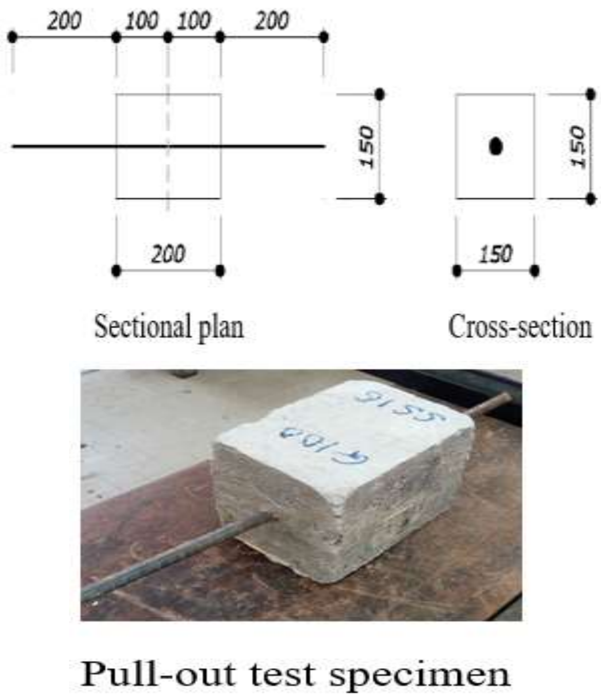



Figure 2: Details of double pull-out specimen

*Table 2: Geometric and physical properties of the steel samples*

| Manufacturer | | Diameter d (mm) | Rib Height a (mm) | Distance Between Ribs b (mm) | Rib Angle θ (°) | Rib Thickness c (mm) | a/b |
|---|---|---|---|---|---|---|---|
| TS | Max | 16.00 | 0.65 | 8.95 | 50 | 3.10 | 0.0726 |
| | Min | 12.00 | 0.50 | 7.00 | 50 | 2.60 | 0.0714 |
| RS | Max | 14.00 | 0.80 | 11.02 | 60 | 2.00 | 0.0726 |
| | Min | 10.00 | 0.75 | 10.55 | 60 | 1.20 | 0.0711 |
| FF | Max | 14.56 | 0.85 | 11.30 | 56 | 2.68 | 0.0752 |
| | Min | 11.00 | 0.74 | 10.55 | 56 | 1.65 | 0.0701 |
| US | Max | 14.85 | 0.65 | 9.35 | 55 | 2.75 | 0.0695 |
| | Min | 11.20 | 0.60 | 8.25 | 55 | 2.12 | 0.0727 |
| SS | Max | 15.18 | 0.55 | 8.60 | 65 | 0.75 | 0.0640 |
| | Min | 11.50 | 0.51 | 7.40 | 65 | 0.65 | 0.0689 |

