# Journal of
# Applied Sciences

ISSN 1812-5654

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 8 (18): 3207-3213, 2008
ISSN 1812-5654

# Influence of Cementitious Materials and Aggregates Content on Compressive Strength of Palm Kernel Shell Concrete

[1]U.J. Alengaram, [2]M.Z. Jumaat and [2]H. Mahmud
[1]Department of Built Environment, Faculty of Engineering and Technology,
SEGi University College, Kota Damansara, 47810, Malaysia
[2]Department of Civil Engineering, Faculty of Engineering,
University of Malaya, 50603, Kuala Lumpur, Malaysia

**Abstract:** This study reports the effect of cementitious materials, fine and coarse aggregates content on workability and compressive strength of palm kernel shell concrete. Palm kernel shells a by product of the production of palm oil, were used as lightweight aggregates. The following cementitious materials were added: 10% silica fume as additional cementitious material and 5% fly ash as cement replacement on weight of cement. The influence of varying fine aggregate and palm kernel shell contents on workability and compressive strength has been studied. The specimens have been cured under three different curing environments to study the effect on compressive strength. The effect of cementitious materials and curing conditions on compressive strength for a period of 90 days was analyzed. The fresh density of concrete was found to be in the range of 1810 to 1940 kg $m^{-3}$. The strength of Palm Kernel Shells (PKS) was found to be the primary factor controlling the strength. However, the addition of silica fume was found to have influence on compressive strength. An increase in fine aggregate content and subsequent decrease in PKS content had positive effect on both workability and compressive strength. The 28 day compressive strengths of the mixes containing cementitious materials were found in the range of 26 to 36 MPa. The difference in strength between water cured and specimens cured under controlled environment was found to vary between 3 and 5%.

**Key words:** Lightweight aggregate, fly ash, silica fume, aggregates content, density

## INTRODUCTION

The excessive use of Normal Weight Concrete (NWC), lead to exploitation of gravel and crushed rock at the expense of the ecological balance of our environment. The increasing volume of concrete used in plain and reinforced concrete works led us to manufacture of alternate Light Weight Aggregates (LWA) that could be used in place of normal weight aggregates (NWA). In most of the developed countries, the use of Light Weight Concrete (LWC) in different forms, such as Light Weight Aggregate Concrete (LWAC), no-fines concrete and aerated concrete enabled faster building rates than with more traditional material. The most obvious characteristic of LWC is its density as it reduces the dead load and lower haulages and handling costs. Also LWC has relatively low thermal conductivity, as smaller walls built using LWC can give thermal insulation four times greater than normal clay brick wall.

In the industrially advanced countries, increased knowledge of materials technology and of structural performance through research and experience has been reflected in the modern design procedures. And hence the large-scale development of new types of LWA is more rapid. However, in many developing and underdeveloped countries in Asia and Africa, manufactured LWA are not available and this may be attributed to many reasons, such as general lack of understanding on production technique of LWA, towering production cost, non-availability of raw materials and resources.

Manufactured LWA have been used to produce structural concrete in developed countries for many years. The use of synthetic lightweight aggregates from natural raw materials like clay, slate, shale etc. and from industrial by-products such as fly ash and slag ash hasn't been fully explored in developing and underdeveloped countries. However, researches in Asia and Africa on the use of organic natural aggregate in the form of palm kernel shells (PKS) (1988; Basri *et al*., 1999; Mannan and Ganapathy, 2004; Ata *et al*., 2006) are on the rise. One of the reasons for the use of such natural organic materials is the availability of such industrial

**Corresponding Author:** U. Johnson Alengaram, Department of Built Environment, Faculty of Engineering and Technology, SEGi University College, Kota Damansara, 47810, Malaysia Tel: 0060361452777 Fax: 0060361452666

by-products as waste materials. Malaysia is the second largest producer of palm oil and in that process it produces millions of tonnes of PKS as waste material.

The compressive strength depends on factors such as water, sand, aggregate contents and density. Okafor (1988) has found that the failure of PKS concrete is generally governed by the strength of PKS and this has been agreed by other researchers. However, the smooth and convex surfaces of PKS produce poorly compacted concrete and these result in bond failure between PKS and cement matrix. Silica Fume (SF) has been used to produce high strength concrete and SF particles are 100 times smaller than cement particles. The extremely very fine SF particles have the ability to be located in the very close proximity of the aggregate particles (Neville, 1996). Thus the zone between aggregate and cement paste interface, which is called zone of weakness, could be strengthened by the use of SF. However the study on properties of concrete containing PKS as coarse aggregates incorporating SF as cementitious material hasn't been carried out.

