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Pozzolana and Palm Kernel Shells as Replacements of Portland cement and Crushed Granite in Concrete

Daniel Yaw Osei
Department of Civil Engineering, Cape Coast Polytechnic, Cape Coast, Ghana

Abstract: *The properties of concrete using pozzolana and palm kernel shells as replacement of portland cement and crushed granite were investigated. Twelve concrete mixes were produced by combining pozzolana and palm kernel shells (PKS) to replace 10%, 20%, 30% and 40% of portland cement and 20%, 30% and 40% crushed granite respectively in a 1:2:4 control mix. The workabilities of the fresh concrete mixes were evaluated using the compacting factor test. The compressive strengths and densities were evaluated at 7days, 14 days and 28 days. The density and workability of concrete decreased as the pozzolana and palm kernel shells content increased; however the maximum strength at each palm kernel shell replacement was reached at 20% pozzolana replacement. The 28-day compressive strength ranged from 8.01Nmm^{-2} to 14.21Nmm^{-2}, whereas the density ranged between 2163kgm^{-3} to 2317 kgm^{-3}. The effects of pozzolana and PKS on the density and workability of concrete were similar, however their effects of the strength of concrete were remarkably different. Pozzolana and PKS can be used as partial replacement of portland cement and crushed granite in the production of lightweight concrete.*

Keywords: *Compressive strength, concrete, density, palm kernel shells, portland cement, pozzolana, workability.*

I. INTRODUCTION

The advantages of concrete as construction material are well known, but according to (Short and Kinniburgh, 1978; Chandra and Berntsson, 2002; Crow, 2006; Naik, 2008), its production exacts a heavy toll on the environment. The negative environmental impacts coupled with rising costs of materials have necessitated research into alternative materials to reduce over-dependence on portland cement and rock aggregates used in construction. Replacing portland clinker either partially or entirely is being investigated as an alternative to carbon dioxide emissions (Crow, 2006) and also as an alternative to reduction of the substantial amount of energy used in the production of cement (Chandra and Berntsson, 2002).

A pozzolana is a siliceous or aluminosiliceous material which is not cementitious, but in finely divided form, and in the presence of moisture, chemically reacts with calcium hydroxide released by the hydration of portland cement to form calcium silicate hydrate and other cementitious materials. Incorporation of pozzolana into a concrete mix improves properties such as durability, strength, resistance to sulphates and weathering (Torri and Kawamura, 1994; Chengzhi et. al, 1996). The durability of pozzolana is attested by ancient Roman structures some of which are still standing today (Jackson et. al, 2003). The advantages of using pozzolana as partial replacement of portland cement in construction have been reported (Hammond, 1983; Atiemo, 2005; Adu-Boateng and Bediako, 2006; Sarfo-Ansah et al., 2009).

Generally, the utilization of waste materials in construction provides both practical and economic advantages (Chandra and Berntsson, 2002). It contributes to resource conservation and environmental protection (Ramezanianpour et al, 2009). The potential uses of agricultural wastes in construction have been investigated by (Nimityongskul and Daladar, 1995; Kankam, 2000; Ndoke, 2006; Alengaram et al, 2008; Alengaram et al 2010Olutoge, 2010; Osei and Jackson, 2012).

Palm kernel shells (PKS) are by-products of palm oil production. They consist of small size particles, medium size particles and large size particles in the range 0-5mm, 5-10mm and 10-15mm **(**Alengaram et al, 2010**)**. In a study on the potential of PKS in construction, Kankam (2000) concluded that PKS could be used economically as aggregates in the production of durable lightweight concrete of appreciable mechanical properties and can attain a compressive strength of about 95% of the strength of concrete produced from normal crushed rock aggregate. Concrete produced by 8% and 13% replacement of crushed granite by PKS by volume and by weight respectively attained a 28-day compressive strength of 20Nmm^{-2} (Osei and Jackson, 2012); equivalent to grade 20 concrete recommended for use in reinforced concrete construction by BS 8110 (1997). In an experimental investigation, palm kernel shell concrete (PKSC) beams exhibited ductility until failure, showing a stronger bond between PKSC and reinforcement while normal weight concrete beams failed in brittle manner without warning (Alengaram et al, 2008).

