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**Research Paper**

# Assessment of the ternary coarse aggregates for economic production of sustainable and low-cost concrete

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ABSTRACT

This paper study the effects of construction and agricultural wastes (CAW) as coarse aggregates in ternary blends on the properties of concrete. A concrete mix ratio of 1:2:4 by weight of cement, sand and granite was adopted with water-cement ratio of 0.50. Five different concrete mixes were prepared in this study; one natural aggregate concrete (NAC) and four concretes with 10%, 20%, 30% and 40% recycled aggregate and 40%, 30%, 20% and 10% palm kernel shell (PKS) contents in reverse order at constant 50% natural coarse aggregate (NCA). The results of slump tests showed an increase in workability as the percentage replacement level of RCA reduces and PKS respectively. The compressive strength of concrete mixes was observed to be less than the strength of lightweight concrete recommended by standards by 23.2%, 28.87%, 31.2%, 43.2% and 45.6% respectively. Based on the result of calculated thermal conductivity, it was observed that as the %RCA content reduces with increasing %PKS content significant amount of energy was saved. Also, an analysis of variance (ANOVA) was carried out to determine the effect of the % replacement and curing period on the compressive strength of concrete. It showed that % replacement had a statistically significant effect on the concrete performance. This type of concrete can be classified as lightweight concrete based on the strength and bulk density.

## 1 Introduction

Concrete is an essential building construction material but the combination of high cost of its aggregate component, the negative environmental impact and the high energy demand associated with its production, are averse to principles of sustainability. Measures for reduction of the embodied energy in concrete mitigates the harm to the environment, and when otherwise waste products are incorporated, reduction in unit cost of production is also achieved. Such a measure is therefore an environmentally-responsible, sustainability-conscious and budget-responsive one. The highlighted problems with the use of traditional aggregates for concrete production have necessitated the research for alternative cost effective aggregates that could partially or wholly replace its virgin granite. Therefore, this research is set out to investigate the use of the mix of aggregates from construction and industrial wastes as partial replacements respectively for aggregate (virgin granite) in the

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production of high-performance concrete. The overall intention is to produce concrete that is cheaper, durable, strong more sustainable than conventional concrete.

The high growth rate in population has been accompanied by challenges, one of which is the provision of sustainable, low-cost and durable housing for the population. In spite of the efforts of governments, institutions and individuals, the housing challenge remains largely unsolved. Consequently, resourcefulness is required in developing solution approach. In a bid to address this challenge, a sizable amount of research has been conducted on the use of recycled coarse aggregate and palm kernel shell as a substitute for coarse aggregate. Unfortunately, most of the researchers have treated various factors (use of recycled aggregate and palm kernel shell) separately rather than in combination for maximum effect. Furthermore, the results have been largely uncoordinated. The current research considered the various elements of cost, strength, durability, sustainability and environmental-consciousness in developing high performance concrete that addresses the highlighted challenges.

This research has provided a standard mix design procedure for high-performance concrete containing recycled aggregate and palm kernel shell for building and infrastructure applications. It reduced the carbon footprint of concrete structures thereby contributing to sustainable development of built environment in addition to reducing the amount of agricultural demolition waste products in the environment.

The generation of huge quantity of construction and demolition (C&D) and agricultural wastes is also associated with the activities related to the infrastructural development [1]- [2]- . However, due to these huge quantity of wastes, the disposal is one of the major problem all over the world. Hence, instead of using it for land fill or burning it which may contribution to gas emission, the utilization of the same as a potential substitution of natural aggregate is the best alternative solution. It will not only solve the problem of land filling but also reduce its impact on the environment. The waste concrete from the laboratory and palm kernel shell (PKS) from agricultural waste can be utilized to a coarse aggregates for the production of eco-friendly and sustainable concrete [3]- .

Apart from the use of PKS in the production of fibre-roofing materials, as an aggregate in plain lightweight concrete, it use in the production of concrete and road building material have not been well research [4]- [5]- . PKS is light in weight and therefore, ideal for substitution as coarse aggregate in the production of lightweight concrete. Ref. [6]- in his investigations into the physical properties of palm kernel shell found that density to be 740kg/m$^3$. He concluded that these materials have properties which resembled those of lightweight concrete materials. Ref. [7]- investigated the properties of palm kernel shells (PKS) as coarse aggregate for concrete production. They noted that the compressive strength of the concrete decreased.

