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The Use of Palm Kernel Shell and Ash for Concrete Production

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***Abstract*—**This work reports the potential of using Palm Kernel (PK) ash and shell as a partial substitute for Portland Cement (PC) and coarse aggregate in the development of mortar and concrete. PK ash and shell are agro-waste materials from palm oil mills, the disposal of PK ash and shell is an environmental problem of concern. The PK ash has pozzolanic properties that enables it as a partial replacement for cement and also plays an important role in the strength and durability of concrete, its use in concrete will alleviate the increasing challenges of scarcity and high cost of cement. In order to investigate the PC replacement potential of PK ash, three types of PK ash were produced at varying temperature (350-750^{0}C) and they were used to replace up to 50% PC. The PK shell was used to replace up to 100% coarse aggregate in order to study its aggregate replacement potential. The testing programme included material characterisation, the determination of compressive strength, tensile splitting strength and chemical durability in aggressive sulfate-bearing exposure conditions. The 90 day compressive results showed a significant strength gain (up to 26.2 N/mm^2). The Portland cement and conventional coarse aggregate has significantly higher influence in the strength gain compared to the equivalent PK ash and PK shell. The chemical durability results demonstrated that after a prolonged period of exposure, significant strength losses in all the concretes were observed. This phenomenon is explained, due to lower change in concrete morphology and inhibition of reaction species and the final disruption of the aggregate cement paste matrix.

***Keywords*—**Sustainability, Concrete, mortar, Palm kernel shell, compressive strength, consistency.

I. INTRODUCTION

To mitigate the continuously increasing demand for low cost and environmental friendly construction materials, while strengthening economic growth and competitiveness, agricultural wastes can be used as replacement material in construction industry, especially, in countries where abundant agricultural wastes are discharged. The production of palm oil for example, result in various waste product materials such as empty fruit bunches, palm kernel ash and palm kernel shells.

In most countries, these waste product materials are being stockpiled in open land-fields and thus it had negative impact on environment. These palm kernel ash and shell have the potential to be used as a partial replacement for cement and aggregate, leading to reduction in the cost of construction, and a convenient means of waste disposal, resource preservation and other environmental gains. The applications of agricultural wastes as aggregate or cement replacement material in concrete have engineering potential and economic advantage especially in low-cost non-load bearing lightweight concrete, where compressive strength is not important.

Previous studies have shown that palm kernel shell can be used as a lightweight aggregate for concrete production [1]. Although the compressive strength of the concrete made with palm kernel shell fulfils the requirement for lightweight concrete, higher strength of is preferred for medium strength structural members [1]. The results of another work on the ductility behaviour of reinforced palm kernel shell concrete beams showed that the mode of failure observed in palm kernel shell was ductile [2]. The work by another worker [3] reported on the engineering properties of concrete incorporating palm kernel shell and demonstrated that that concrete made with palm kernel shell has lower modulus of elasticity when compared to conventional concrete; however, palm kernel shell concrete has sufficient strength to be accepted as structural lightweight. Shafigh et al. [4] reported on a new method of producing high strength oil palm shell lightweight concrete and showed that crushed oil palm shells are hard and also have a stronger physical bond with the hydrated cement paste, in addition, the study demonstrated that it was possible to produce lightweight concrete with palm oil shell with significantly lower cement content.

The focus of this paper is to report on the material characterisation, the compressive strength and chemical durability and statistical modeling of concrete made with palm kernel shell and ash. This is an attempt to come up with up-to-date information on palm kernel ash as partial substitutes for cement and the use of palm kernel for aggregate replacement. The use of PK ash and shell for cement and aggregate replacement will help to alleviate the disposal problems of which is an environmental concern and will potentially reduce the increasing challenges of scarcity and high cost of cement. This paper will be of interest to civil engineers and other built environment professionals who need quick access to new generation concrete through the application of new technologies.

II. METHODOLOGY

A. Materials

The materials used in the research consisted of Portland cement, limestone aggregate, palm kernel shell/ash and natural sea-dredged sand.

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1) Portland Cement

Portland Cement (PC), manufactured in accordance with BS EN 197-1 [5], supplied by Lafarge Cement UK, was used throughout this research programme. Some of the oxide and chemical composition of PC can be seen in Table I, the physical properties of the PC in Table II and the particle size distribution for the PC as determined by light scattering in Table III.

