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Influence of Sand/Cement Ratio on Mechanical Properties of Palm Kernel Shell Concrete

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Abstract: An experimental investigation was carried out to improve the mechanical properties of Palm Kernel Shell Concrete (PKSC) by varying sand content and incorporating mineral admixtures, to achieve strength of 35 MPa. The mineral admixtures included 10% silica fume as additional cementitious material and 5% class F fly ash as cement replacement material. Sand to cement ratio (s/c) was varied between 1.0 and 1.6 and superplasticizer was added to all mixes to provide adequate workability. Twenty-eight days saturated density and compressive strength of the concrete were in the range of 1850-1960 kg m⁻³ and 28-38 MPa, respectively. Increase in sand content has positive influence on the mechanical properties of concrete. When the sand to cement ratio was increased from 1.0 to 1.6, increase in 28 day compressive strength by about 24% was noted for a small density increase of about 4%. The other mechanical properties such as flexural and splitting tensile strengths were found in the range of 2.76-4.76 and 1.9-2.61 MPa, respectively over a period of 90 day. The static modulus of elasticity was in the range of 8-11 GPa. These results confirm that the combined use of maximum sand to cement ratio of 1.6 and mineral admixtures have significant influence on the mechanical properties as compared to the previous research findings. The addition of silica fume resulted in cohesive mix and use of a superplasticizer can provide slump in the range of 65-105 mm. However, an increase of s/c ratio beyond 1.6 is likely to increase the concrete density above 2000 kg m⁻³.

Key words: Palm kernel shell, sand to cement ratio, silica fume, fly ash, mechanical properties

INTRODUCTION

The high demand for concrete in construction drastically reduces the natural stone deposits such as gravel and granite and this has damaged the environment thereby causing ecological imbalance. The use of synthetic lightweight aggregates from natural raw materials such as clay, slate and shale and from industrial by-products such as fly ash and slag ash has not been fully explored in the developing and underdeveloped countries in Asia and Africa. However researches in these regions on the use of organic natural aggregate in the form of Palm Kernel Shells (PKS) are on the rise. Malaysia alone produces nearly 4 million tonnes of PKS annually and this is likely to increase as more production is expected in the near future. One of the reasons for the use of such natural organic materials is the utilization of the wastes into a cheaper construction material. In addition, these wastes are available in plenty as an industrial by-product in Malaysia.

The past researches on using PKS as lightweight aggregate (LWA) produced compressive strength in

the range of 15-25 MPa (Abdullah, 1984; Okafor, 1988; Basri *et al.*, 1999; Ata *et al.*, 2006). Generally, the mechanical properties of PKS concrete depend on factors such as cement, water, sand and aggregate contents and density. They also reported that the failure of PKS concrete (PKSC) is commonly governed by the strength of the PKS. However, the smooth and convex surfaces of PKS produce poorly compacted concrete and these resulted in bond failure between PKS and cement matrix. In order to achieve PKSC in excess of 30 MPa, the bond between mortar and PKS has to be improved. Generally, grade 30 concrete is acceptable for structural members, though some of the codes of practice stipulate minimum strength of LWC as 15 MPa (FIP Manual, 1983). One of the ways to improve the bond is to identify the influence of sand content as mechanical properties of LWC, in general, is governed by density.

Silica Fume (SF) has been used to produce high-strength concrete since SF particles are finer than cement. However, the use of these fine materials demands more water to maintain workability and they are often used with superplasticizing admixtures. The SiO₂ from the SF

particles reacts with the liberated calcium hydroxide from cement hydration to produce calcium silicate and aluminate hydrates. This pozzalanic reaction increases the strength and reduces the permeability by densifying the matrix of the concrete (Neville, 1996; Robert *et al.*, 2003). Thus the zone between the aggregate and cement paste interface, which is called the zone of weakness, could be strengthened by the inclusion of SF.