Ref. [8]- carried out an experimental study on the effect of RCA on the mechanical properties of concrete. Their outcomes show that there is no significant change in the compressive strength of recycled aggregate concrete (RAC) up 30% replacement as compared to the normal aggregate concrete (NAC). The relative density and water absorption of RAC was found to be 7% to 9% lower and 2 times higher than that of NAC. Ref. [9]- conducted an experimental investigation on some of the mechanical properties of RCA using waste concrete obtained from demolished building. The concrete compressive strengths were found to be between 25 and 50 Mpa, while the modulus of elasticity of RAC was only 3% lower than that of natural NAC. Ref. [10]- studied the effects of size of RCA on 28-d compressive strength. It was found that the size of 10 mm and 14 mm of RCA in RAC have similar performance with 10 mm and 14 mm size of NCA in NAC.

Ref. [11]- studied the effect of RCA on concrete properties. Three different water ratios 0.60, 0.52 and 0.43 and aggregate replacement of 0%, 15%, 30%, 50% were used. Experimental results show that there is up to 25% reduction in compressive strength, 23% reduction in flexural strength, 26% reduction in split tensile strength and a noticeable reduction in workability with the increase in percentage of aggregate replacement. Ref. [12]- concluded that the use of RCA weakens the quality of RAC. The compressive, flexure and split tensile strength of RAC is found to be less than that of NAC. Ref. [13]- studied the sustainability of fly ash and RCA in concrete. Ref. [14]- studied the effects of RCA obtained from the local renovation demolition wastes on concrete strengths. The outcomes of this study indicate that there are significant reductions in concrete compressive strength up to 21% and concrete flexural tensile strength up to 39% and these reductions were found to increase with the level of aggregate replacements. Ref. [15]- carried out study on strength of concrete using RCA from demolition concrete waste. It was found that the compressive strength, split tensile strength and flexural strength decreased as the percentage replacement of RCA content increases. The compressive strength was found to be decreased by 10% for RCA. The split tensile strength was found to be decreased by 8% while the flexural was found to be decreased by 18%.

This study presented a feasibility study on concrete performance using ternary coarse aggregates (i.e., natural coarse aggregate, NCA, recycled coarse aggregate, RCA obtained from the abandoned cube specimens in the structural laboratory of the Federal University of Technology Akure, Nigeria and the palm kernel shells, PKS). The NCA is kept constant at 50% for all the mix designs while the proportion of RCA and PKS were varied concurrently. Based on the physical and mechanical properties of the recycled aggregate, the concrete produced was categorised as lightweight concrete which can use in low weight bearing structural components.

## 2 Experimental Program

### *2.1 Materials: Particle Size Distribution, Physical and Mechanical Properties*

Pit-sand instead of sharp sand is commonly used as fine aggregate in concrete works in Akure, Nigeria (Fig. 1). This is often mixed with natural coarse aggregate, NCA (granite) and ordinary Portland cement (OPC). Sieve analysis which was used to determine the grading of aggregates in accordance with BS 812: Part 104, [16]- . The overall grading limit as given by BS882 [17]- requires percentage mass passing to be between 0 – 15% for sieve size 150 μm. The results in figure show that sample does not satisfy the overall grading limit as given by BS882 [17]- . The percentage mass passing is 33.34%, which indicates that the sand contains finer particles than the one recommended by 2.84%. This implies that the high percent finer may influences strongly the aggregate-cement ratio for the desired workability, compressive strength and stipulated water-cement ratio. However, from the figure, the coefficient of uniformity, $C_u$ and coefficient of curvature ($C_z$) is obtained to be 4.91 and 1.09 respectively. Therefore, since, $C_u < 4$ and $C_z = 1.09$ which according to the Unified Soil Classification System, the soil infers as poorly graded soil. The fineness modulus, specific gravity, $G_s$, bulk density and water absorption are 27.4%, 2.34, 1390 and 2.42 respectively.