Based on the advantages of pozzolana and the potential of PKS, a combination of pozzolana and PKS as partial replacement of portland cement and coarse aggregates in concrete provides an opportunity to use relatively cheap and durable materials to improve infrastructure development in developing countries whilst reducing construction costs.

Various studies have been carried out on the use of supplementary cementitious materials such as pozzolana to replace portland cement and on the use of PKS to replace crushed rock in concrete. However, little has been reported on the combination of pozzolana and PKS as replacements of portland cement and crushed rock aggregates in concrete. This study investigated the effects of utilizing PKS and natural pozzolana as replacements of crushed rock aggregate and portland cement on the compressive strength, density and workability of concrete.

II. MATERIALS AND METHODS

Portland cement of strength class 32.5R, conforming to BS 12 (1996) was used in producing concrete. ASTM Type N pozzolana was used to replace portland cement. Natural river sand was used as fine aggregate. Crushed granite of nominal size 20mm was used in producing concrete. Palm kernel shells were obtained from a palm kernel production yard at Abura in Cape Coast. They were flushed with water to remove impurities and then dried before use. Ordinary tap water was used in mixing the materials. It appeared clean and free from any deleterious material. It conformed to the requirements of BS 1348(1980). A concrete mix of 1:2:4 by weight using a water cement ratio of 0.6 was used as control. Pozzolana was used to replace 10%, 20%, 30% and 40% of portland cement by weight while PKS replaced 20%, 30% and 40% of granite by volume. Concrete produced by volume replacement of crushed granite with PKS performed better than one in which crushed granite was replaced with PKS by weight (Osei and Jackson, 2012). A total of thirteen mixes were produced. Nine cubes of each mix were cast to obtain one hundred seventeen specimens. The control mix was designated as CM, while concrete made of X%, and Y% replacement with pozzolana and PKS respectively was designated as PXY. The workabilities of the fresh concrete mixes were assessed using the compacting factor test (BS 1881, 1983). To prepare specimens for the determination of compressive strength, concrete was cast in 150mm×150mm×150mm cast iron moulds (Fig. 1) whose internal walls were oiled prior to casting. After casting, the moulds were covered with plastic sheets to prevent water loss through evaporation. The specimens were demoulded after twenty four hours and then immersed in curing tank to cure for strength gain and general improvement of properties in the hardened state. Three specimens of each mix were crushed at 7days, 14 days and 28days using a 1500kN capacity Matest digital compression tester (Fig. 2). The cubes were removed from the curing tank and left in the open air for about two hours after which their densities were determined prior to crushing.

Fig. 1 Concrete specimens

Fig. 2 Matest compression tester

III. RESULTS AND DISCUSSION

III.1 Workability

Table 1 presents the results of the compacting factor test.

Table 1 Results of Compacting Factor Test

Pozzolana Replacement (%)	PKS (%)		
	20	30	40
10	0.88	0.87	0.86
20	0.85	0.84	0.83
30	0.83	0.82	0.81
40	0.82	0.81	0.80

It is seen from the Table 1 that, at a constant pozzolana replacement, the workability of concrete decreased as the percentage of PKS increased. Similarly, at the same PKS content, the workability decreased as pozzolana replacement increased. Both pozzolana and PKS decreased the workability of concrete. As the quantity of PKS increased, there was a corresponding increase in specific surface. This required more water to maintain the same level of workability. However, since the same water binder ratio was used for all mixes, the workability reduced. Kankam (2000) found out that high water absorption of PKS resulted in lower workability of the constituent concrete compared with natural rock aggregate.

III.2 Compressive strength

The results obtained from the determination of the compressive strength of concrete are presented in Table 2.

Table 2 Results of compressive strength testing

Designation	Pozzolana replacement (%)	PKS replacement (%)	Compressive strength(Nmm^{-2})		
			7days	14days	28 days
CM	0	0	15.42	18.42	20.73
P1020	10	20	10.85	12.62	13.57
P1030	10	30	8.98	9.87	10.90
P1040	10	40	6.58	8.10	10.37
P2020	20	20	8.69	11.17	14.21
P2030	20	30	7.89	8.59	11.29
P2040	20	40	6.62	7.93	11.02
P3020	30	20	7.82	9.89	11.53
P3030	30	30	6.19	7.93	9.81
P3040	30	40	5.71	6.90	9.42
P4020	40	20	7.26	8.26	9.13
P4030	40	30	5.57	7.05	8.49
P4040	40	40	5.02	7.62	8.01

The variation of compressive strength with age is shown in Fig. 3. The compressive strength of all concrete mixes increased with age. The compressive strengths of all the mixes were lower than the compressive strength of the control mix.