The objective of this study was to improve the mechanical properties of LWC by varying the sand content and adding SF as mineral admixture. In this study, 10% SF and 5% class F Fly Ash (FA), both by weight of cement were employed on the mix proportions. The effect of varying the sand content, influence of SF and FA as mineral admixtures on the workability and compressive strength up to the age of 90 days were studied and reported here.

MATERIALS AND METHODS

Cement, mineral admixtures and aggregates: Locally produced Ordinary Portland Cement (OPC) with specific gravity and surface area of 3.10 and 335 m² kg⁻¹, respectively was used for all mixes. The mineral admixtures used in preparation of PKSC were: 5% class F Fly Ash (FA) and 10% Silica Fume (SF) as cement replacement and additional cementitious materials by cement weight, respectively. The SiO₂ content and specific gravity of FA used in this investigation were 65% and 2.10, respectively. Undensified SF of specific gravity of 2.10 was used. Table 1 shows the chemical composition of cement, FA and SF.

Mining sand was used as fine aggregate with particle density of 2.7. It was dried and sieved to particle size ranging from 0.15-2.36 mm. PKS obtained from a local palm oil producing mill was used. Figure 1 shows the PKS of different sizes, while Fig. 2 shows the particle size distribution of sand and PKS. Table 2 shows the properties of PKS, crushed stone and mining sand. The properties of crushed stone aggregates are given for comparison. Since, PKS are waste materials, they are normally stockpiled in open field, thus they were subjected to varying climatic conditions. As Malaysia is a tropical country with unpredictable rainfall throughout the year, the shells are bound to absorb moisture but during sunny spells, the surface moisture may be dried

out leaving some moisture inside the PKS. Hence the water absorption characteristic of PKS was also determined.

Preparation of PKS as coarse aggregate: Preparation of PKS was done 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 air dried and then stockpiled. Due to the 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.



Fig. 1: Palm kernel shells

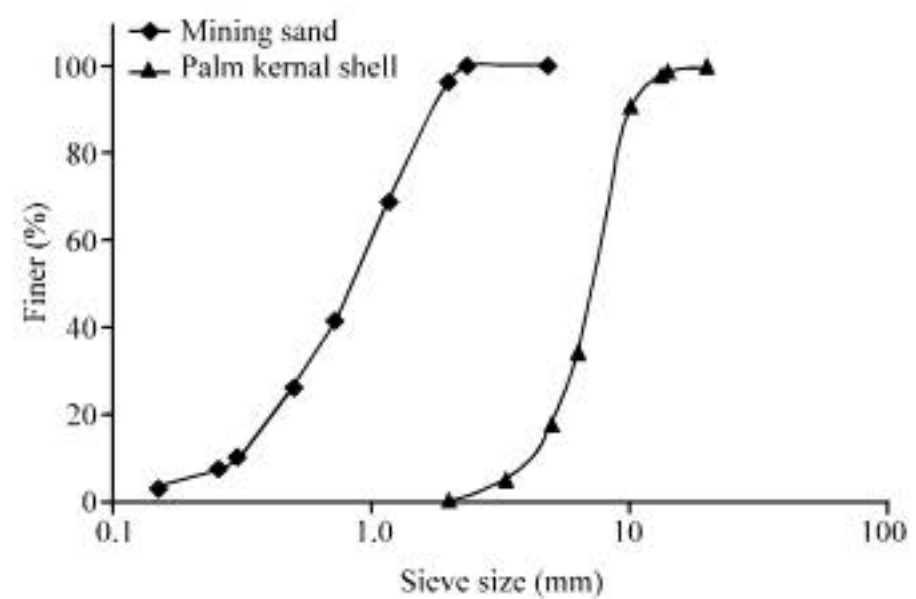


Fig. 2: Particle size analysis

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

Materials	Oxide composition (%)										
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₂	K ₂ O	Na ₂ O	LOI	TiO ₂	P ₂ O ₅
Cement	19.8	5.10	3.10	63.40	2.50	2.40	1.00	0.19	1.80	-	-
Fly ash	64.6	20.90	4.00	1.00	0.66	0.30	1.20	0.32	5.10	1.10	0.07
Silica fume	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 PKSC