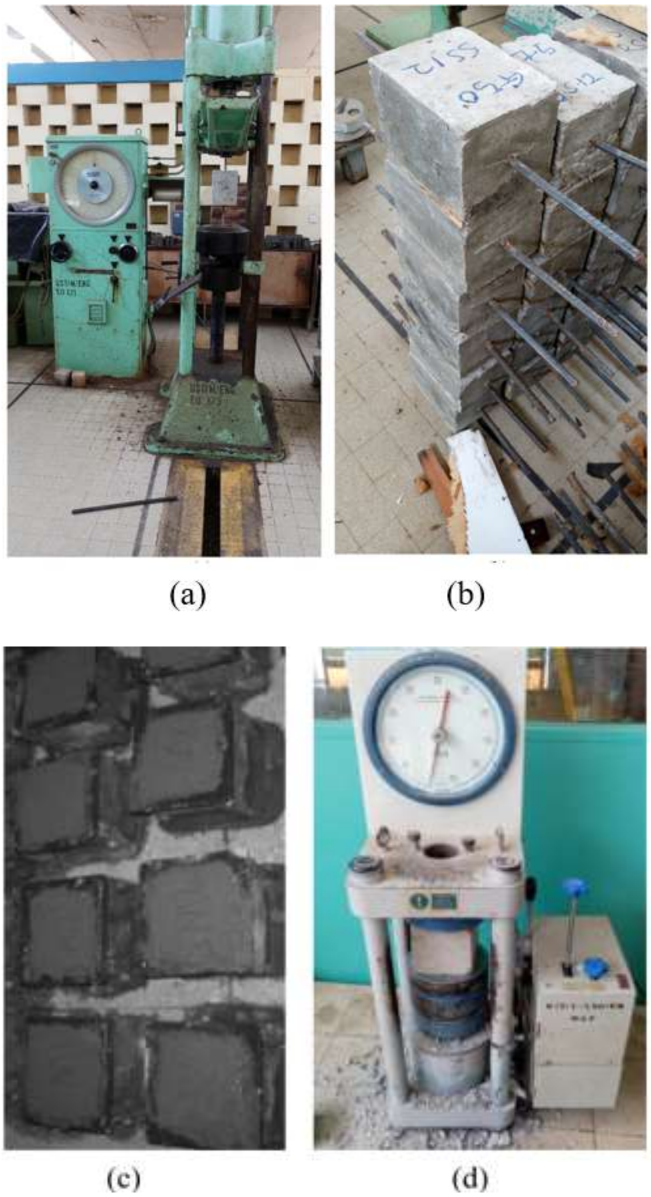


*Figure 3: Test specimens and experimental setups (a) pull-out test setup (b) pull-out test specimens (c) cubes in moulds (d) cube test setup*

*Table 3: Physical properties of coarse aggregates*

| Properties | PKS (LWA) | Granite (NWA) | Limit | Reference |
|---|---|---|---|---|
| Aggregate abrasion value (AAV) % | 4.50 | 20.01 | N/A | BS EN 12620 [13] |
| Aggregate crushing value (ACV) % | 4.81 | 24.99 | N/A | BS 812-110 [9] |
| Specific gravity (Gs) | 1.32 | 2.67 | ≥3 | Neville [14] |
| Aggregate impact value (AIV) % | 3.26 | 12.12 | <25 | BS 882 [15] |
| 24hour-water absorption % | 20.34 | 0.65 | >0.40 | Neville [14] |

* LWA = Lightweight aggregate; NWA = Normal weight aggregate; N/A = Not applicable

### C. *Test Procedure*

Double pull-out specimens and concrete cubes were tested on the 28th day. Cube test was carried out in conformity with the recommendations in BS EN 12390-3 [16] using an Automatic 1000kN/500kN Motorised Compression/Tension Machine. The pull-out test was carried out using an Avery brand of Hydraulic Universal Tension Machine (HUTM) of 50ton capacity [17,18]. Figure 3 shows test specimens and experimental setups. The ends of the rebars embedded in the prismatic double pull-out specimen were firmly held in position with metallic wedges in both the upper and the lower jaws of the Hydraulic Universal Tensile Machine. The specimen was then monolithically pulled in tension until the embedded reinforcing steel bars lost grip. This occurred as the bond between the rebar and the surrounding concrete failed after exceeding the maximum force. The maximum bond stress fb was estimated using equation one in Section III (D) [19,20]. The experimental setup for the pull-out test is shown in Figure 3.10. The total anchorage bond slip at failure between the rebar and the surrounding concrete was observed and recorded using an electronic digital calipers.

## III. Test Results

### A. *Physical Properties of Coarse Aggregates*

Physical properties of PKS and granitic aggregates that were tested are water absorption, aggregate impact value, specific gravity, aggregate crushing value and aggregate abrasion value. The test results shown in Table 3 conform to code provisions and reasonably compare with other related works.

### B. *Slump Test*

The slump values reduced with increase in PKS aggregate content. This could be attributed to the highly porous nature as well as the rough surface texture of the PKS aggregates. The PKS aggregates might have absorbed a significant amount of water leaving the concrete mix with little 'mixing water' that impeded the flow-ability of the PKS aggregates concrete. The rough surface texture of PKS aggregate could have also increased friction and adhesion between the constituent materials of the fresh PKS concrete, thus, reducing its workability. The slump values obtained are reasonably within the range (10mm to 210mm) stipulated by BS EN 12350-2 [21] as well as slump values reported by previous researchers [2,22]. Table 4 shows concrete mixes, slump values and compressive strengths.