A natural coarse aggregate, NCA (crushed granite) (Fig. 2) with smooth surface used in thus study, were sourced from a quarry site in Akure, Nigeria. Also, the maximum size of aggregate commonly used in production of concrete in Akure is 14 mm. The fineness modulus, specific gravity, bulk density and absorption rate are 5.78, 2.65, 1635 and 1.86 respectively. The coefficient of uniformity, $C_c$, is 1.93 while coefficient of curvature $C_u$, is 1.47. Other physical and mechanical properties of the NCA is as shown in Table 1. According to BS 812 [16]- , the standard values for ACV range between 30 and 45. In this study, the average value of ACV for NCA is obtained to be 30.4. Also, the AIV values of the normal aggregates is approximately 23**.** Therefore, the granite used as a coarse aggregate meet specification for both wearing and non-wearing surface.

Recycled coarse aggregates, (RCA) (Fig. 3)) was sourced from the abandoned crushed concrete cubes dumped at Federal University Technology, Akure, (FUTA) structural laboratory. It consists of crushed concrete aggregate and hardened concrete paste. The compressive strength of the crushed concrete cubes is believed to be within the range of 8 N/mm$^2$ and 15 N/mm$^2$. It was crushed manually with the use of hammer and mallet. Prior to the mix design) n, the RCA was sieved and graded to ensure quality concrete matrix. The gradation of RCA is presented in Fig. 5. Also, in order to reduce the water demand by RCA, all particles less than 4.75 mm were not used.

However, from the practical application point view, the RCA is directly used in its natural state (i.e., dry state) in the concrete mix. In other words, RCA is used as a partial replacement for NCA in it dry state that it was neither washed nor pre-saturated in this study. The Aggregate Impact Value (AIV) obtained for Recycled Coarse Aggregate (RCA) is 23.1%. The BS 882 [17]- sets the upper limiting value of AIV at 25%, for aggregates which are adequate for concrete of good impact resistance. This means that aggregates of higher impact values are weaker than aggregates with lower AIV. RCA used in this study, adequate for the production of concrete of good impact resistance.

Palm kernel shell (PKS) is the hard endocarp of palm kernel fruit that surrounds the palm seed. Fig. 4 shows the sample of PKS used in this study. It was obtained at palm kernel oil Production Company in Akure Nigeria. Weathered PKS was washed and flushed with portable warm water to remove dirt oil film coating and other impurities which could be detrimental to the properties of the concrete. it was then dried at ambient temperature of 27±2ºC for a period of 2 days. All the particle of the PKS were less than 20 mm nominal size based on particle size distribution. Although PKS had a higher proportion of fine particles when compared with RCA and NCA. The specific gravity and 24-hr water absorption obtained for PKS are 1.33 and 18%. This indicate high porosity of PKS aggregate as compared with RCA and NCA with specific gravity of 2.60 and 2.65 respectively. The Aggregate Impact Value (AIV) obtained for PKS is 7.6%. The aggregate impact value measures the toughness of the aggregates when impact loads are applied to the aggregates. The BS 882 [17]- sets the upper limiting value of AIV at 25%, for aggregates which are adequate for concrete of good impact resistance. Therefore, PKS as aggregate used in this study is adequate for the production of concrete of good impact resistance.

The aggregate crushing values (ACV) obtained from the study were 16.8% for PKS aggregates. The ACV gives the relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. Aggregates with lower ACV have higher resistance to compressive loads. The recommended maximum ACV stipulated in BS 812 [16]- for aggregates for concrete production is 30%, indicating that the ACV of PKS was within the recommended limit while that of granite was a little. This implies that PKS aggregates used in this research would be adequate for structural concrete production.