Mix designation	s/c ^a	Cement	Sand	PKS	FA	SF	Total ^b	SP ^c
		----- (kg m ⁻³)-----						(%)
PKSC-PS	1.0	596	596	477	0	0	596	1.0
PKSC-S1	1.0	532	560	448	28	56	616	1.0
PKSC-S2	1.2	504	637	424	27	54	585	1.0
PKSC-S3	1.6	465	784	392	25	50	540	1.0

^aSand to cement ratio, ^bTotal cementitious materials, ^cSuperplasticizer-percentage on weight of cement

Mix design, concrete mixtures and testing: 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. The selection of SF as additional cementitious materials was based on the fact that the excess SF cannot be located at the surface of the aggregates (Neville, 1996). It is generally recommended to use 8 to 10% of SF on cement weight to have the desired impact (Neville, 1996; Robert *et al.*, 2003). Basri *et al.* (1999) reported a reduction in the compressive strength of 29% for a replacement of 15% fly ash. Thus, it was decided to use a minimum percentage of about 5% as cement replacement in this research.

A total of three concrete mixes incorporating cementitious materials with varying s/c ratio were prepared as shown in Table 2. The water to binder ratio (w/c) and aggregate to cement ratio (a/c) were kept constant at 0.35 and 0.8, respectively for all mixes. The sand to cement (s/c) ratio was varied between 1.0 and 1.6. A control mix without any mineral admixtures, but with similar mix proportions as that of PKSC-S1 was also prepared. All the materials were weight batched. The mixing of the materials was done in the following order: firstly one-half of PKS and sand were mixed. This was followed by addition of one-half of cement, fly ash and silica fume; part of water with superplasticizer was then added, after which the remaining portion of materials were added. Specimens of 100×100×100 mm cubes, 150Φ×300 mm cylinders and 100×100×500 mm prisms were cast and covered with plastic sheeting in uncontrolled laboratory condition for 24 h before demoulding. The cement content for mixes PKSC-S1 to S3 was between 465 and 532 kg m⁻³, as shown in Table 2 while for mix, PKSC-PS it was 596 kg m⁻³. The saturated and oven dry densities of PKS concrete at 28 days were also measured. Workability tests by slump and flow measurements were done in accordance with British Standards. The compressive strengths were measured at 1, 7, 14, 28, 56 and 90 days. The splitting tensile, flexural strengths and modulus of elasticity were measured at 28, 56 and 90 days.

RESULTS AND DISCUSSION

Physical and mechanical properties of PKS: Table 3 shows some of the physical and mechanical properties of PKS. The thicknesses of PKS shells were in the range of

Table 3: Physical and mechanical properties of aggregates

Properties	Crushed stone	PKS	Mining sand
Thickness (mm)	15	0.7-3.50	-
Bulk density (kg m ⁻³)	1510	620	-
Specific gravity (saturated surface dry)	2.67	1.27	2.57
Fineness modulus	6.57	6.24	2.81
Water absorption-1 h (%)	<1	10-12	-
Water absorption-24 h (%)	<1	24.5	<1
Aggregate impact value (%)	16.78	3.91	-

Table 4: Properties of PKSC

Mix	s/c	Fresh density	Density (kg m ⁻³) (28 days)		Workability (mm)	
		(kg m ⁻³)	Saturated	Oven-dry	Slump	Flow
PKSC-PS	1.0	1845	1875	1630	160	NA
PKSC-S1	1.0	1856	1887	1642	103	370
PKSC-S2	1.2	1896	1910	1685	65	330
PKSC-S3	1.6	1930	1961	1728	60	350

0.7- 3.5 mm and the size of the shells vary between 2 and 15 mm. The relative density in saturated surface dry condition was 1.27. The loose and compacted densities were 568 and 620 kg m⁻³, respectively. The natural moisture content and 24 h water absorption of PKS were in the range of 10-12 and 25%, respectively.