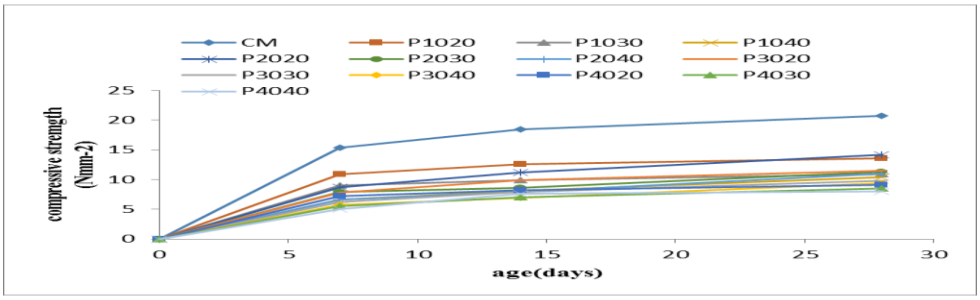

Fig. 3 Compressive strength development

Fig. 4 shows the variation of the 28-day compressive strength with pozzolana replacement at different PKS contents.

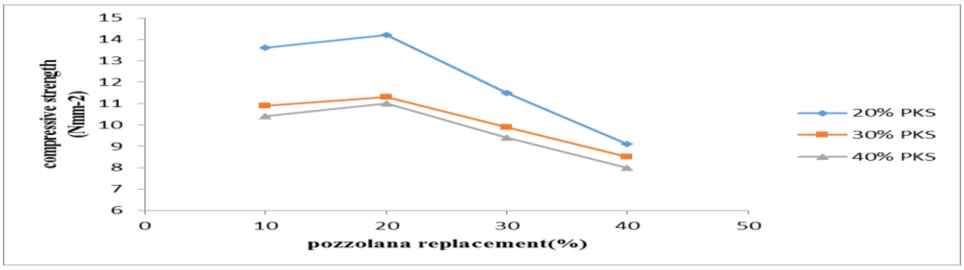

Fig. 4 Variation of compressive strength with pozzolana replacement

As the pozzolana content changed from 10% to 40%, the compressive strength increased from13.57 Nmm^{-2} at 10% pozzolana replacement to a maximum of 14.2 Nmm^{-2} at 20% PKS replacement and then reduced to 9.13 Nmm^{-2} as the pozzolana content reached 40%. The variation of compressive strength with pozzolana replacement showed similar trends at all PKS contents. Though the compressive strength of concrete reduced as pozzolana replacement changed from 10% to 40%, it reached a maximum value at 20% pozzolana replacement. Concrete derives its strength from the pozzolanic reaction between silica in pozzolana and the calcium hydroxide liberated during the hydration of portland cement. At both high and low pozzolana replacements, the compressive strength of concrete is low as a result of the limited quantity of calcium silicate hydrate formed due to the relative proportions of portland cement and pozzolana. An optimum replacement level exists for which the strength is maximum. The maximum compressive strength of PKSC was about 70% of the compressive strength of the control mix. From the strength development trends shown in Fig. 3, P2020 which attained the maximum compressive strength has the potential to reach a higher long term strength. Fig. 5 shows the variation of 28-day compressive strength with PKS replacement at different pozzolana replacements.