As mentioned, most of the studies in the past on the PKS concrete produced concrete of strength of about 25 MPa. And one of the reasons for such low strength of PKS concrete has been the weaker bond between the PKS and the cement matrix. Thus, there is a need for improvement of this weak zone between the PKS and the cement matrix. This study focuses on this objective of improving the aggregate-cement interface by adding 10% of SF as cementitious material. In addition, the stiffness of the matrix also plays an important role in the development of strength. Hence the fine aggregate content has been altered to study its effect on the compressive strength.

In this study, 10% of SF on weight of cement has been used as additional cementitious material. In addition, 5% of class- F Fly Ash (FA) was also used as cement replacement material. Both of these cementitious materials were based on the weight of the cement. The effect of SF and FA as cementitious materials on workability and compressive strength up to the age of 90 days has been studied. The strength development under different types of curing has been analysed and compared. The influence of sand and coarse aggregate (PKS) contents on workability and compressive strength has also been studied and reported. The highest fresh density of PKS concrete was found about 1940 kg $m^{-3}$ and the as cured densities were found in the range of 1802 to 1971 kg $m^{-3}$.

## MATERIALS AND METHODS

**Cement and cementitious materials:** Ordinary Portland cement conforming to MS 522; Part-1:2003 with specific gravity and surface area of 3.10 and 335 $m^2$ $kg^{-1}$, respectively was used for all mixes. The residue on 45 and 90 μm were, respectively 6.8 and 0.6%. Class - F fly ash obtained from Lafarge Malayan Cement with $SiO_2$ content about 65% and relative density of 2.10 was used. SF in densified form with specific gravity of 2.10 was used as additional cementitious material for all mixes. The chemical compositions of cement, FA and SF are given in Table 1. The superplasticizer (SP), Rheobuild 1000 M with specific gravity of 1.21 was used at different percentages. The percentages of the FA, SF and the SP on the basis of weight of cement used in different mixes are shown in the Table 2.

**Fine and coarse aggregates:** Mining sand was used as fine aggregates with particle density of 2.7. It was dried and sieved to a particle size range between 0.15 and 2.36 mm. Figure 1 shows the different particle sizes of the

Table 1: Chemical composition of cement, fly ash and silica fume (%)

| | Oxide composition | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Materials | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | LOI | $TiO_2$ | $P_2O_5$ |
| Cement | 19.8 | 5.10 | 3.10 | 63.4 | 2.50 | 2.40 | 1.00 | 0.19 | 1.80 | - | - |
| Fly Ash (FA) | 64.6 | 20.9 | 4.00 | 1.00 | 0.66 | 0.30 | 1.20 | 0.32 | 5.10 | 1.10 | 0.07 |
| Silica Fume (SF) | 94.6 | 0.14 | 0.11 | 0.01 | 0.01 | 0.01 | 0.62 | 0.01 | 4.10 | 0.01 | 0.22 |

Table 2: Mix proportions of PKSFC and PKSC

| Mix description | Water/binder ratio | Fly ash (%) | Silica fume (%) | Superplasticizer (%) | Sand/cement ratio | Aggregate/cement ratio |
|---|---|---|---|---|---|---|
| PKSC-W1 | 0.30 | 5 | 10 | 1.3 | 0.8 | 1.0 |
| PKSC-W2 | 0.32 | 5 | 10 | 1.0 | 0.8 | 1.0 |
| PKSC-W3 | 0.35 | 5 | 10 | 0.8 | 0.8 | 1.0 |
| PKSC-PW | 0.35 | 0 | 0 | 1.0 | 0.8 | 1.0 |
| PKSC-S1 | 0.35 | 5 | 10 | 1.0 | 1.0 | 0.8 |
| PKSC-S2 | 0.35 | 5 | 10 | 1.0 | 1.2 | 0.8 |
| PKSC-S3 | 0.35 | 5 | 10 | 1.0 | 1.6 | 0.8 |
| PKSC-PS | 0.35 | 0 | 0 | 1.0 | 1.0 | 0.8 |