Density: The measured fresh, saturated and oven dry densities as of 28 days are shown in Table 4. The fresh densities of PKSC: S1-S3 ranged between 1856 and 1930 kg m⁻³. The oven dry densities were 220 to 260 kg m⁻³ lower than the saturated densities. The highest density of 1961 kg m⁻³ was recorded by the mix containing s/c ratio of 1.6. Increase in sand content beyond s/c ratio of 1.6 may result in higher density than the limit for LWC of 2000 kg m⁻³ and hence mixes containing s/c ratio higher than 1.6 was not considered.

Workability: Table 4 also shows the measured slump and flow values. The mixes PKSC: S1-S3 with constant w/b ratio of 0.35 and a/c ratio of 0.8 exhibited medium to high workability. Though s/c ratio of 1.0 and 1.2 showed high workability, further increase in sand content would require additional water or superplasticizer to maintain the required workability. Thus for mix PKSC-S3 with s/c ratio of 1.6, medium workability of about 60 mm was obtained.

The control mix PKSC-PS containing no mineral admixtures produced very high workability with slump value of 160 mm. However, for mix PKSC-S1 of similar mix proportion as that of PKSC-PS, slump of 103 mm was recorded. The SF in the mix resulted in lower slump value due to the fineness of the material.

Slump test tends to underestimate workability of lightweight aggregate concrete and therefore flow values using the flow table test were also measured (Clarke, 1993). Flow table value of 370 mm was recorded for mix PKSC-S1 which has higher sand and lower PKS contents.

Table 5: Compressive strength of PSKC

Mix designation	s/c ratio	Saturated density (kg m^{-3})	28 day cube strength (N mm^{-2})
PKSC-PS	1.0	1875	26.98
PKSC-S1	1.0	1887	29.49
PKSC-S2	1.2	1910	34.49
PKSC-S3	1.6	1961	37.79

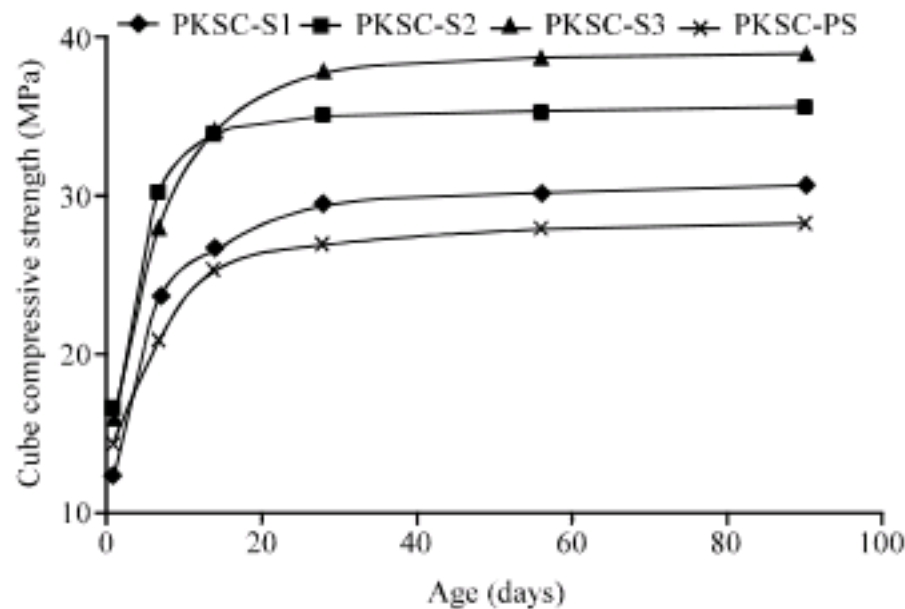


Fig. 3: Compressive strength development of PSKC

Though only 5% fly ash was added, its contribution to workability cannot be ignored as the spherical shape of FA reduces friction forces between aggregate particles and increases the workability. The addition of SP also increased the workability and the use of SP is essential due to the inclusion of SF.