***Fig. 1 - Akure Pit-Sand (Fine Aggregate)***

***Fig. 2 - Granite.***

***Fig. 3 - Recycled Coarse Aggregate (RCA)***

***Fig. 4 - Palm Kernel Shell (PKS)***

**Table 1 - Aggregate Properties**

| **Properties** | **Sand** | **NCA** | **PKS** | **RCA** |
|---|---|---|---|---|
| Fineness modulus | 1.82 | 5.78 | - | - |
| Max. aggregate size | 4.75 | 12.5 | 12.5 | 19 |
| Shell thickness (mm) | - | - | 1-5.9 | - |
| Moisture content (%) | 7 | - | 9.7 | - |
| Specific gravity, $G_s$ | 2.34 | 2.65 | 1.33 | 2.60 |
| Bulk Density (kg/m$^3$) | 1390 | 1635 | - | 2280 |
| Absorption | 2.42 | 1.86 | 18 | 7.53 |
| ACV | - | 30.4 | 16.8 | 35.3 |
| AIV | - | 22.76 | 7.6 | 23.1 |
| Shape | - | Irregular | irregular | irregular |

Note: *AIV – aggregate impact value; ACV – aggregate crushing value.*

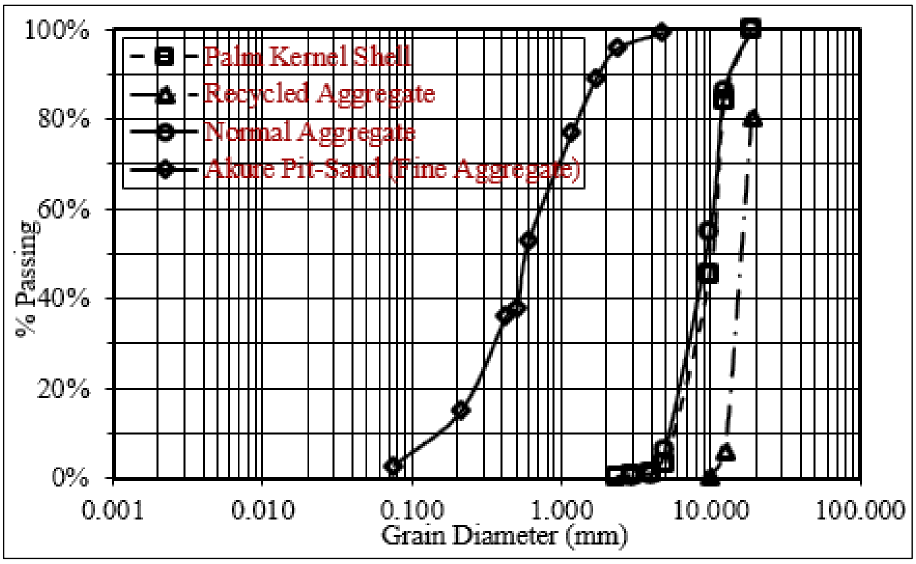


***Fig. 5 - Particle size distribution curves for fine aggregate, NCA, PKS and RCA.***

### *2.2 Methods*

For the purpose of this investigation, a mix ratio of 1:2:4 by weight of cement, sand and coarse aggregate (natural coarse aggregate, NCA/palm kernel shell, PKS/recycled coarse aggregate, RCA) with water-cement ratio of 0.50 was used. Five different concrete mix designs were adopted to have 28-d compressive strength of 15 N/mm$^2$ in this study; one normal aggregate concrete (NAC) and four recycled aggregate concrete (RAC). The NAC in the concrete was kept constant at 50%, while RCA and PKS were varied and tagged with 'Grp' as follows: Grp 1 (50%NCA, 40%RCA, 10%PKS), Grp 2 (50%NCA, 30%RCA, 20%PKS), Grp 3 (50%NCA, 20%RCA, 30%PKS) and Grp 4 (50%NCA, 10%RCA, 40%PKS). The mixtures designation and quantities of various materials for each designed concrete mixes are given in Table 2.

All the samples were prepared in accordance to BS1881: Part 111, [18]- . Slump test was carried on the fresh concrete in order to measure it workability. The samples were placed in the concrete moulds, free of debris and oil. Care was also taken that there were no gaps, so as to avoid the possibility of leakage from the slurry. After 24 hr at ambient temperature, the concrete cubes were removed from the mould, weigh and kept under water in accordance to BS1881: Part111 [18]- . The ambient temperature for was 27±2$^o$C. After the removal from the water and allow to air-dried, hardened concrete tests such as compressive strength test was carried out, well documented and analysed.