Fig. 1: Palm Kernel Shells (PKS)

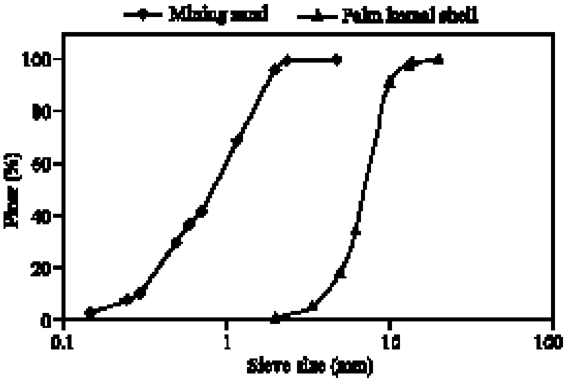

Fig. 2: Particle size distributions of sand and PKS

PKS. The particle size distribution of fine and coarse aggregates is shown in Fig. 2. PKS used as coarse aggregates were obtained from local crude palm oil producing mill. Since PKS are waste materials, the shells are normally stockpiled in open fields, thus subject to varying climatic conditions. As Malaysia is a tropical country with unpredictable rainfall throughout the year, the shells are bound to absorb moisture during such storage conditions; also during sunny days, the surface moisture may be dried out leaving some moisture inside the pores of PKS. Hence the water absorption characteristics of PKS were determined.

**Preparation of PKS as coarse aggregate:** Preparation of PKS was done first by drying, sieving and washing the aggregates with detergents in order to remove dust, oil and mud particles that adhered to the surfaces of PKS. After washing, the particles were again dried under roof and then stockpiled. Due to high water absorption of PKS (about 25%), pre-soaking of aggregates for about 45 min to 1 h is mandatory. The absorption during this period of pre-soaking was determined and found to be in the range of 10 to 12%. Particles with size less than 3.35 mm were removed and not used in mixes due to large relative surface area and high absorption.

Table 3: Curing environment

| Symbol | Mould (days) | Water (days) | Room (days) (23°C and RH 65±5%) |
|---|---|---|---|
| W | 1 | 89 | - |
| P-1 | 1 | - | 89 |
| P-2 | 1 | 6 | 83 |

**Mix design and concrete mixtures:** The mix design was done based on relative densities of materials, 5% FA as cement replacement, 10% SF as additional cementitious material and proportion of the constituent materials. Varying water to binder ratio (w/b), sand to cement ratio (s/c) and aggregate to cement ratio (a/c) were used for designing mixes. A total of six concrete mixes incorporating cementitious materials and varying w/b and s/c ratios were prepared as shown in Table 2. The mix series with varying w/b and s/c ratios were labelled as PKSC-W and PKSC-S, respectively. Two mixes containing no cementitious materials were also prepared for comparison and labelled as PKSC-PW and PKSC-PS. All the materials were weight batched. The mixing of materials was done in the following order: Firstly one-half of PKS and sand were mixed in the mixer. This was followed by addition of one-half of cement, fly ash and silica fume; part of water with superplasticizer was then added; on complete mixing, the remaining portion of materials were added in appropriate order. The specimens were cast in 100 mm cube moulds and covered with plastic sheeting in the uncontrolled laboratory condition for 24 h and then demoulded. The cement content for mixes containing cementitious materials varied in the range of 440 to 530 kg m$^{-3}$.

**Testing procedures:** The fresh, as cured and oven dry densities of PKS concrete were measured. Workability tests by slump and flow measurements were done in accordance with BS standards. The samples were cured as shown in Table 3. The specimens cured under P-1 type of curing were wrapped immediately after demoulding using two layers of cling film. However for P-2 type cured specimens, the samples on demoulding were cured in water for 6 days and then wrapped in cling film. Both P-1 and P-2 type cured specimens were stored in sealed condition at 23°C and relative humidity of 65±5% until day of testing. The densities of all specimens were measured before testing and the samples that were not cured in water have been soaked in water before testing. The compressive strengths based on British Standards were measured at 1,7,14, 28, 56 and 90 days.