*Table 4: Concrete mixes and their properties*

| Mix ratio | % of PKS Replacement | Average compressive strength ($N/mm^2$) | Slump (mm) | Average Density ($kg/m^3$) | Water content (ltr) |
|---|---|---|---|---|---|
| **G-0** | 100 | 8.86 | 30 | 1851.75 | 21.5 |
| **G-50** | 50 | 15.59 | 35 | 2061.53 | 21.5 |
| **G-75** | 25 | 26.04 | 40 | 2309.43 | 21.5 |
| **G-100** | 0 | 28.49 | 65 | 2591.41 | 21.5 |

### C. *Compressive Strength*

Cube crushing tests were conducted to experimentally determine the compressive strengths of the 12 concrete cubes (3 cubes for each concrete mix). Concrete mixes G-100, G-75, G-50 and G-0 recorded average compressive strengths of $28.49N/mm^2$, $26.04N/mm^2$, $15.59N/mm^2$ and $8.86N/mm^2$ with their corresponding densities $2591.41kg/m^3$, $2309.43kg/m^3$, $2061.53kg/m^3$ and $1851.75kg/m^3$ respectively.

These concrete mixes with their corresponding densities and water contents and other properties are as shown in Table 4.

### *D. Anchorage Bond Strength*

The anchorage bond strengths were estimated from the experimental results obtained from the pull-out tests using the expression:

$$F_b = \frac{P}{\pi d l} \quad (1)$$

where $F_b$ is the bond stress in N/mm$^2$, $P$ is the applied load in Newtons, $d$ is the nominal bar diameter in mm and $l$ is the embedment length of rebar in mm. The results shown in Tables 5 and 6 and Figure 4 clearly indicate that an increase in PKS content resulted in a reduction in the compressive strength which subsequently caused a decrease in the anchorage bond strengths. This consequently reduced the total anchorage bond slip. The normal weight concrete (100% granite) obtained a compressive strength 28.49N/mm$^2$. The 12mm rebars embedded in this concrete mix obtained anchorage bond strengths of 10.13N/mm$^2$, 9.00N/mm$^2$, 8.40N/mm$^2$, 8.25N/mm$^2$ and 7.33N/mm$^2$ for RS, FF, SS, US and TS respectively. For the 16mm rebars, RS had the maximum anchorage bond strength of 7.26N/mm$^2$ followed by FF with 7.24N/mm$^2$, SS with 6.78N/mm$^2$, US with 6.38N/mm$^2$ and TS with 6.09N/mm$^2$.

With 25% PKS coarse aggregate partial replacement, the compressive strength decreased by 8.60%. The smaller bars recorded an average reduction of 17.55% in anchorage bond strengths resulting in 8.52N/mm$^2$, 7.31N/mm$^2$, 6.87N/mm$^2$, 6.50N/mm$^2$ and 6.30N/mm$^2$ respectively for RS, FF, SS, TS and US. The lager bars had anchorage bond strengths reduced by an average of 9.05% with FF, RS, US, SS and TS recording anchorage bond strengths of 6.82N/mm$^2$, 6.20N/mm$^2$, 5.96N/mm$^2$, 5.96N/mm$^2$ and 5.72N/mm$^2$ respectively. For the 50% PKS coarse aggregate partial replacement, there was a reduction of 45.28% in compressive strength. The 12mm bars obtained an average reduction of 24.50% in anchorage bond strengths with RS, FF, TS, SS and US recording 7.27N/mm$^2$, 6.41N/mm$^2$, 5.62N/mm$^2$, 5.53N/mm$^2$ and 5.51N/mm$^2$ respectively. The 16mm bars had an average reduction of 29.14% in anchorage bond strength with 5.21N/mm$^2$, 5.10N/mm$^2$, 4.89N/mm$^2$, 4.45N/mm$^2$ and 4.20N/mm$^2$ respectively for RS, US, FF, TS and SS. This trend continued in the 100% PKS coarse aggregate concrete. The compressive strength reduced by 68.90%. The corresponding anchorage bond strengths for the smaller bars recorded an average reduction of 54.07%. United Steel (US) obtained the minimum anchorage bond strength of 3.60N/mm$^2$ while Sentuo Steel (SS), Tema Steel (TS), Rider Steel (RS) and Ferro Fabrik obtained in the order of 3.70N/mm$^2$ and 3.73N/mm$^2$, 4.26N/mm$^2$ and 4.41N/mm$^2$. The anchorage bond strengths for the lager bars reduced by an average of 53.36%. US, SS, TS, FF and RS recorded anchorage bond strengths of 2.78N/mm$^2$, 2.84N/mm$^2$, 3.10N/mm$^2$, 3.39N/mm$^2$ and 3.63N/mm$^2$ respectively.