**Table 2 - Mix Proportion of Concrete**

| **Mixture Identification** | **Unit weight (kg/m$^3$)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | CA | **RCA** | **NCA** | **FA** | **Cement** | **Water** | ***w*/c** |
| Control (Ctrl) | 844 | - | - | 422 | 211.2 | 126.7 | 0.50 |
| Grp 1 : 50%NCA+40%RCA+10%PKS) | 422 | 337.6 | 84.4 | 422 | 211.2 | 126.7 | 0.50 |
| Grp 2 : 50%NCA+30%RCA+20%PKS) | 422 | 253.2 | 168.8 | 422 | 211.2 | 126.7 | 0.50 |
| Grp 3 : 50%NCA+20%RCA+30%PKS) | 422 | 168.8 | 253.2 | 422 | 211.2 | 126.7 | 0.50 |
| Grp 4 : (50%NCA+10%RCA+40%PKS) | 422 | 84.4 | 337.6 | 422 | 211.2 | 126.7 | 0.50 |

## 3 Results and Discussion

### *3.1 Slump Test*

The slump of normal aggregate concrete (NAC) and concrete with different addition of RCA and PKS were 60 mm, 25 mm, 37 mm, 45 mm and 55 mm, respectively as shown in Fig. 6. The slump of all the concrete groups fell within the range of 25-60 mm, indicating that the concrete mixes exhibits lower to medium workability. The low workability may be due to the rapid absorption of part of mixing water by RCA. It can be seen that the slump increases as the percentage RCA content reduces with increase in % PKS content. Based on the low degree of workability, both NAC and concrete with different addition of RCA and PKS concrete may be suitable for mass concrete foundations without vibration, or lightly reinforced sections with vibration. It can be concluded that the differences between the slump of NAC and concrete containing varying percentage of RCA and PKS might be as a result of the varying particle size distribution, shape index or roughness of NCA. Generally, workability increases when the overall aggregate grading becomes coarser. The low workability can be attributed to the decreasing percentage of humidity content of dry RAC, because it rapidly absorbed part of mixing water. In fact, the use of RCA in its natural state is more practical.

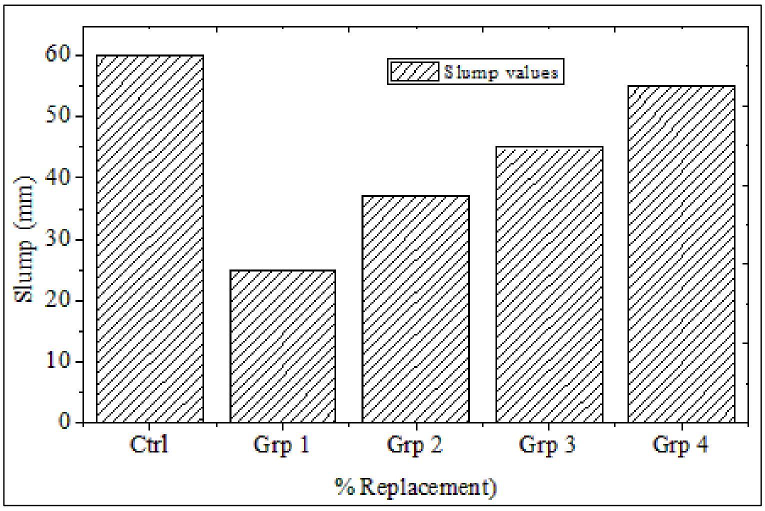


***Fig. 6 - Slump values for concretes with different addition of RCA and PKS with w/c = 0.55***

### *3.2 Concrete Density*

The results of average air-dried densities for the various ages of NAC and concrete different % of RCA and PKS was carried in accordance to BS 1881-114 [19]- and are shown in Fig 7. The densities of concrete mixes with different % of RCA and PKS are less than 2000 kg/m$^3$ at 28-d, the maximum density of lightweight concrete [20]- . However, RCA and PKS can be used to produce concrete members with lower self-weight in comparison with NAC for 1:2:4 mix ratio and 0.5 water/cement ratio. Lower bulk density obtained for concrete mixture with varying percent of RCA and PKS maybe as a result of the lower specific gravity and lower bulk density of RCA and PKS. 28-d bulk density for Grp 1, Grp 2, Grp 3 and Grp 4 were 86.5%, 86.7%, 85.2% and 87% respectively of the bulk density of the control concrete (NAC). The bulk density of the control concrete for all the curing ages were within the range of 2200-2600 kg/m3, the density ranges for normal weight concrete, except the at 7-d which 5.79% less than 2200 kg/m$^3$ (Neville and Brooks, 2010).