Compressive strength

Influence of sand content on compressive strength:

Table 5 shows the 28 days strength of PKSC. Figure 3 shows the progress of compressive strength for up to 90 days. Generally, the compressive strength depends on factors such as density, w/b, a/c and s/c ratios. As with normal weight concrete, the lower the w/b ratio, the higher the compressive strength. For mix PKSC-S3, the s/c ratio was maintained at 1.6 and this resulted in the highest saturated density of 1961 kg m^{-3} and the highest 28 day strength of about 37.8 MPa. It was evident during the test that rupture of PKS took place before final failure, thus indicating failure of PKS rather than mortar. Hence, it can be concluded that the failure of PKS governed the strength of LWC. Twenty eight days compressive strength of 37.8 MPa obtained in this investigation is 56% higher than the result of 24.22 MPa reported by Mannan and Ganapathy (2004). The cement content used in their investigation was 480 kg m^{-3} compared to 465 kg m^{-3} used in this investigation. However, the total cementitious material used in this investigation was 540 kg m^{-3} .

For the 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

Table 6: Rate of strength development of PKSC

Mix designation	s/c ratio	Cube compressive strength (N mm^{-2})				Ratio of strength (1/2)	Increase in strength (%) 28 to 90 days
		7 (1)	28 (2)	56 (3)	90 (4)		
PKSC-PS	1.0	20.16	26.98	27.94	28.30	0.74	4.89
PKSC-S1	1.0	23.61	29.49	30.19	30.68	0.80	4.04
PKSC-S2	1.2	30.18	34.49	34.92	35.13	0.88	1.86
PKSC-S3	1.6	28.18	37.79	38.71	39.01	0.75	3.23

Number in brackets show column number

enabled the concrete to sustain higher load. The presence of high volume of pores in PKS because of its high water absorption of about 25% may weaken the particle strength and stiffness. However, the pores may help in the development of good bond by the suction of the paste into the pores of PKS. This behaviour is under investigation and its effect will be reported subsequently.

Compared to PKSC-S1, PKSC-S2 shows strength increase of 17%. Similarly, PKSC-S3 exhibited an increase of about 28% compared to PKSC-S1. Thus the influence of sand content on compressive strength is evident. It can also be shown that the increase in compressive strength between PKSC-S2 and S3 is not high as compared to PKSC-S1 and it can be concluded that s/c ratio of 1.2 is an ideal ratio to provide concrete having density of less than 2000 kg m^{-3} . The density of mix PKSC-S3 is nearing 2000 kg m^{-3} and hence it is likely that a small increase in any constituent material may increase the density beyond the limit of 2000 kg m^{-3} normally associated with lightweight concrete.

Influence of silica fume on compressive strength: The addition of SF influenced the compressive strength as high early strength of 80 to 90% of the 28 day strength was obtained at 7 days for mixes containing SF, as shown in Table 6. This may be attributed to the fineness and pozzolanic reaction of SF. The infilling of the voids in the shells by very fine SF particles further increased the bond between PKS and cement matrix.

Thus SF plays a 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 as was evident during the test. The increase in strength from 28 and 90 days is in the range of 2 to 5% indicating that hydration continues at a slower rate after 28 days.

Modulus of rupture and splitting tensile strengths of PKSC:

It can be seen from the results that these strengths also follow a similar trend to that of compressive strength. As the sand content is increased

Table 7: Tensile Strengths of PKSC

Mix	s/c ratio	Splitting tensile strength (MPa)			Modulus of rupture (MPa)		
		Days			Days		
		28	56	90	28	56	90
PKSC-PS	1.0	1.98	2.01	2.10	2.79	2.98	3.17
PKSC-S1	1.0	1.90	1.95	2.00	2.76	2.81	2.84
PKSC-S2	1.2	2.00	2.11	2.21	3.22	3.25	3.30
PKSC-S3	1.6	2.35	2.56	2.61	4.10	4.45	4.56