The anchorage bond strengths obtained in this study are similar to the values reported in previous studies. Kankam [23] used 25mm diameter bars in a concrete of 50N/mm$^2$ compressive strength and reported local bond strengths of between 6.0N/mm$^2$ and 6.7N/mm$^2$. Yeih et al. [24] experimented 10mm and 12mm rebars in concrete of 35.9N/mm$^2$ compressive strength and obtained anchorage bond strengths of 11.95N/mm$^2$ and 12.77N/mm$^2$ respectively for 12mm and 10mm diameter bars. Teo et al. [25] used PKS coarse aggregate concrete of compressive strength 22.9N/mm$^2$ and obtained anchorage bond strengths of 6.32N/mm$^2$, 8.61N/mm$^2$ and 8.99N/mm$^2$ respectively for 16mm, 12mm and 10mm rebars. Both studies by Yeih et al. [24] and Teo et al. [25] adopted the simple pull-out bond test method, and therefore as a result of the compression in the surrounding concrete while the embedded bar was in tension, bond strengths would be over-estimated and greater than when both concrete and bar were in tension as in a double pull-out specimen.

*Table 5: Concrete mix proportions and anchorage bond strengths (minimum rebar size)*

| Concrete Mix Proportion | | | Anchorage Bond Strength (N/mm$^2$) | | | | |
|---|---|---|---|---|---|---|---|
| S/N | % PKS replacement | Average Concrete Strength (N/mm$^2$) | TS12 | RS12 | FF12 | US12 | SS12 |
| G-0 | 100 | 8.86 | 3.73 | 4.26 | 4.41 | 3.60 | 3.70 |
| G-50 | 50 | 15.59 | 5.62 | 7.27 | 6.41 | 5.53 | 5.51 |
| G-75 | 25 | 26.04 | 6.50 | 8.52 | 7.31 | 6.30 | 6.87 |
| G-100 | 0 | 28.49 | 7.33 | 10.13 | 9.00 | 8.25 | 8.40 |

*Table 6: Concrete mix proportions and the anchorage bond strengths (maximum rebar size)*

| Concrete Mix Proportion | | | Average Bond Stress (N/mm$^2$) | | | | |
|---|---|---|---|---|---|---|---|
| S/N | % PKS replacement | Average Concrete Strength (N/mm$^2$) | TS 16 | RS 16 | FF 16 | US 16 | SS16 |
| G-0 | 100 | 8.86 | 3.10 | 3.63 | 3.39 | 2.78 | 2.84 |
| G-50 | 50 | 15.59 | 4.45 | 5.21 | 4.89 | 5.10 | 4.20 |
| G-75 | 25 | 26.04 | 5.72 | 6.20 | 6.82 | 5.96 | 5.96 |
| G-100 | 0 | 28.49 | 6.09 | 7.26 | 7.24 | 6.38 | 6.78 |

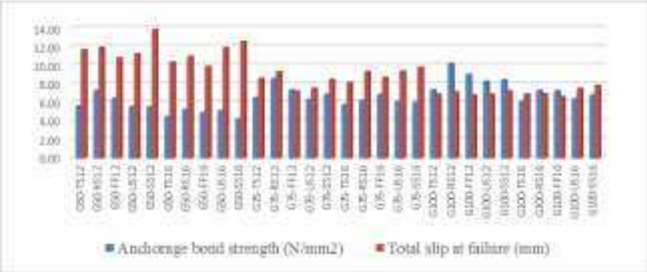

(a)


(b)

*Figure 4: Anchorage bond strength versus compressive strength ((a) 12mm bars (b) 16mm bars)*


*(a)*


*(b)*




(c)

*Figure 5: Mode of bond failure, anchorage bond strength and slip (a) shear failure (b) splitting failure (c) anchorage bond strength versus sli*