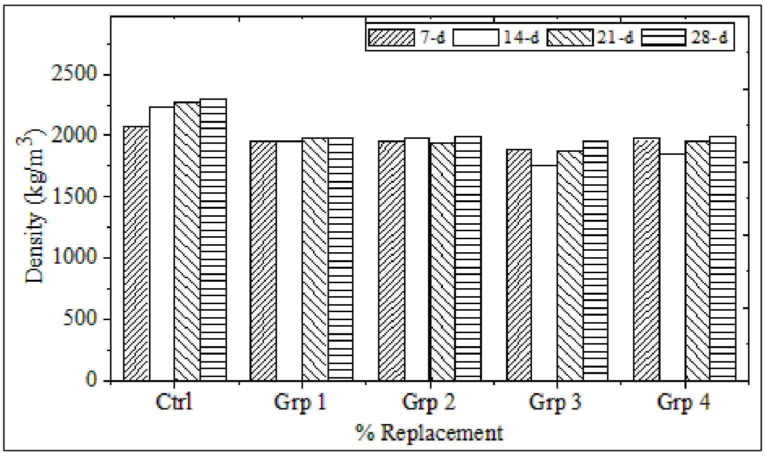


***Fig 7 - Density of concretes with different addition of RCA and PKS, w/c = 0.55 cured at 27±2ºC.***

Ref. [21]- defines the density of structural lightweight concrete as concrete having dry density not exceeding 1840 kg/m$^3$. The values obtained for Grp 1, Grp 2, Grp 3 and Grp 4 exceeds the value recommended by ASTM C 330-04 [21]- by 7.99%, 8.53%, 6.47% and 8.59% at 28-d.

### *3.3 Compressive Strength*

The compressive strength development for concretes with different addition of RCA and PKS, and w/c = 0.5 cured at 27±2ºC at 7, 14, 21, and 28-d is presented in Fig. 8. The figure shows that the compressive strength of each concrete mix increased with a decreases with varying % of RCA and PKS content. As expected, the 7-day concrete cube attained the lowest compressive strength while the 28-day concrete cube had the highest compressive strength for all concrete groups including the control mix (NAC). The low compressive strength of concrete might be attributed to poor physical and bond properties of the RCA and PKS that is due to potentially degraded bond at interfacial transition zone (ITZ) between the RCA, PKS, NCA and the cement matrix. Lower compressive strength can also be explained by smoother surface of NCA, PKS and RCA which induced a lower interparticle attrition. Compressive strength of concrete generally decreases rapidly within the first few days, and the rate of decrease in compressive strength later becomes more gradual. Concrete containing 100% natural aggregate gained high early strength at age of 7-d than all other concrete mixture containing different addition of RCA and PKS.

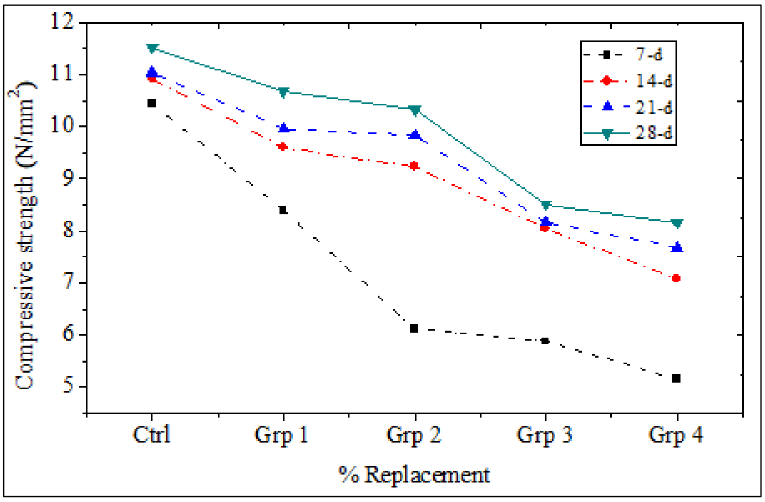


***Fig. 8 - Compressive strength development for concretes with different addition of RCA and PKS, w/c = 0.50 cured at 27±2ºC.***