TABLE I
THE OXIDE AND SOME CHEMICAL COMPOSITION OF PC

Oxide	PC
SiO_2	20.00
TiO_2	–
Al_2O_3	6.00
Fe_2O_3	3.00
MgO	4.21
MnO	0.03 - 1.11
CaO	63.00
Na_2O	–
K_2O	–
P_2O_5	–
SO_3	2.30
N_2O	–
S^{3-}	
$CaCO_3$	–
Loss on Ignition	0.8
Chemical (%)	
Cl	0.03
Free lime	1.32
Bogue's composition	
Tricalcium aluminate (C_3A)	6.48
Tricalcium silicate (C_3S)	70.58
Dicalcium silicate (C_2S)	6.09
Tetracalcium alumunate-ferrite (C_4AF)	6.45

TABLE II
SOME PHYSICAL PROPERTIES OF PC

Properties	PC
Insoluble Residue	0.5
Bulk Density (kg/m³)	1400
Relative Density	3.1
Blaine fineness (m^2/kg)	365
pH	
Liquid Limit (LL) (%)	–
Plastic Limit (PL) (%)	–
Plasticity Index (%)	–
Maximu Dry Density {MDD} (mg/m^3)	–
Optimum Moisture Content {OMC} (%)	–
Colour	Grey
Glass Content	–

TABLE III
PARTICLE SIZE DISTRIBUTION FOR PC

Size(mm)	PC (%)
>40	18
20– 40	27
10–20	12
>10	43

2) Limestone Aggregate

The limestone aggregates used throughout this investigation was size 10/4. The aggregates were supplied by a local quarry and complied with the requirements of PD 6682-1[6] and BS EN 12620 [7]. The results of sieve analysis of the limestone aggregate performed in accordance with BS EN 12620 [7] and BS EN 933-1 [8] are given in Table IV. Some geometrical, mechanical and physical properties of the limestone aggregate in compliance with BS EN 1097-6 [9], BS EN 933-3 [10], BS EN 933-4 [11], BS EN 1097-6 [9] and BS 812-112 [12] are shown in Table V.

TABLE IV
THE SIEVE ANALYSIS OF THE AGGREGATES AND PALM KERNEL SHELL WASTE

Sieve Sizes (mm)	Sand	Limestone	Palm kernel shell
		10/4.	**10/4.**
31.5	100	100	100
16	100	100	100
8	100	77	72.1
4	100	2	1.9
2	83	0.3	0.15
1	54	0.28	0.31
0.5	21.8	0.19	0.13
0.25	6	0.14	0.11
0.125	1.2	0.1	0.11

TABLE V
SOME GEOMETRICAL, MECHANICAL AND PHYSICAL PROPERTIES OF THE AGGREGATES AND PALM KERNEL SHELL WASTE

Property	Sand	Limestone 10/4.	Palm kernel shell 10/4.
Water absorption (%)	0.85	1.5	12.8
Saturated density (Mg/m^3)	2.82	2.68	1.33
Dry density (Mg/m^3)	2.71	2.57	1.42
Shape index (%)	–	12	32
Impact value (%)	–	18	12
Flakiness index (%)	–	23	37

3) Palm Kernel Shell and Ash

Palm kernel shell is a waste product of the palm mill industry; this industry extracts oil from oil palms fruits. The palm kernel shell used in this current work was supplied by a local contractor. Palm kernel shell are hard, flaky and of irregular shape. The most important aspects of using palm kernel shell as aggregate replacement was to ensure that the palm kernel shells are properly prepared. This is of extreme importance during the mixing of material for the various mixes. First, pre-treatment of the palm kernel shell was carried out by removing oil coating with detergent and water, washing and sieving the palm kernel shell into the required particle sizes for the current work. Some of the Palm kernel shell were then burnt to a temperature of around 350- 750^{0}C and grinded into fine as particles for use as palm kernel ash. The results of sieve analysis of the palm kernel shell performed in accordance with PD 6682-1 [6], BS EN 12620 [7] and BS EN 933-1 [8] are given in Table IV. Some geometrical, mechanical and physical properties of the palm kernel shell in compliance with BS EN 1097-6 [9], BS EN 933-3 [10], BS

EN 933-4 [11], BS EN 1097-6 [9] and BS 812-112 [12] are also shown in Table V.

4) Sand

The sand used throughout this study was natural sea-dredged sand from the Bristol Channel. The sieve analysis performed in accordance with PD 6682-1 [6], BS EN 12620 [7] and BS EN 933-1:1997. Some geometrical, mechanical and physical properties of the palm kernel shell in compliance with BS EN 1097-6 [9], BS EN 933-3 [10], BS EN 933-4 [11], BS EN 1097-6 [9] and BS 812-112 [12] are also shown in Table V.

B. Mix Design, Sample Preparation and Testing

The control mix for the concrete in the current research work adopted a mix used on various occasions in previous studies by the authors. This mix had been used to assess the strength and consistency of concrete incorporating metakaolin (MK), pulverised fuel ash (Pfa) and slate waste [13]. The mix used a binder: sand: aggregate proportion of 1 : 1.85 : 2.64, using limestone aggregate and a Portland cement content of 390 kg/m^3. The water/binder ratio was 0.5, with a slump of 70 mm. Based on this control mix for the concrete, the current investigation used Palm Kernel Shell (PKS) aggregates to replace the limestone aggregate in the control mix (PKSC-1). The intention was not to maintain a specified consistency but to obtain usable concrete, irrespective of consistency, using PKS aggregate and, if possible, without using superplasticisers, for cost-effectiveness.