Table 8: Static and dynamic moduli of PKSC

Mix	s/c ratio	Static modulus of elasticity (kN mm ⁻²)			Dynamic modulus of elasticity (kN mm ⁻²)		
		Days			Days		
		28	56	90	28	56	90
PKSC: PS	1.0	7.08	7.91	7.98	14.35	14.65	15.27
PKSC: S1	1.0	8.57	8.59	9.01	13.20	13.76	14.02
PKSC: S2	1.2	10.01	10.21	10.25	15.47	15.73	15.75
PKSC: S3	1.6	10.90	11.51	11.87	16.69	20.01	20.15

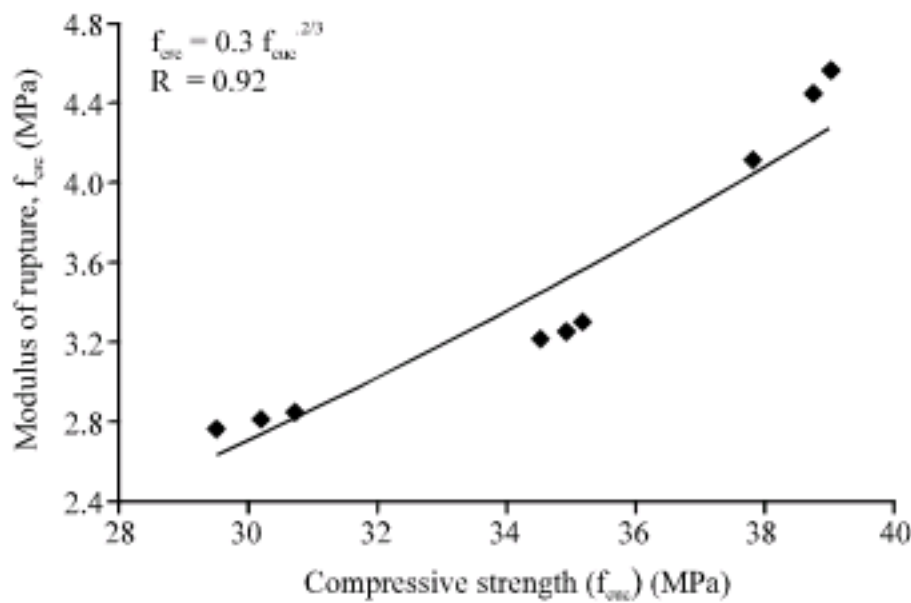


Fig. 4: Relationship between modulus of rupture and compressive strength

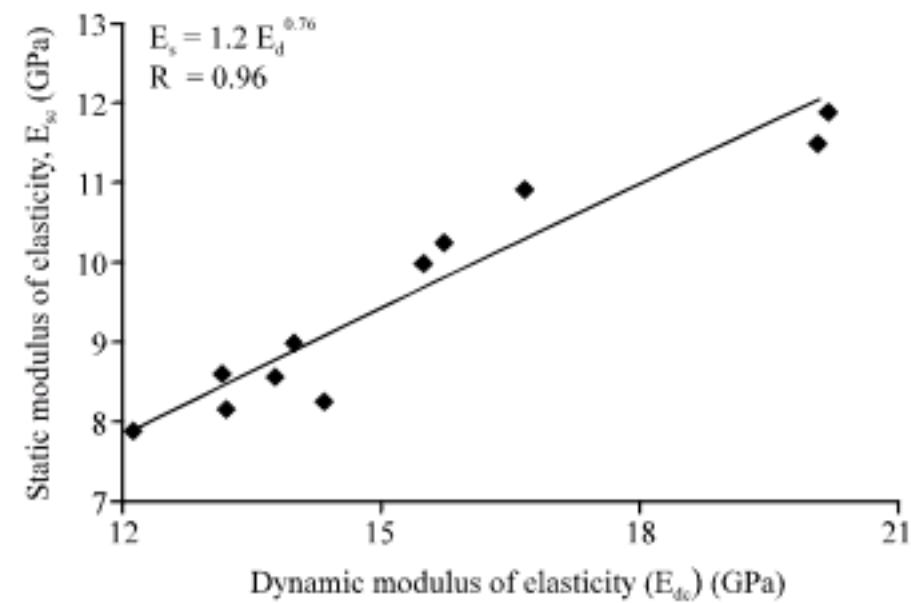


Fig. 5: Relationship between static and dynamic modulus of elasticity

the flexural and splitting tensile strengths also increased (Table 7). The highest flexural and splitting tensile strengths were obtained for PKSC-S3 which has the highest s/c ratio of 1.6. The ratio of splitting tensile and flexural was found to be between 60-70%. The increase in these strengths from 28 to 90 days was between 2 and 8%. The control PKSC-PS mix that contained no cementitious materials produced comparable strengths as that of mix PKSC-S1. However, PKSC-PS had a higher cement content of about 600 kg m⁻³ and hence likely to cause higher drying shrinkage. A relationship between flexural strength and compressive strength as shown in Fig. 4 yields the following:

$$f_{cr} = 0.3(f_{cuc})^{0.23} \quad (R = 0.92) \quad (1)$$

where, f_{fc} and f_{cuc} are flexural and cube compressive strengths, respectively in MPa.