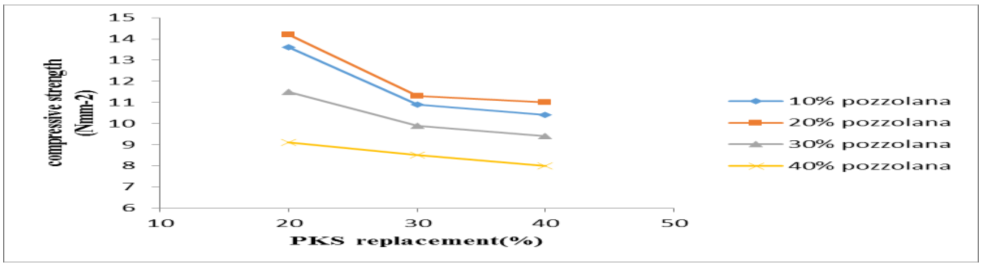

Fig. 5 Variation of compressive strength with PKS replacement

As the PKS content increased from 20% to 40%, the compressive strength decreased at all pozzolana replacement levels. At 10% pozzolana replacement, the compressive strength reduced from 13.57 Nmm^{-2} to 10.37 Nmm^{-2}. The variation of the compressive strength with PKS showed similar trends at all pozzolana contents. The compressive strength of concrete reduced as the percentage replacement by PKS increased. Strength depends to a large extent on good bonding between the cement paste and the aggregates. As the PKS content increased, the specific area increased, thus requiring more cement paste to bond effectively with the shells. Since the binder content remained the same, extra bonding could not be mobilised to accommodate the increased specific surface. It can also be seen from Fig. 4 that at all PKS contents, the optimum strength was attained at 20% pozzolana replacement. The 28-day strengths of the various mixes ranged from 5-19.5 Nmm^{-2}, satisfying the criteria for classification as lightweight concrete (Chandra and Berntsson, 2002). From the trends shown in Fig. 5, attainment of higher compressive strengths is possible at PKS replacement less than 20%.

III.3 Density

The results obtained from density determination are presented in Table 3

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Table 3 Density (kgm^{-3})

Pozzolana replacement (%)	PKS replacement (%)		
	20	30	40
10	2317	2262	2202
20	2255	2212	2175
30	2212	2188	2166
40	2198	2172	2163

It is seen from Table 3 that at any pozzolana replacement, the density reduced as the PKS content increased. Similarly, at any PKS replacement, the density reduced as the pozzolana replacement increased. At 10% pozzolana replacement, the density of concrete reduced from 2317 kgm^{-3} to 2202 kgm^{-3} as the PKS content increased from 20% to 40%; representing an average density reduction rate of 5.7 kgm^{-3} per unit percentage increase in PKS replacement. At 20%, 30% and 40% pozzolana contents the density reduced at average rates of 4 kgm^{-3}, 2.3 kgm^{-3}, and 1.8 kgm^{-3} per unit percentage increase in PKS replacement respectively. At 20% PKS replacement, the density of concrete reduced from 2317 kgm^{-3} to 2198 kgm^{-3} as the pozzolana content increased from 10% to 40%. This represented an average density reduction rate of 4 kgm^{-3} per unit increase in pozzolana replacement. Similarly, at 30%, and 40% PKS replacement, the density reduced at average rates 3 kgm^{-3}, and 1.3 kgm^{-3} per unit percentage increase in pozzolana replacement respectively. Compared to the control concrete, as the percentage of PKS increased, the mass of the mix reduced since PKS is lighter than the granite. Replacing granite with an equal volume of PKS decreased the mass of the mix, hence a reduction in density.

IV. CONCLUSION

The effect of replacing portland cement and crushed granite with pozzolana and PKS on the workability, density and strength of concrete investigated. Based on the results obtained from the study, the following conclusions are drawn:

- Pozzolana and PKS exhibited similar influences on the density and workability of concrete both of which. reduced as the pozzolana and PKS contents increased.
- The influence of pozzolana on the compressive strength of concrete was remarkably different from the influence of PKS on the strength of concrete. On the average at any pozzolana content, the compressive strength of concrete reduced as the PKS increased, whereas at all palm kernel shells content its maximum value was reached at 20% pozzolana replacement.
- The maximum compressive strength of 14.2 Nmm^{-2}, about 70% of the compressive strength of the control mix was reached at a combined 20% pozzolana and 20% PKS replacements.
- Pozzolana and PKS can potentially be used as partial replacements of portland cement and crushed granite respectively to produce cheaper lightweight concrete.

It is recommended that

- Durability studies of the properties of pozzolana palm kernel shell concrete should be carried out to ascertain its potential use in aggressive environments
- The possibility of concrete reaching a higher compressive strength at lower PKS contents should be investigated.
- The combined use of PKS and pozzolana in concrete production in Ghana should be encouraged as an environmental protection and construction cost reduction strategy.

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