After several trials with wide range of mixes, four mixes (PKSC-2 -PKSC-5) were selected, in which PKS aggregate was used to replace the limestone aggregate in the control mix, in various combinations as shown in Table VI. For the first mix using PKS aggregate (PKSC-2), the limestone aggregate in the control concrete mix was replaced with 25% PKS aggregate sizes 10/4. For the second mix (PKSC-3), the limestone aggregate in the control concrete mix was replaced with 50% PKS aggregate.

TABLE VI
THE MIX PROPORTION FOR THE CONTROL CONCRETE AND BLENDED CONCRETE MIX

Mix Code	w/b	Cement	Coarse aggregate (kg/m^3)		Sand
		Kg/m^3	Limestone 10/4	PKS 10/4	Kg/m^3
PKSC-1 (Control)	0.5	390	1118	0	755
PKSC-2	0.5	390	837.5	280.5	755
PKSC-3	0.5	390	559	559	755
PKSC-4	0.5	390	279.5	838.5	755
PKSC-5	0.5	390	0	1118	755

PKS = Palm kernel Shell Mass of water = 195 Kg/m^3

The third mix was designated PKSC-4 and the mix was produced by replacing the limestone aggregate in the control concrete mix with 75% PKS aggregate. The final mix was designated PKSC-5 and the mix was produced by replacing the limestone aggregate in the control concrete mix with 100% PKS aggregate.

In order to investigate the cement replacement potential of PKS, the shell was burnt in an oven, at three different temperatures (350^0C, 550^0C and 750^0C) to produce PKS Ash and they were used to replace up to 50% PC for the production of masonry mortar. The PKS Ash produced at a temperature of 350^0C were designates as PKS Ash 2, the PKS Ash produced at a temperature of 550^0C were designates as PKS Ash 3, while the PKS Ash produced at a temperature of 750^0C were designates as PKS Ash 4. The control mix for the masonry mortar in the current research work was also adopted from an earlier work by the same authors [14]. The mix was prepared with a water: binder ratio 1:2, using fine aggregate and a Portland cement. A wide range of mortar mixes (20 mixes) was prepared as part of the initial preliminary trial.

The control masonry mortar mix in the current investigation (PKS Ash 1) was prepared with a water: binder ratio 1:3, using natural sea-dredged sand and PC. After several trials with wide range of mixes, six mixes were selected in which PKS Ash was used to replace the PC in the mortar control mix, in various combinations as shown in Table VII. For the first mix using PKS Ash (PKS Ash 2-30), the PC in the control mix was replaced with 30% PKS Ash 2. For the second mix (PKS Ash 2-50), the PC in the mortar control mix was replaced with 50% PKS Ash 2. The third mix was designated PKS Ash 3-30 and the mix was produced by replacing the PC in the mortar control mix with 30% PKS Ash 3. The forth mix was designated PKS Ash 3-50 and the mix was produced by replacing the PC in the mortar control mix with 50% PKS Ash 3. The fifth mix was designated PKS Ash 4-30 and the mix was produced by replacing the PC in the mortar control mix with 30% PKS Ash 4. The final mix was designated PKS Ash 4-50 and the mix was produced by replacing the PC in the mortar control mix with 50% PKS Ash 4.

TABLE VII
THE MIX PROPORTION FOR THE CONTROL MORTAR AND BLENDED MORTAR MIX

		Binder proportion (%)			
Mix Code	**w/b**	**PC**	**PKS Ash 2**	**PKS Ash 3**	**PKS Ash 4**
PKS Ash 1 (Control)	1.3	100	0	0	0
PKS Ash 2-30	1.3	70	30	0	0
PKS Ash 2-50	1.3	50	50	0	0
PKS Ash 3-30	1.3	70	0	30	0
PKS Ash 3-50	1.3	50	0	50	0
PKS Ash 4-30	1.3	70	0	0	30
PKS Ash 4-50	1.3	50	0	0	50

Note : PKS = Palm kernel shell PC = Portland cement

Cube (100 mm × 100 mm × 100 mm) and cylinder (150 mm × 300 mm) test specimens were used in the production of all the concrete. On the other hand, 50mm x 50mm cube test specimens were used in the production of all the mortar. For all mix compositions, the test specimens, were prepared in accordance with BS EN 206-1 [15], BS EN 12350-1 [16] and BS EN 12390-1 [17]. The consistency of the fresh concrete was measured using the slump test and compaction index test in accordance with BS EN 12350-2 [18] and BS EN 12350-4

[19]. The consistency of the fresh mortar was determined using flow table test in accordance with BS EN 1015-3 [20]. De-moulding of the test specimens was done after 24 h. The curing of the test specimens were carried out in accordance with BS EN 12390-2 [21]. The cube test specimens were cured under two curing regimes. The first curing condition was the standard curing condition (in water). The second curing condition was in aggressive sulfate-bearing solution. All the cube specimens were tested for 3, 7, 14, 28, 56 and 90-day compressive strength in accordance with BS EN 12390-3 [22] and BS EN 12390-4 [23]. The concrete cylinders were tested for 28-day tensile splitting strength in accordance with BS EN 12390-6 [24]. For all mix compositions, the results reported are the average obtained from five individual specimens for compressive strength and three for tensile splitting strength.