Static and dynamic moduli of elasticity: Table 8 shows the static and dynamic moduli of elasticity of the four mixes. Mannan and Ganapathy (2004) reported the static modulus of elasticity of PKS concrete in the range of between 7 and 8 GPa. The lower E-values of PKS concrete is generally attributed to poor stiffness of PKS and its lower particle density. Thus, the lower E-values tend to produce larger deflections and hence increasing E-values

of PKS concrete is necessary. In this research, the 28 days E-value of about 11 GPa was obtained for mix PKSC-S3, mainly due to higher sand content and density. Thus an increase of about 13-40% on E-value as reported by to Mannan and Ganapathy (2004) is significant improvement and hence this mix will produce lower deflections if used as structural concrete.

The increase in E-value between S1 and S3 mixes was calculated at 27%. An increase in the sand content enhanced the E-values of PKS concrete. The control PKSC-PS mix that contained no cementitious materials exhibited the lowest E-value. This may be attributed to the contribution of SF that was added to the PKSC: S1-S3 mixes, producing good bond between aggregate and matrix that enable the mixes to sustain higher strains. Difference in E-values for mixes PKSC-S1 and PKSC-PS is about 20% higher for the former. A non-destructive dynamic modulus test was performed on prisms, the results obtained of which was used to predict the E-values of PKSC, as shown in Fig. 5. The relationship between the two moduli is given by the following equation:

$$E_s = 1.2 (E_d)^{0.76} \quad (R = 0.96) \quad (2)$$

where, E_s and E_d are static and dynamic moduli of elasticity in GPa.