### E. Anchorage Bond Slip

The pull-out test results show that an increase in PKS content impacted a decrease in compressive strength which resulted in anchorage bond strength reduction and corresponding reduction in slip displacement. The rebar type, its lug patterns and geometry also influenced the anchorage bond strength as well as the total slip at failure. Rider Steel (RS) had an average rib height to rib distance ratio of 0.07185, rib angle of 60° which corresponded with the minimum slip of 6.89mm and a maximum bond strength of 10.13N/mm$^2$. Figure 5 (c) shows anchorage bond strength versus slip.

The 12mm diameter bars in normal weight concrete of compressive strength 28.49N/mm$^2$ obtained an average anchorage bond strength of 8.62N/mm$^2$ with a corresponding slip of 7.03mm. The maximum bars (16mm Ø bars) obtained average slip of 7.13mm with a corresponding anchorage bond strength of 6.75N/mm$^2$. With 25% PKS coarse aggregate partial replacement, the compressive strength decreased by 8.60%. The smaller bars recorded an average reduction of 17.55% in anchorage bond strengths with a corresponding average slip of 8.2mm. The maximum bars had anchorage bond strengths reduced by an average of 9.05% with a corresponding average slip of 9.04mm. For the 50% PKS coarse aggregate partial replacement, there was a reduction of 45.28% in compressive strength. The 12mm bars obtained an average reduction of 24.50% in anchorage bond strengths and 11.87mm slip. The maximum bars had an average reduction of 29.14% in anchorage bond strengths with an average slip of 11.09mm.

These results reasonably compare with what exists in literature. In an experiment to compare the mechanical and bond properties of palm kernel shell concrete with normal weight concrete, Alengaram et al. [6] used 12mm diameter deformed bars in concrete of compressive strength 36.7N/mm$^2$ and obtained 6N/mm$^2$ and 1.7mm respectively for anchorage bond strength and slip. Campione et al. [20] experimented bond stress–slip relationship of reinforcing bars embedded in lightweight fiber reinforced concrete with expanded clay aggregates. 12mm diameters bars embedded in double pull-out prismatic specimens in concrete of compressive strength 23N/mm$^2$ recorded 5N/mm$^2$ and 8mm respectively for the bond strength and slip.

### F. Mode of Bond Failure

Two major failure modes, i.e. shear failure and splitting failure as shown in Figure 5 (a) and (b) were observed. From Figure 5 (c), it can also be observed that increase in the bond strength caused an increase in the slip displacement. This increase appears in nearly a constant proportion until it reaches a point where the gradient of the curvature changes till the ultimate bond strength is reached. Albeit concrete is a brittle material, it becomes more brittle with increase in compressive strength. This phenomenon might have caused the high strength concrete to have a minimum slip leading to a sudden and abrupt bond failure as compared to the concrete with lower compressive strength which recorded higher slip with lower bond stress. This abrupt failure usually results in splitting cracks. This could also be attributed to the fracture mechanism which causes strain energy to accumulate in the form of micro-cracking. This leads to the cracks formation between the rebar and the surrounding concrete. This instantly leads to the spread of cracks making use of the accumulated strain energy. Development of longitudinal severe cracks occur swiftly by triggering bond failure in a highly unexpected and inelastic manner. The splitting failure characteristically records lower slip compared to the shear failure which usually occurs in concrete with lower strength [2,6]. The shear failure occurs as a result of the shearing of the rebar lugs crushing the concrete surrounding the rebar. Consequently, the concrete in front of the rib shears and makes a pull-out alongside a surface in cylindrical frictional stress. After the shear failure over the whole length of embedment of the rebar, the force drops and then only friction resists the residual pull-out which is plastic in nature and usually occurs at a lower force than its initial maximum force [26].