III. RESULTS

A. Consistency of Fresh Concrete and Mortar

The results for Consistency of fresh concrete measured using slump test are presented in Fig. 1. The target slump of 70 mm was only achieved with the control mix (PKSC-1). It was not possible to achieve this target slump for the mixes containing PKS aggregate. All mixes incorporating PKS aggregate (PKSC-2 - PKSC-5) showed higher slump values. Mix PKSC-2, where the limestone aggregate in the concrete control mix was replaced with 25% PKS aggregate showed a marginally higher slump value of 100mm. The observed slump value for mix PKSC-3 was 130mm. The slump value for the mix where 100% limestone aggregate was replaced with PKS aggregate (PKSC-5) was significantly higher (200mm). No segregation was observed in these mixes.

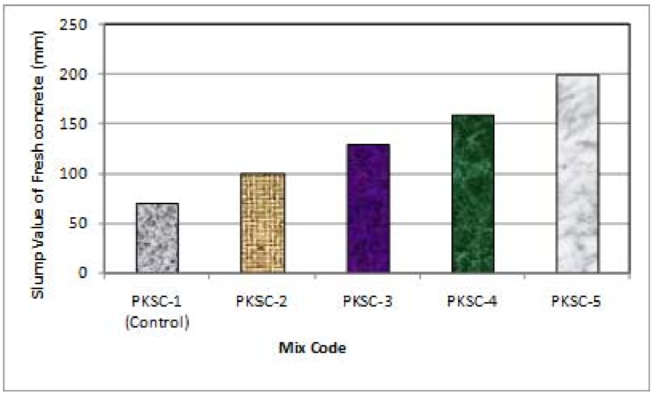

Fig. 1 Consistency of fresh concrete measured by slump test

Fig. 2 shows the results of the compaction index test for all the concrete mixes. As expected, the control concrete mix show significantly higher compaction index value when compared with the values obtained for the mixes incorporating PKS aggregate. The lowest compaction index value was obtained for PKSC-5.

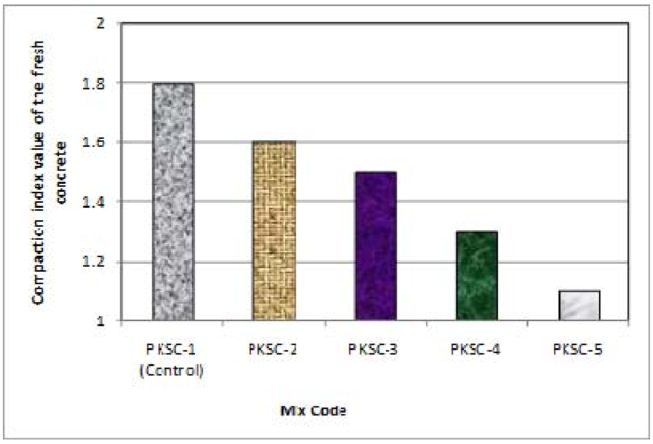

Fig. 2 Consistency of fresh concrete measured by compaction index test

Fig. 3 shows the mortar flow value for all the mortar mix proportions. The mortar flow value for the control mortar mix (PKS Ash 1) was observed to be 175. This value is within the acceptable limit specified in the British Standard for masonry units, namely BS EN 1015-3 [20] and BS EN 413-2 [25]. For the mortar mix PKS Ash 4-30, where the PC in the control mortar mix was replaced with 30% of PKS Ash 2, the mortar flow value was observed to be 169. The mortar flows values for all the other blended mixes (PKS Ash 2-30, PKS Ash 2-50, Ash 3-30, Ash 3-50 and Ash 4-50), were considered low (154–160). The lowest mortar flows value of 154 was obtained for mix PKS Ash 2-50.

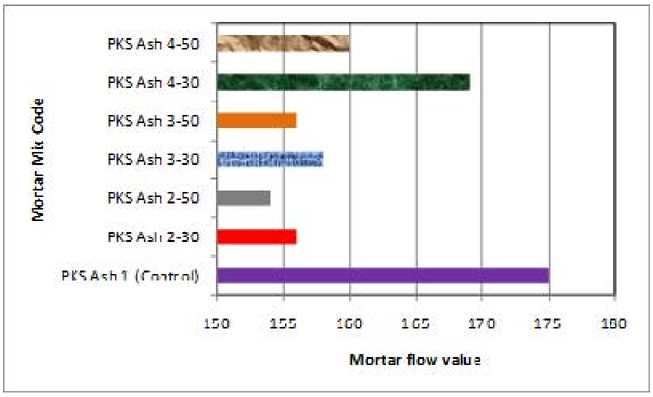

Fig. 3 Mortar flow value for all the mortar mix proportions

B. Compressive Strength

Fig. 4 shows the compressive strength development of the 100 mm × 100 mm × 100 mm test concrete cubes at the end of the 90 days standard curing condition (in water). The highest 3-day strength value of about 12 N/mm2 was obtained for the control mix (PKC-1). The lowest 3-day strength value (3•8 N/mm^2) was obtained for mix PKSC-5, this was the mix where 100% limestone aggregate was replaced with PKS aggregate. At the end of the 90-day curing period, the highest compressive strength value (26.2 N/mm2) was also observed from mix PKC-1. Mix PKSC-5 again showed the lowest compressive strength at 90 days.