## RESULTS AND DISCUSSION

**Properties of PKS:** The thicknesses of shells were in the range of 1.7 to 2.6 mm and the sizes of shells vary between 2 to 15 mm. The relative density in saturated surface dry condition determined was found to be 1.37. The loose and compacted densities were found as 568 and 620 kg $m^{-3}$, respectively. The natural moisture content and 24 h water absorption of PKS were found in the range of 8 to 15 and 25%, respectively. The pre-soaking of PKS for a period of about 45 to 60 min. increased the total moisture content. This however could be beneficial in the hydration process for specimens cured under controlled environment. The above results are close to the findings of the past researches.

**Density:** The measured fresh, as cured and oven dry densities as of 28 day are given in Table 4. The fresh densities of PKSC ranged between 1802 and 1940 kg $m^{-3}$. It has been found that oven dry densities were about 220 to 260 kg $m^{-3}$ lower than water cured densities. The highest density of 1971 kg $m^{-3}$ was reported for mix containing s/c ratio of 1.6. Increase in sand content beyond s/c ratio of 1.6 might have resulted in density limit for LWC of 2000 kg $m^{-3}$ and hence mixes containing s/c ratio higher than 1.6 was not considered. The densities of specimen cured under controlled environment at the age of 28 days were found in the range between 1802 and 1946 kg $m^{-3}$, a decrease of about two to five percent compared with specimens cured in water. This reduction in density was due to moisture loss during hydration and this trend increases with age.

**Workability:** Figure 3 and Table 4 show workability tests and their results respectively. The poor workability of mixes PKSC: W1 and W2 was primarily due to lower w/b ratio and higher PKS content. Higher PKS content combined with irregular and angular shapes of PKS resulted in poor workability. This might be due to friction between angular surfaces of PKS particles and lower fines content. However for mixes PKSC: S1 - S3 with w/b ratio of 0.35 and a/c ratio of 0.8, the workability ranges from medium to high. Thus, a reduction in PKS content and a subsequent increase in fine aggregate content increases workability. Similar findings were reported by Okafor (1988). However for mix, PKSC: S3 with a/c of 0.8 and s/c ratio of 1.6, medium workability of about 50 mm was obtained, indicating higher fine aggregate content reduces workability.

The mix PKSC: PS containing no cementitious materials produced very high workability with slump value of 160 mm. However for mix PKSC: S1 of similar mix proportion containing cementitious materials, a slump of 105 mm was found. The silica fume added as additional cementitious material has produced cohesive mix and this

(a) Slump cone test

(b) Flow table test

Fig. 3: Workability tests

Table 4: Properties of palm kernel shell concrete

| Mix description | Fresh density (kg $m^{-3}$) | As cured density (28 days) (kg $m^{-3}$) W | P-1 | P-2 | Oven dry density (kg $m^{-3}$) | Slump (mm) | Flow (mm) |
|---|---|---|---|---|---|---|---|
| PKSC-W1 | 1802 | 1837 | 1810 | 1821 | 1592 | 0 | 200-250 |
| PKSC-W2 | 1810 | 1841 | 1802 | 1820 | 1583 | 0 | 200-260 |
| PKSC-W3 | 1816 | 1839 | 1789 | 1806 | 1579 | 30 | 200-280 |
| PKSC-PW | 1849 | 1865 | 1821 | 1846 | 1630 | 35 | - |
| PKSC-S1 | 1852 | 1893 | 1845 | 1857 | 1639 | 105 | 220-370 |
| PKSC-S2 | 1912 | 1940 | 1850 | 1885 | 1705 | 103 | 200-330 |
| PKSC-S3 | 1940 | 1971 | 1935 | 1946 | 1715 | 50 | 200-290 |
| PKSC-PS | 1895 | 1915 | 1842 | 1887 | 1694 | 160 | - |

resulted in lower slump values. This could be related to the effect of SF, as it increases the cohesiveness of the mix due to its fineness and filling the gap between particles of cement (Neville, 1996).

Slump test tends to underestimate workability of lightweight aggregate concrete (Clarke, 1993) and therefore flow values using flow table test were measured. Higher flow table values in the range of 220-370 mm were recorded for mixes having higher sand and lower PKS contents. However for mixes with lower sand and higher PKS content, lower flow values were found. Though only 5% of FA was added, its contribution to workability can't be ignored as spherical shape of FA reduces friction forces between aggregate particles and increases the workability (Neville, 1996). The addition of SP has also increased workability and the use of SP is mandatory due to the inclusion of SF. A slightly higher SP content as mentioned in Table 2 has been used for the mix PKSC: W1 due to lower w/b ratio.