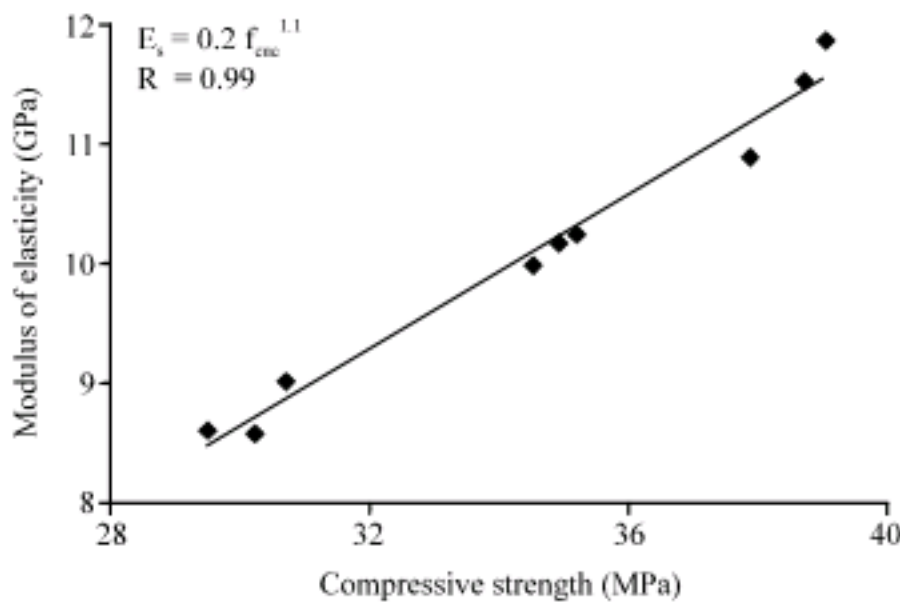


Fig. 6: Relationship between modulus of elasticity and compressive strength

Similarly, the relationship between compressive strength and static modulus for PKS concrete as shown in Fig. 6, is given by the following equation.

$$E_s = 0.2 f_{cuc}^{1.1} \quad (R = 0.99) \quad (3)$$

where, E_s and f_{cuc} are static modulus and compressive strengths in GPa and MPa, respectively.

CONCLUSIONS

- The mix, PKSC-SC3 produced the 28 day compressive strength of 37.8 MPa for the 100 mm cube samples. Thus, using PKS as coarse aggregate and s/c ratio of 1.6, grade 35 lightweight concrete can be produced. However, the mix, PKSC-SC2 is ideal as far as density is concerned as the saturated density of PKSC-SC3 is close to 2000 kg m^{-3}
- The use of superplasticizer is essential due to the lower w/b ratio and high sand content in the mixes. The mixes yielded medium to high slump and the mix with the highest sand content produced lower slump and flow values. The addition of silica fume produced cohesive mix, but lower workability
- The fresh and saturated densities of PKSC: S1-S3 varied between $1856\text{-}1961 \text{ kg m}^{-3}$, while the oven dry densities were about 15% lower than the saturated densities. The highest density of PKSC-SC3 shows that this concrete can be categorized as lightweight. The increase in compressive strength between PKSC-S1 and PKSC-S3 was found to be 24% and the corresponding increase between PKSC-S1 and PKSC-S2 was 17%
- The increase in s/c ratio from 1.0 to 1.6 resulted in slight increase of density between 2-5%. However, the increase in the compressive strength was found to vary between 16 and 28%. The highest 28 day compressive strength of about 38 MPa was obtained

for PKSC-S3 with s/c of 1.6. Thus, grade 35 PKS concrete can be produced with cement content of about 470 kg m^{-3} and 10% silica fume

- Higher sand content enhanced the mechanical properties of PKS concrete. The splitting and flexural tensile strengths were found to be in the range of 1.90-2.61 and 2.76-4.56 MPa, respectively. The ratio between splitting tensile and flexural strength is within 60-70%
- The E-values of PKSC-S1-S3 produced values in the range of about 9-12 GPa, due to the increased sand content and inclusion of silica fume. Lower deflection is expected if they are used as structural concrete

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REFERENCES

- Abdullah, A.A.A., 1984. Basic strength properties of lightweight concrete using agricultural wastes as aggregates. Proceedings of International Conference on Low-cost Housing for Developing Countries, 1984, Roorkee, India, pp: 624-636.
- 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. *Cem. Concr. Res.*, 29: 619-622.
- Clarke, J.L., 1993. *Structural Lightweight Aggregate Concrete*. 1st Edn., Chapman Hall, Glasgow, ISBN: 0 7514 0006 8.
- FIP, 1983. *Manual of Lightweight Aggregate Concrete*. 2nd Edn., Surrey University Press, London, ISBN: 0-903384-43-4.
- Mannan, M.A. and C. Ganapathy, 2004. Concrete from an agricultural waste-oil palm shell (OPS). *Build. Environ.*, 39: 441-448.
- Neville, A.M., 1996. *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.
- Robert, L., S. Lindon, W. Peter and R. Ray, 2003. Cementitious Additions. In: *Advanced Concrete Technology*, John, N. and S.C. Ban (Eds.). Elsevier Publications, Amsterdam, ISBN: 0 7506 5103 2, pp: 43-45.