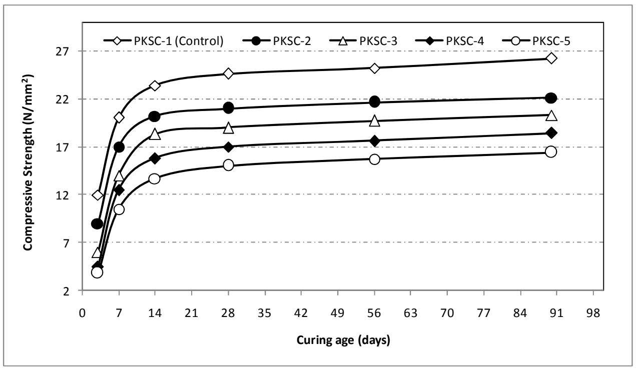

Fig. 4 Compressive strength development of the 100 mm × 100 mm × 100 mm concrete cubes up to 90 days

Fig. 5 shows the results of the compressive strength testing for the 50mm x 50mm cube specimens for control and blended mortars, cured in water at ages of 3, 7,14, 28, 56 and 90 days. It can be seen from Fig. 5 that the blended mortars (PKS Ash 2-30, PKS Ash 2-50, Ash 3-30, Ash 3-50 and Ash 4-50), tended to have lower compressive strength, at all curing ages when compared to the control mortar (PKS Ash 1). The highest compressive strength value (10.2 N/mm2) was obtained from mix PKS Ash 1 at the end of the 90 day curing age. Mix PKS Ash 2-30 showed the lowest compressive strength value (5.7 N/mm2) at 90 days, this was the mortar mix where the PC in the control mix was replaced with 30% of PKS Ash 2 (the PKS Ash produced at a temperature of 350^0C).

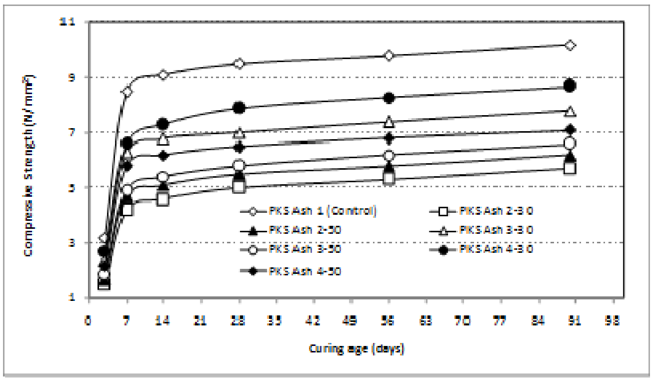

Fig. 5 The compressive strength development of the 50 mm × 50 mm × 50 mm mortar cubes up to 90 days.

C. Tensile Splitting Strength

Fig. 6 presents the results of the tensile splitting strength of all the concrete mixes at the end of the 28-day curing period. The highest tensile splitting strength of 3.8 N/mm^2 was obtained from mix PKSC-1. The lowest tensile splitting strength was obtained from mix PKSC-5. The variation in tensile splitting strength value of mixes PKSC-2 - PKSC-5 relative to the control mix (PKSC-1) is presented in Fig. 7. It can be observed that the variation was greater for mix PKSC-5 (42%).

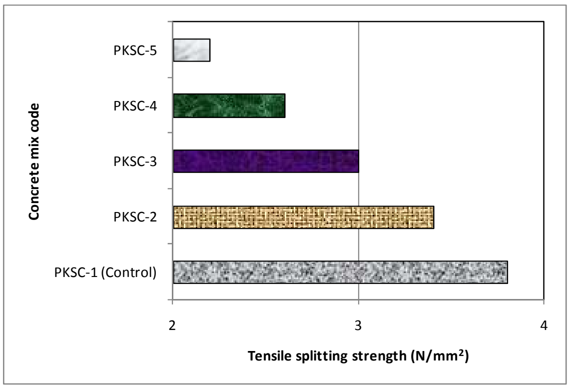

Fig. 6 Tensile splitting strength for all concrete mixes

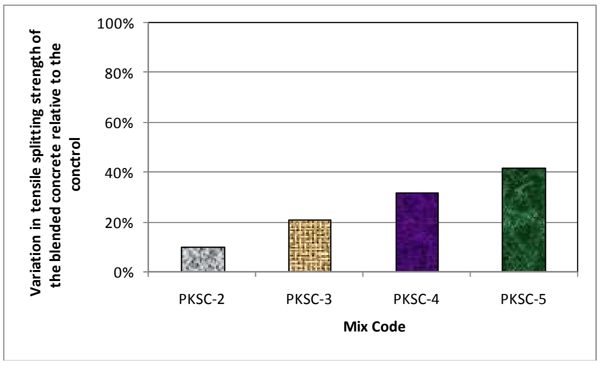

Fig. 7 The variation in tensile splitting strength for mixes PKSC-2 - PKSC-5 with respect to the control