Ref. [22]- classified of strength of lightweight concrete to be range between 5 and 19.4 N/mm$^2$, therefore, the compressive strength at 28-d for all the concrete mixtures were within the range, which satisfying the strength criteria for classification of lightweight concrete. BS 8110-1 [23] also recommend the minimum compressive strength for lightweight concrete used for reinforced concrete works to be equal or more than 15 N/mm$^2$, therefore all the compressive strength development at 28-d for concretes with different addition of RCA and PKS were less than the strength recommended by BS8110-1 [23]- by 23.2%, 28.87%, 31.2%, 43.2% and 45.6% respectively. The 28- compressive strength of all the concrete mixture also less than the minimum compressive strength of 10 N/mm$^2$ for plain concrete specified in BS 8110-1 [23]- by 15.2%, 6.8%, and 3.2% except for concrete mixture Grp 3 and Grp 4 which were less than by 14.8% and 18.4% respectively. However, the compressive strength at 28-d of all concrete containing different percentage of RCA and PKS were less than the 28-d compressive strength of concrete containing NCA. In general, the relatively low compressive strength of concrete at 28-d may been as a result of weaker bond between the aggregates due the shape and smooth texture of the fine aggregate, coarse aggregate, RCA and PKS used in this study.

The overall grading, particle, shape and surface texture of the coarse aggregates may likely be contributed to low compressive strength.

### *3.4 Thermal Conductivity*

Eq. (1) is used to determine the thermal conductivity, *T* of the experimental concretes in this study [24]- - [27]- .

$$T = 0.055e^{(0.0014D_d)} \tag{1}$$

where $D_d$ is the dry density.

Generally, from Fig. 9. It can be seen that as density increased, the thermal conductivity increases. The figure also shows that as the percentage replacement of different RCA and PKS changes, the density and thermal conductivity of concretes decreases. It was observed that adding 40%RCA/10%PKS (Grp 1), 30%RCA/20%PKS (Grp 2), 20% RCA/30%PKS (Grp 3), and 10%RCA/40%PKS reduces the thermal conductivity by approximately 35%, 34%, 38% and 34% respectively which is very significant amount in terms of energy saving. This implies that combination of RCA and PKS are very good thermal reduction materials. From the figure, the optimum thermal conductivity was achieved with 20%RCA and 30% PKS (Grp 3) concrete mix.

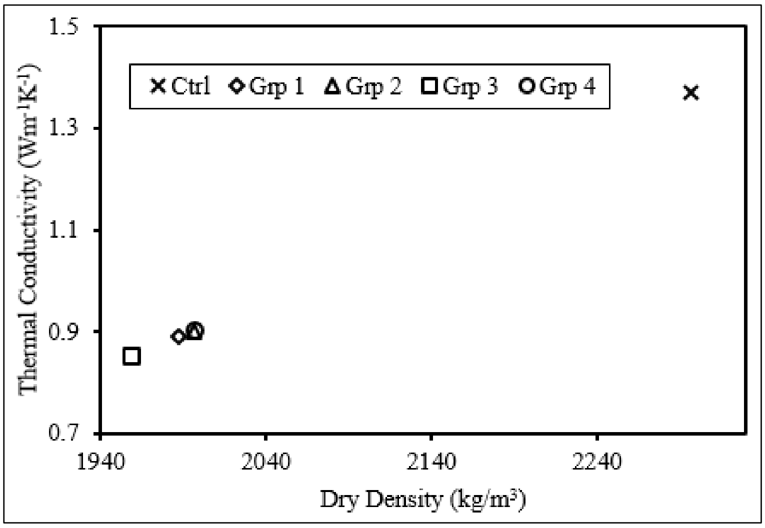


***Fig. 9 - Effect of different addition of RCA and PKS, w/c = 0.55 cured at 27±2ºC on dry density and thermal conductivity at 28-d.***