## IV. The Effect Of PKS Percentage Replacement On Concrete And Anchorage Bond Strengths

The PKS replacements impacted on the compressive strengths of the concrete mixes which consequently affected the bond strengths. Tables 4 to 6 and Figures 4 to 5 show that the percentage of PKS replacement resulted in a decrease in the compressive strength. It was observed that higher compressive strength yielded higher bond strength. However, the difference in compressive strength between the optimum content PKS replacement (25%) and the normal weight concrete is very minimal. The optimum content PKS replacement obtained about 91.40% of the compressive strength of the normal weight concrete. These observations are similar to what exists in literature. Compressive strengths of 21.80N/mm$^2$, 16.64N/mm$^2$, 15.18N/mm$^2$, 15.00N/mm$^2$ and 10.37N/mm$^2$ for PKS coarse aggregate replacements of 0%, 25%, 50%, 75% and 100% respectively were reported in concrete mix ratio 1:2:4 [27]. Mannan and Ganapathy [28] recorded PKS aggregate concrete of compressive strength between 9.5N/mm$^2$ to 29.4N/mm$^2$ for various concrete mixes. Olanipekun et al. [29] obtained compressive strength of

34.50N/mm$^2$, 24.00N/mm$^2$, 20.05N/mm$^2$, and 17.50N/mm$^2$ for PKS coarse aggregate replacements of 0%, 25%, 50%, and 75% reactively in concrete mix ratio 1:1:2.

## V. The Influence of Bar Size, Type and Geometry on Anchorage Bond Strength and Slip

From observation of all the test results, rebar type, size and surface geometry impacted significantly on the anchorage bond strength, thus, a confirmation of what exists in literature [18]. The smaller size developed the highest averaging bond stresses with corresponding slip values while the larger size developed the least. As shown in Tables 4.5 to 4.7 and Figures 4.10 to 4.18, the rebars with higher rib heights and rib inclinations developed higher anchorage bond strengths than those with smaller rib heights and rib angles. On the average, RS and FF recorded the largest rib height of 0.8mm each for the larger rebars. These figures correspond with the high bond strengths associated with these rebar types. SS had the average lowest rib height 0.51mm and the largest rib angle of 65°. It was noted that the corresponding slips also varied with SS having the largest slip of 13.84mm. These observations are also consistent with what Kankam [30] reported in an experimental study of a routine method for measuring bond stress, steel strain and slip in reinforced concrete beams at service loads.

## VI. Conclusions

Pull-out test was conducted to determine the bond strength of reinforcing steel bars locally milled from scrap metals in concrete with palm kernel shell as partial coarse aggregate. The following conclusions are drawn from the tests results:

1. Water absorption was very minimal for granite (0.65%) compared to the very high (20.34%) for the PKS aggregates. This phenomenon explains increase in the slump values obtained for the fresh concrete as PKS content reduced.
2. Compressive strength of concrete decreased with an increase in the PKS content. This consequently caused a reduction in the bond strength with a corresponding reduction in anchorage slip.
3. The anchorage bond strength decreased with increase in bar diameter. The smaller bars recorded an average bond strength of 6.43N/mm$^2$ while the bigger bars had 5.20N/mm$^2$.
4. The rebar type, its lug patterns and geometry influenced the anchorage bond strength. The maximum rib angle of 65° with a corresponding minimum rib height to rib distance ratio of 0.0640 obtained the lowest bond strength of 4.2N/mm$^2$ with a corresponding 13.83mm largest slip.
5. PKS percentage replacement of not more than 50% obtained compressive strength of more than the 15N/mm$^2$ minimum requirement stipulated in BS 8110-1 [7] for structural concrete.