D. Chemical Durability

Fig. 8 shows the compressive strength of the control and blended concrete mixes, cured in water and in aggressive sulfate-bearing exposure conditions up to 90 days. For the control and blended concrete mixes cured in water, it can be seen that there was a progressive increase in strength values up to 90 days. The highest strength value was observed in the control concrete mixture (PKSC-1). The strength value of the PKS aggregate blended concrete (PKSC-2 - PKSC 5) decreased as the PKS aggregate replacement level in the concrete increased from 25–100%.

In the case of the concrete specimens cured in sodium sulfate solution, it can be seen that the control concrete (PKSC-1) showed a higher strength value at the curing ages of 3 to 28 days. At the late curing age (90 days) something dramatic occurred: The control concrete in the sulfate-bearing exposure started losing strength. Visible signs of minor cracking were also observed in the surface of the control concrete specimen. Similar trends were observed for the blended concrete, a progressive increase in strength in the sulfate-bearing exposure up to 28 days and lost in strength at late age. More significant cracking were also observed in the surfaces of the blended concretes

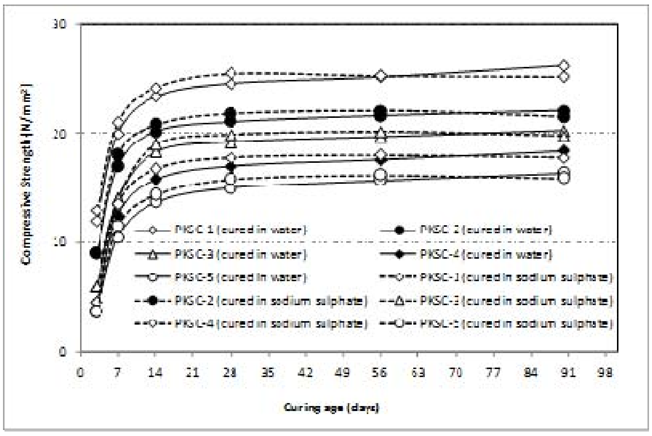

Fig. 8 Compressive strength of the control and blended concrete cured in water and in sodium sulfate solution

E. Statistical Modeling

In this part of study, the statistical relation (model) between compressive strength of the concrete in water/sodium sulphate solution and curing age was introduced. Regression analysis method was used to obtain this type of relation. For the wide range of concrete formulations (see Table VI and Fig. 9), the relation between compressive Strength of the concrete in water/sodium sulphate solution and curing age was found to be approximately linear.

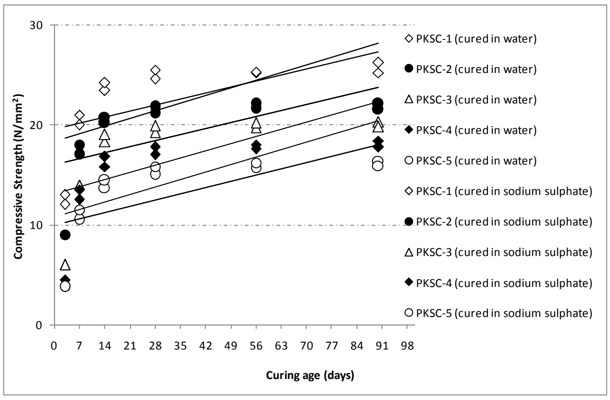

Fig. 9 The linear relationship between of the control and blended concrete cured in water and sodium suphate

The statistical model for the control concrete (PKSC-1) cured in water is $y = 0.109x + 18.30$ (where y is the compressive strength in water, x is the curing age) and $R^2 = 0.484$. On the other hand, the equation for the control concrete (PKSC-1) cured in sodium sulphate solution is $y = 0.086x + 19.52$ (where y is the compressive strength in sodium sulphate solution, x is the curing age) and $R^2 = 0.357$. For the first blended concrete where the limestone aggregate in the concrete control mix was replaced with 25% PKS aggregate (PKSC-2), the statistical model for the concrete cured in water is $y = 0.096x + 15.30$ and $R^2 = 0.430$, the equation for the concrete cured in sodium sulphate is $y = 0.085x + 16.04$, $R^2 = 0.329$. For the second blended concrete where the limestone aggregate in the concrete control mix was replaced with 50% PKS aggregate (PKSC-3), the statistical model for the concrete cured in water is $y = 0.108x + 12.67$ and $R^2 = 0.446$, the equation for the concrete cured in sodium sulphate is $y = 0.102x + 13.09$ and $R^2 = 0.38$.