## Compressive strength

**Influence of w/b, s/c and a/c ratios on compressive strength:** Figure 4 and 5 show progress of compressive strength of PKSC for a period of 90 days in different curing environments. It was observed that the compressive strength depends on factors such as w/b, a/c and s/c ratios. As with normal weight concrete, lower the w/b ratio, higher the compressive strength. The highest 28 day compressive strength of about 30 MPa, amongst PKSC-W series was found for mix PKSC-W1 with w/b ratio of 0.30 (Fig. 4a). The mixes with w/b ratio of 0.32 and 0.35, respectively produced lesser strength of about 9 and 12% compared to mix with w/b ratio of 0.3 on 28 day strength (Fig. 4c, d). Figure 5a-d show the effect of higher fine aggregate and lower PKS contents on compressive strength. Generally higher density concrete produces higher strengths. For mix PKSC: S3, the s/c ratio was maintained at 1.6 and this had resulted in the highest density of approximately 1970 kg m$^{-3}$ and the highest 28 day strength of about 36 MPa was achieved. It was evident during test that the breaking of PKS took place before final failure, thus indicating failure of PKS than mortar. Hence it can be concluded that the failure of PKS governed the strength for both concretes with w/c and s/c ratio as variables. The 28 day strength of 36 MPa obtained for the mix PKSC: SC3 is the highest and if compared with the previous findings (Mannan and Ganapathy, 2004), it is nearly 45% higher. Similarly another comparison with that of Ata *et al.* (2006) shows that it is nearly 2 ½ times higher. Thus, it is evident from the test results that the addition of silica fume and an increase in sand content had influenced the compressive strength in the PKSC.

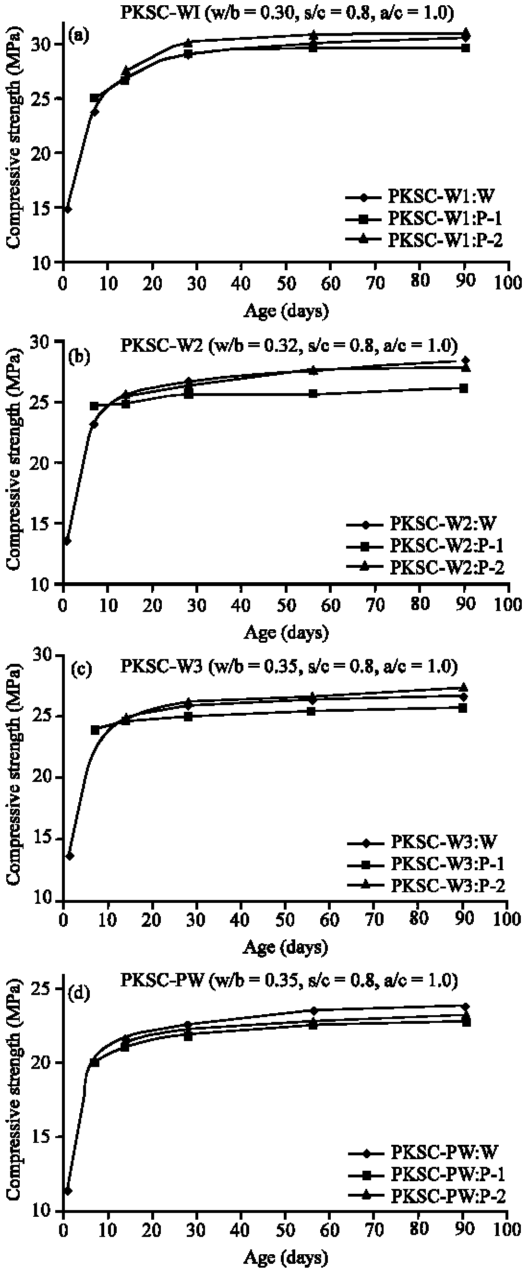

Fig. 4: Development of compressive strengths of PKSC-W series

Due to higher PKS content combined with lower fine aggregate content, the failure of PKS in PKSC: W1-W3 occurred earlier. However for mixes PKSC: S1-S3, the strength gain due to higher fine aggregate and lower PKS contents was evident as good bond between PKS and cement matrix enabled the concrete to sustain higher load. Mixes of PKSC: S1-S3 series with higher fine aggregate and lower PKS content show that increase of compressive strength between 14 and 40% as compared to that of