### *3.5 Statistical Analysis of Compressive Strength*

From Table 3, the *p*-value for the % replacement effect is less than 0.05 (i.e. *p*-value = 0.00 < 0.05) with significant partial $\eta^2$ of about 64%. The *p*-value for the days is also less than 0.05 (i.e. *p*-value = 0.00 < 0.05) with significant partial $\eta^2$ of about 63%. This implies that there is statistical significant difference. Also, the *p*-value for the interaction between percentage replacement of NCA with RCA and PKS and days is greater than 0.05 (i.e. *p*-value = 0.08 > 0.05) with significant partial $\eta^2$ of 35%. This implies that there is statistically non-significant interaction effect between the percentage replacement of NCA with RCA and PKS. However, the effect of the time (days) on the compressive strength depend on the percentage replacement. Also, the effect of the percentage replacement on compressive strength can be said to depend on the time (days).

From table, it is observed that the effect of % replacement only explain about 64% of the total variability in the compressive strength of the concrete. The effect of days (time) explains about 63% of the variance in the compressive strength. The interaction between the % replacement and days only accounts for about 35% in the variability in the compressive strength of the concrete. These findings further support, the fact that effect of % replacement is more significant than the effect of day on the compressive strength of the concrete.

Based on the Tukey Honest Significant Difference (HSD) outcomes for 28-d compressive strength, Seven (7) groups with equal variances were identified: group A (*p*-value = 0.52 > 0.05); group B (*p*-value = 1.00 > 0.05); group C (*p*-value = 0.72 > 0.05); group D (*p*-value = 0.06 > 0.05); group E (*p*-value = 0.52 > 0.05) for percentage replacement; and group F (*p*-value = 0.70 > 0.05); group G (*p*-value = 0.13 > 0.05). There were no significant differences for the concrete mixes Grp 1 and Grp 2; Grp 1 and Grp 3; Grp 1 and Grp 4; Grp 2 and Grp 4; Grp 3 and Grp 4 and also there were statistically non-significant difference at 14-d and 21-d; 21-d and 28-d respectively.

**Table 3 - Summary of two-way univariate ANOVA results**

| Property | Effect | df | Mean square | F-value | P-value | Partial $\eta^2$ |
|---|---|---|---|---|---|---|
| Compressive strength | % replacement | 4 | 18.05 | 17.56 | 0.00 | 0.64 |
| | days | 3 | 23.37 | 22.74 | 0.00 | 0.63 |
| | Interaction between % replacement and days | 12 | 1.87 | 1.82 | 0.08 | 0.35 |

## 4 Conclusions

This study has presented the performance of concrete containing construction and agricultural wastes (CAWs) as a partial replacement for natural coarse aggregate (NCA) in producing lightweight concrete. The normal aggregate concrete, NAC (control mixture) contained 100% natural coarse aggregate (NCA) as coarse aggregate whereas the other four mixtures incorporated binary blends of recycled coarse aggregate (RAC) and palm kernel shell (PKS) at different percentage. The results of slump tests showed an increase in workability as the percentage replacement level of RCA reduces and PKS respectively. The compressive strength of concrete mixes was observed to be less than the strength of lightweight concrete recommended by standards by 23.2%, 28.87%, 31.2%, 43.2% and 45.6% respectively. It can be concluded that the reduced compressive strength of concrete due to the inclusion of RCA and PKS do not limit its use in some structural applications. Based on the result of calculated thermal conductivity, it was observed that as the %RCA content reduces with increasing %PKS content significant amount of energy was saved. The light weight qualities of RCA and PKS compared to NCA may be suitable for architectural application, interior construction and building of light weight structures. Using the PKS and RCA as aggregate in concrete can reduce the material cost in construction because of the low cost and abundant agricultural waste. Although this can be only applicable in light weight structure. Also, an analysis of variance (ANOVA) was carried out to determine the effect of the % replacement and curing period on the compressive strength of concrete. It showed that % replacement had a statistically significant effect on the concrete performance.

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