It can also be seen from Fig. 9 that for the third blended concrete where the limestone aggregate in the concrete control mix was replaced with 75% PKS aggregate (PKSC-4), the statistical model for the concrete cured in water is $y = 0.106x + 10.80$ and $R^2 = 0.472$, the equation for the concrete cured in sodium sulphate is $y = 0.093x + 11.66$ and $R^2 = 0.355$. For the last blended concrete where the limestone aggregate in the concrete control mix was replaced with 100% PKS aggregate (PKSC-5), the statistical model for the concrete cured in water is $y = 0.099x + 9.219$ and $R^2 = 0.508$, the equation for the concrete cured in sodium sulphate is $y = 0.089x + 9.982$ and $R^2 = 0.398$. Overall, the highest R^2 value was obtained for the concrete made with the PKSC-5 mix.

IV. DISCUSSION

There were variations in the consistency of the concrete and mortar. Higher compaction index values were observed in the fresh concrete made with the limestone aggregate (PKSC-1) in comparison with the concretes made using PKS aggregate (PKSC-2 - PKSC 5) while, the observed slump values for the concretes produced with PKS aggregate were by far higher than that of the control concrete. For the control and blended mortar, higher mortar flow value was observed for the control mortar mix (PKS Ash 1) when compared to the blended mortars. This is due to the difference in mix compositions, coupled with the varying influence of the differences in particle shape, grading and interlock effect.

There were variations in the compressive strength of concrete and mortar with age. For the various concretes and mortars investigated under this study, the compressive strength at the time of testing appears to increase as the age of the specimen increases. The control concrete (PKSC-1) and mortar (PKS Ash) showed better compressive strength than the strength values observed using PKS aggregate and PKS Ash, throughout the 90 days of curing. The variation in strength may be attributed to the differences in aggregate and stabiliser content, aggregate impact values and other varied engineering factors. The higher strength development may also be attributed to either the gradual continued formation of C–S–H gel within the pore structure, blocking pores and providing strength as the gel develops and ages as reported in previous research studies [13], [14], [26]. The lower strength observed for the concretes incorporating PKS aggregate, dependent upon the breakdown of the bond between the aggregate and the paste, failure of the shell aggregate and the aggregate paste interface.

Like the compressive strength, there is variation in the tensile splitting strength values of the concretes. The control concrete (PKSC-1) showed better tensile splitting strength than the strength values observed using PKS aggregate at 28 day of curing. The variation in tensile splitting strength may be attributed to multiple factors such as, for example, aggregate type and particle size distribution, the curing

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process and air content. In addition, other factor such as aggregate–paste bond, which thus have a greater influence on tensile than compressive strength may results to this variations.

The chemical durability of concretes was demonstrated by the positive effect of sodium sulfate solution on the strength of the concrete, as shown in Fig. 7. For both the control and blended concrete, the positive effect of sodium sulfate lasted for only 56 days and from 56 to 90 days the effect was negative (loss in strength). This effect may be attributed to change in concrete morphology, inhibition of reaction species and the final disruption of the aggregate cement paste matrix, resulting in loss of strength. This current observed trend supported the results of previous research studies by [27] on the salting-out effects in aqueous ionic liquid solutions. Their paper described the positive effects and consequences of sodium sulphate solution in strengthening. Sodium sulphate solution can enter into chemical reactions with cement-based materials causing expansion, initial strength increase and loss in strength, cracking and spalling and disintegration [27].

The classical form of sulfate attack involves alkali sulfates, such as sodium sulphate, which react with portlandite (CH), monosulfate and unreacted tricalcium aluminate (C_3A) to form gypsum (C–S–H) and ettringite, which can cause expansion, initial strength increase and loss, cracking and deterioration of concrete [28]; this phenomenon is widely reported. Chatveera and Lertwattanaruk [29] reported on the compressive strength loss due to sulfate attack of mortars mixed with black rice husk ash from a rice mill. Other reported cases of both positive and negative effect of sodium sulfate solution on the strength can be seen in previous literature [30], [13], 14].

From the results of the statistical model for the control and blended concrete in water and sodium sulphate solution, it can be seen that the R^2 values (coefficient of determination) were positive and very close to unity. This means that the parameters being matched were highly dependent on each other. In this way, the model can be used to predict the compressive strength of concrete in water/sodium sulphate solution and the curing. These relations can be useful for making recommendations regarding the mix constituents for concrete made with PKS aggregate. The relation can also be particularly useful as it provides the basis by which the compressive strength of concrete made with PKS aggregate can be broadly assessed.

V. CONCLUSIONS

The results obtained suggest that there is potential for using palm kernel ash as partial substitutes for cement and the use of palm kernel shell for aggregate replacement This will facilitate more sustainable construction. The following conclusions are therefore drawn from this research:

1. The compressive strength of the concrete and mortar produced using palm kernel shell and palm kernel ashes were lower relative to those made with limestone aggregate and Portland cement.
2. The strength value of concrete incorporating palm Kernel shell aggregate decreased as the PKS aggregate replacement level in the concrete increased from 25–100%. The potential to replace up to 100% coarse aggregate with palm kernel shell is still low because of the low strength. However, the potential to replace up to 50% Portland cement with palm kernel ash burnt at oven temperatures of 750^0C is more feasible.
3. The concrete made with coarse aggregate showed better tensile splitting strength than the strength values observed using PKS aggregate at 28 day of curing.
4. The chemical durability results demonstrated that after a prolonged period of exposure, significant strength losses in all the concretes were observed. This phenomenon is explained, due to lower change in concrete morphology and inhibition of reaction species.
5. The results of the statistical model for the control and blended concretes reveal that the coefficients of determination were positive and very close to unity. This means that the parameters being matched were highly dependent on each other.