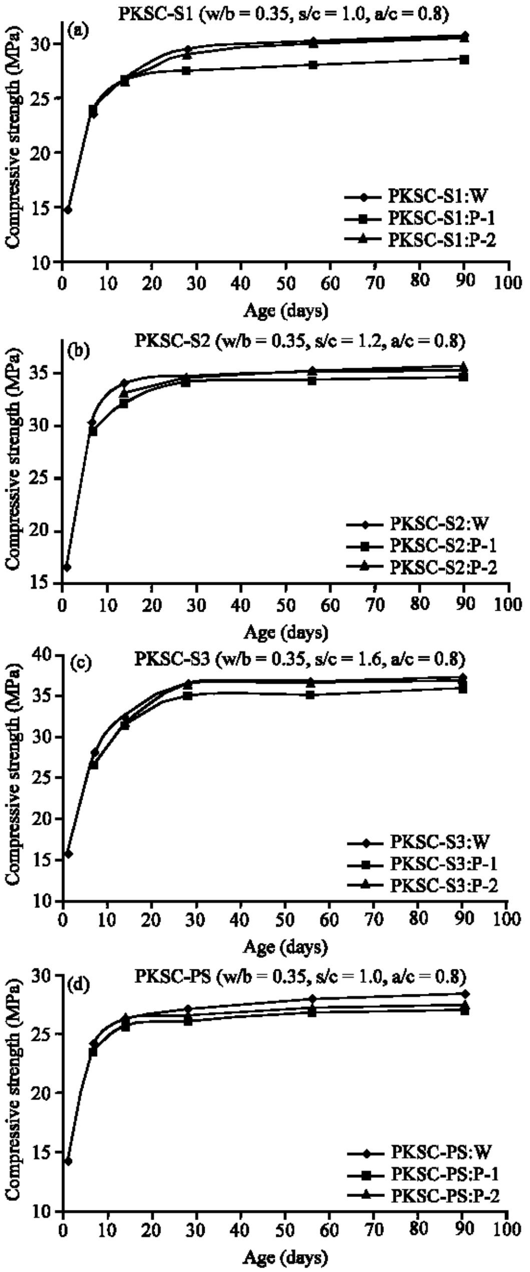

Fig. 5: Development of compressive strengths of PKSC-SC series

PKSC: W3. The presence of high volume of pores in PKS which was evident because of high water absorption of about 25% may weaken the particle strength and stiffness. Though the pores may weaken the compressive strength and elastic modulus properties of PKSC, these pores may help in development of good bond by the suction of the paste into the pores of PKS. However further investigation is required to study this effect.

**Influence of silica fume on compressive strength:** The addition of SF has influenced the compressive strength as seen from comparison of Fig. 4 and 5. The 28 day compressive strengths of PKSC-W3 and PKSC-PW show that an increase of about 10 to 15% for mix containing SF for same w/b ratio. However, for mixes PKSC: W1 and W2 with low w/b ratio, the increase in 28 day compressive strength was found in the range between 18 and 35% compared to mix, PKSC:PW that contained no SF. A similar trend of increase in compressive strength was noticed for PKSC: S series mixes. High early strength of about 40 to 50% and 80 to 90% in one day and 7 day, respectively on 28 day strength was observed for mixes containing SF. This may be attributed to fineness of SF and reaction between silicon dioxide and calcium hydroxide (Neville, 1996). The infilling of the voids in the shells by very fine SF particles may have increased the bond between PKS and cement matrix. SF plays major role in early strength development, allowing aggregates better to participate in stress transfer. However, as mentioned earlier further research is required to study the effect of SF in the pores of PKS. Thus for all PKSC specimens containing SF, the failure was predominantly due to failure of PKS that was evident during test. The development of strength beyond the period between 28 and 90 days has been in the range of two to seven percent on 28 day compressive strength, though not significant, indicates that hydration continues at slower rate. Thus the addition of five percent of FA hasn't significantly improved hydration at later stages.