## References

[1] S. Pillai, D. Menon, Reinforced Concrete Design, Third, Tata McGraw-Hill Education Pvt. Ltd., 2009.
[2] A.M. Diab, H.E. Elyamany, M.A. Hussein, H.M.A. Ashy, Bond behavior and assessment of design ultimate bond stress of normal and high strength concrete, Alex. Eng. J. 53 (2014) 355–371.
[3] S. Tastani, S.P. Pantazopoulou, Experimental Evaluation of The Direct Tension - Pullout Bond Test, in: Research Gate, Budapest, Hungary, 2002.
[4] Y. Zhao, H. Lin, K. Wu, W. Jin, Bond behaviour of normal/recycled concrete and corroded steel bars, Constr. Build. Mater. 48 (2013) 348–359.
[5] de M. Pereira, Pull Off test to evaluate the compressive strength of concrete: an alternative to Brazilian standard techniques, Rev. IBRACON Estrut. E Mater. 5 (2012).
[6] U.J. Alengaram, H. Mahmud, M.Z. Jumaat, Comparison of mechanical and bond properties of oil palm kernel shell concrete with normal weight concrete, Int. J. Phys. Sci. 5 (2010) 1231–1239.
[7] BS 8110-1: 1997, Structural use of Concrete - Part 1: Code of Practice for Design and Construction, British Standards Institute, 2002.
[8] H.J. Chen, C.H. Huang, Z.Y. Kao, Experimental Investigation on Steel-Concrete Bond in Lightweight and Normal Weight Concrete, Struct. Eng. Mech. Int. J. 17 (2004) 141–152.
[9] BS 812, Testing aggregates - Part 110: Methods for determination of Aggregate Crushing Value (ACV), British Standards Institution, 1990.
[10] ASTM C 131/C 131M, Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine, ASTM International, 2014.
[11] ASTM C127-07, Standard test method for specific gravity and absorption of coarse aggregates, in: American Standard for Testing Materials (ASTM) International, PA, USA, 1993: pp. 1–5.
[12] C.K. Kankam, M. Adom-Asamoah, Strength and ductility characteristics of reinforcing steel bars milled from scrap metals, Mater. Des. 23 (2002) 537–545.
[13] BS EN 12620, Aggregates for concrete, British Standards Institution, 2002.
[14] A.M. Neville, Properties of concrete, Fourth and Final Edition, Pearson Prentice Hall, 2002.
[15] BS 882:1992, Specification for aggregates from natural sources for concrete, British Standard International, 2002.
[16] BS EN 12390-3, Testing hardened concrete - Part 3: Compressive strength of test specimens, European Committee for Standardization, 2009.
[17] N. Verma, A.K. Misra, Bond characteristics of reinforced TMT Bars in Self Compacting Concrete and Normal Cement Concrete, Alex. Eng. J. 54 (2015) 1155–1159.
[18] Z. Achillides, K. Pilakoutas, Bond behavior of fiber reinforced polymer bars under direct pullout conditions, 8 (2004) 173–181.
[19] C.K. Kankam, Bond strength of reinforcing steel bars milled from scrap metals, Mater. Des. 25 (2004) 231–238.
[20] G. Campione, C. Cucchiara, L. La Mendola, M. Papia, Steel–concrete bond in lightweight fiber reinforced concrete under monotonic and cyclic actions, Eng. Struct. 27 (2005) 881–890.
[21] BS EN 12350-2, Testing fresh concrete - Slump-test, European Committee for Standardization, 2009.
[22] U.J. Alengaram, B.A. Al Muhi, M.Z. Jumaat, Utilization of oil palm kernel shell as lightweight aggregate in concrete, Constr. Build. Mater. 38 (2013) 161–172.
[23] C.K. Kankam, Relationship of Bond Stress, Steel Stress and Slip in Reinforced Concrete, J. Struct. Eng. 123 (1997) 79–85.
[24] W. Yeih, R. Huang, J.J. Chang, C.C. Yang, A pullout Test for Determining Interface Properties between Rebar and Concrete, Adv. Cem. Based Mater. 5 (1997) 57–65.
[25] D.C.L. Teo, M.A. Mannan, V.J. Kurian, C. Ganapathy, Lightweight Concrete Made from Oil Palm Shell (OPS): Structural Bond and Durability Properties, Build. Environ. 42 (2007) 2614–2621.
[26] Z.P. Bazant, S. Sener, Size Effect in Pullout Tests, Mater. J. 85 (1988) 347–351.
[27] D.Y. Osei, E.N. Jackson, Experimental Study on Palm Kernel Shells as Coarse Aggregates in Concrete, Int. J. Sci. Eng. Res. 3 (2012).
[28] M.A. Mannan, C. Ganapathy, Concrete from an agricultural waste-oil palm shell (OPS), Build. Environ. 39 (2004) 441–448.
[29] E.A. Olanipekun, K.O. Olusola, O. Ata, A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates, Build. Environ. 41 (2006) 297–301.
[30] C.K. Kankam, A routine method for measuring bond stress, steel strain and slip in reinforced concrete beams at service loads, Mag. Concr. Res. 55 (2003) 85–93.