REFERENCES

[1] Alengaram J. U, Jumaat M.Z and Mahmud H., 2010. Comparison of mechanical and bond properties of oil palm kernel shell concrete with normal weight concrete. International Journal of the Physical Sciences 5(8), p. 1231-1239.

[2] Alengaram J. U, Jumaat M.Z and Mahmud H., 2008. Ductility Behaviour of Reinforced Palm Kernel Shell Concrete Beams. European Journal of Scientific Research 23(3), p.406-420

[3] Mannan M.A and Ganapathy C., 2002. Engineering properties of concrete with oil palm shell as coarse aggregate. Construction and Building Materials 16, p29-3

[4] Shafigh P, Jumaat M.Z, Mahmud H.B and Alengaram U.J., 2011. A new method of producing high strength oil palm shell lightweight concrete. Materials & Design 32(10), p. 4839–4843.

[5] BS EN 197-1:2011.Cement Part 1: Composition, specifications and conformity criteria for common cements.

[6] PD 6682-1:2009. Aggregates – Part 1: Aggregates for concrete – Guidance on the use of BS EN 12620

[7] BS EN 12620:2002 +A1:2008. Aggregates for concrete

[8] BS EN 933-1:1997. Tests for geometrical properties of aggregates Part 1: Determination of particle size distribution — Sieving method

[9] BS EN1097-6:2000. Tests for mechanical and physical properties of aggregates — Part 6: Determination of particle density and water absorption

[10] BS EN 933-3:1997. Tests for geometrical properties of aggregates - Part 3: Determination of particle shape - Flakiness index

[11] EN 933-4:2008. Tests for geometrical properties of aggregates Part 4: Determination of particle shape — Shape index

[12] BS 812-112: 1990. Testing aggregates — Part 112: Methods for determination of aggregate impact value (AIV)

[13] Oti J.E., Kinuthia J.M, Bai J, Delpak R and Snelson D.G., 2010. Engineering properties of concrete made with slate waste. Construction materials 163 (3), p.131-142.

[14] Oti J.E., Kinuthia J.M, and Bai J., 2010. Sustainable masonry mortar for brick joint and plaster in the UK. Construction materials 163 (2), p87-96

[15] BS BS EN 206-1:2000. Concrete - Part 1: Specification, performance, production and conformity

[16] BS EN 12350-1:2009. Testing fresh concrete Part 1: Sampling.

[17] BS EN 12390-1:2009.Testing hardened Concrete. Part 1: Shape, dimensions and other requirements of specimens and moulds

[18] BS EN 12350-2:2009. Testing fresh concrete Part 2: Slump-test.

[19] BS EN 12350-4:2009. Testing fresh concrete Part 4: Degree of compactability

[20] BS EN 1015-3:1990. Methods of test for mortar for masonry, Part 3: Determination of consistence of fresh mortar by flow Table.

[21] BS EN 12390-2:2009.Testing hardened Concrete. Part 2: Making and curing specimens for strength tests.

[22] BS EN 12390-3:2009.Testing hardened Concrete. Part 3: Compressive strength of test specimens.

[23] BS EN 12390-4:2009.Testing hardened Concrete. Part 4: Compressive strength - Specification for testing machines.

[24] BS EN 12390-6:2009.Testing hardened Concrete. Part 6: Tensile splitting strength of test specimens.

[25] BS EN 413-2: 2005 Masonry cement, Part 2: Test methods.

[26] Bai J., Wild S., Sabir B. B., 2003. Chloride ingress and strength loss in concrete with different MK-PFA-PC binder compositions exposed to synthetic seawater. Cement and Concrete Research, 33(3):353–62.

[27] Trindade JR, Visak ZP, Blesic M, Marrucho IM, Coutinho JAP, Canongia Lopes JN and Rebelo LPN (2007) Salting-out effects in aqueous ionic liquid solutions – cloud-point temperature shifts. Journal of Physical Chemistry B published online 01/27/2007 page EST: 4.6 path.web.ua.pt.

[28] Bassuoni MT and Nehdi ML., 2009. Durability of self-consolidating concrete to sulfate attack under combined cyclic environments and flexural loading. Cement and Concrete Research 39(3): 206–226.

[29] Chatveera B and Lertwattanaruk P (2009) Evaluation of sulfate resistance of cement mortars containing black rice husk ash. Journal of Environmental Management 90(3): 1435–1441.

[30] O'Farrell M, Wild S and Sabir BB (1999) Resistance to chemical attack of ground brick – PC mortar Part I. Sodium sulphate solution. Cement and Concrete Research 29(11): 1781–1790.