**Effect of curing environment on compressive strength:** It has been found that controlled environment played a role in hydration and hence strength gain. For both P-1 and P-2 types of curing, relative humidity and temperature of about 65% and 23±3°C, respectively were maintained. As seen from the Fig. 4 and 5, specimens cured under P-1 cured condition show lower strength than the water cured and P-2 cured specimens. During the first 28 days, the difference in strength between P-1 cured and water cured specimens was found in the range of two to four percent on water cured specimen except for PKSC: S1 that had a difference of about 7%. This may be due to poor hydration in P-1 cured samples as these samples have been sealed immediately after demoulding. However, it can be shown from the results that hydration process continued in specimens cured in P-1 condition indicating supply of water for hydration from pre-soaked PKS. The gain of strength between 28 and 90 day period for water cured was about two to six percent, while P-1 cured recorded a gain in the range of 2-4%.

Specimen cured under P-2 curing condition showed negligible difference in strength gain compared to water cured specimens and in some cases slightly higher strength was recorded than water cured specimen. Here the gain in strength can be attributed to water curing for 6 days on demoulding as between 80 to 90% of strength is achieved during this period. Thus P-2 cured specimens matched the strength as that of water cured specimens. The constant temperature maintained coupled with continued unhindered hydration of P-2 cured specimen may have contributed to slight higher strength achieved than water cured specimens. The strength gain of P-2 type cured specimens was found in the range of two to 6% between 28 and 90 days.

**Comparison between PKSC with and without cementitious materials:** The cement contents used in the mixes were in the range of 440 to 530 kg $m^{-3}$ for mixes containing cementitious materials. However, the mixes PKSC: PW and PKSC: PS, containing no cementitious materials, had cement content of about 550 and 570 kg $m^{-3}$, respectively. Thus a comparison of PKSC: W series containing cementitious materials with PKSC: PW that had no cementitious materials has shown an increase in strength between 12 to 35% for specimens cured in three curing environments. Similar comparison between PKSC: S series and PKSC: PS showed that an increase of about 10 to 35% between 28 and 90 days.

## CONCLUSION

The fresh density of mix containing the highest sand to cement ratio of 1.6 was found about 1940 kg $m^{-3}$ and this is within the density limit of 2000 kg $m^{-3}$ for lightweight concrete and 28 day compressive strength of about 36 MPa was achieved. Thus using PKS as coarse aggregate lightweight concrete of grade 35 could be produced.

The addition of silica fume, higher PKS content and lower fine aggregate content results in poor workability; the angular and irregular surfaces of PKS increases the friction between aggregate particles; however increase in sand content and subsequent decrease in PKS content yielded medium to high slump; the use of superplasticizer is mandatory due to lower w/b ratio and high sand content.

The fine aggregate and PKS contents have influence on the compressive strength. However the addition of 5% of fly ash hasn't contributed to hydration at later stages.

The mixes containing silica fume produced higher strength in the range of 12 to 35% than the mix without silica fume in different types of curing environment.

The specimens cured under P-1 curing environment have shown a reduction in strength between 2 and 4% as compared to water cured specimens. However P-2 cured specimens had achieved almost equal strength as that of water cured specimen.

The addition of ten percent of silica fume as cementitious material to PKS concrete is recommended where the target strength of PKSC is about 30 MPa.

It is recommended to use lower sand to cement ratio than the ratio of 1.6 to obtain PKSC of density below 1900 kg $m^{-3}$.

## ACKNOWLEDGMENT

This project is funded by the Ministry of Science, Technology and Innovation under the Science Fund No. 13-02-03-3053.

## REFERENCES

Ata, O., E.A. Olanipekun and K.O. Oluola, 2006. A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates. Build. Environ., 41: 297-301.

Basri, H.B, M.A. Mannan and M.F.M. Zain, 1999. Concrete using oil palm shells as aggregate. Ceme. Concr. Res., 29: 619-622.

Clarke, J.L., 1993. Structural Lightweight Aggregate Concrete. 1st Edn., Chapman Hall, Glasgow, ISBN: 0 7514 0006 8 .

Mannan, M.A. and C. Ganapathy, 2004. Concrete from an agricultural waste-oil palm shell (OPS). Build. Environ., 39: 441-448.

Neville, A.M., 1995. Properties of Concrete. 4th Edn., Longman Group Limited, London, ISBN: 0-582-23070-5.

Okafor, F.O., 1988. Palm kernel shell as aggregate for concrete. Cem. Concr. Res., 18: 901-910.