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Development of Palm Kernel Shell Lightweight Masonry Mortar

Kazeem K. Adewole

Abstract**—**There need to construct building walls with lightweight masonry bricks/blocks and mortar to reduce the weight and cost of cooling/heating of buildings in hot/cold climates is growing partly due to legislations on energy use and global warming. In this paper, the development of Palm Kernel Shell masonry mortar (PKSMM) prepared with Portland cement and crushed PKS fine aggregate (an agricultural waste) is demonstrated. We show that PKSMM can be used as a lightweight mortar for the construction of lightweight masonry walls with good thermal insulation efficiency than the natural river sand commonly used for masonry mortar production.

Keywords**—**Building walls, fine aggregate, lightweight masonry mortar, palm kernel shell, wall thermal insulation efficacy.

I. Introduction

THE weight and thermal conductivity/insulation of materials used for the construction of building walls are essential. This is due to the fact that the weight of materials used for the construction of building walls and consequently, the weight of the building walls affects the strength requirement of beams, columns and foundations supporting the building walls. Similarly, the thermal conductivity/ insulation of materials used for the construction of building walls and consequently, the thermal conductivity of the building walls are essential affect the thermal efficiency of buildings. The thermal efficiency of the building is a major determinant on the cost of heating and/or cooling of buildings.

In hot climates, such as in the Middle East and other tropical areas of the world, the building indoor temperature is very high especially in summer. Conversely, in cold climates, such as in Europe and other temperate areas of the world, the temperature inside buildings is very low especially in winter. Consequently, buildings are heated and cooled in hot/tropical and cold/temperate areas of the world respectively for the comfort of the occupants. Mostly, electric power and fuel are used for heating and cooling of the buildings. Heating and cooling of building consume high amount of energy and are thus expensive. The effectiveness of the heating and cooling of the indoors of buildings to provide the desired comfort to the occupant depends on the thermal insulation/conductivity of the building walls as heat could be loss to the building outdoors which is colder in cold/temperate regions. Similarly, heat can be conducted from buildings outdoor into the indoor in hot/tropical regions of the world. From an economic and environment conservation perspectives, it is essential to construct building walls with materials having high thermal insulation characteristics (i.e. low thermal conductivity) as this will make the heating and cooling effective and reduce the cost and the environmental pollution associated with cooling and heating needed to make building indoors comfortable [1].

The weight of building walls depends on the weights of the materials (principally, masonry units and mortar) used for walls construction. The lighter, the materials used for the walls construction, the lighter the wall and the lower the strength requirement of the structural members such as beams, columns and foundations carrying the deal load of the walls. Consequently, the lower the strength requirement of structural members such as beams, columns and foundations supporting the wall, the lower the cost of the structural members and the consequently, the lower the cost of the whole building. Concrete masonry unit (bricks and blocks) made of Portland cement, fine aggregates and water is one of the commonest walling units in many parts of the world. This is due to the fact that concrete blocks are extremely durable and are energy savers. Using concrete blocks for walls construction also greatly reduces the construction and Maintenance Costs. Constructing walls with concrete blocks also enables design flexibilities. Concrete blocks are also used for wall constructions because they are unaffected by termites and extreme temperatures, and are virtually soundproof when made of good quality. In addition for using concrete blocks for partition walls, they are also used for foundation and basement walls as well as for the construction of drainage walls.

It is well known that the thermal behavior of concrete is inversely proportional to its density [1]. Consequently, building walls constructed with lightweight concrete masonry bricks/blocks and lightweight mortar prepared with lightweight aggregate are generally lighter and possess a relatively higher thermal insulating efficiency than walls constructed with concrete masonry bricks/blocks and mortar prepared with normal weight aggregate [1], [2]. This is due to the fact that light weight aggregates have large number of voids which reduces their weight and their thermal conductivity (i.e. increases their thermal insulation efficiency) as the thermal conductivity of voids are generally lower than that of solid [1]. In the published literature, efforts on the reduction of the weight of building walls and the reduction of the thermal conductivity of building walls have largely been focus on the development and use of lightweight building units made with lightweight aggregates. Several agricultural wastes such as sawdust, rice bran, groundnut shells etc have been used by researcher largely for the production of

K. K. Adewole is with the Civil Engineering Department, University of Ibadan, Ibadan, Nigeria (phone: +2347083389335; e-mail: kkadewole@yahoo.com).

lightweight masonry units (Bricks and/or blocks). No much published works exist on the use of agricultural wastes for masonry mortar production. Materials that have been used for the production of lightweight mortar includes: pumice, perlite, diatomites, zeolites, clays, expanded aggregates etc.

In recent years, partly due to the legislation on energy use and global warming, building regulations require that both the masonry units and mortar joints be given consideration when considering the heat loss and thermal efficiency (U value) of walls (Cemex Mortar). Consequently, the need to develop lightweight masonry mortar with lightweight aggregates that reduces the weight of building walls and increases the wall's thermal efficiency cannot be overemphasized. Many lightweight natural and recycled aggregates such as polystyrene beads, charcoal, etc. have been used for the production of light weight mortar. To the best of the author's knowledge, the use of crushed Palm Kernel Shell (PKS), an agricultural waste from the processing of palm oil as a lightweight aggregate for the production of masonry mortar has not been published. The published works on the use of PKS as aggregates such as the works of [3]-[7] among others have largely been use as a coarse aggregate in concrete production. PKS is available in large quantities in Malaysia and Indonesia, and other tropical countries of the world such as Nigeria and Ghana in West Africa. 3.2 million tons and 3.1 million tons of palm kernel shells are produced as a bye product of waste from oil palm fruit processing industry in Indonesia and Malaysia respectively. PKS is largely used as biofuel. Consequently, the utilization of PKS as aggregates for building materials production, particularly for the production of mortar for walls construction represents a more environmentally friendly and more valuable use of PKS. PKS has been proved to be durable by [8]. PKS fine aggregate has also been employed as a partial replacement for natural sand in concrete/sandcrete masonry units (blocks and bricks) productions by [8]-[10]. Pulverized PKS has also been employed for the production of particleboards by [11]. Furthermore, PKS fine aggregate has also been employed as a partial replacement for fine aggregate in asphalt concrete production by [12].

In this paper, the development of palm kernel shell masonry mortar (PKSMM) prepared with Portland-limestone cement grade 42.5 and crushed PKS fine aggregate is presented. The bulk densities and water absorptions of PKS fine aggregate are compared with that of normal sand. The dry hardened densities of PKSMM and natural sand masonry mortar (NSMM) are compared and the compressive strengths of 1:3, 1:4 and 1:5 PKSMM cubes are presented. The details of the pre-treatment (washing, sun drying), production of PKS fine aggregate, particle size distribution analysis, batching and production of PKS and normal weight river sand aggregate mortar, compressive strength testing and comparison of the PKS fine aggregate and normal weight river sand masonry mortar cubes are presented.

II. Materials and Methods

The PKS large aggregate shown in Fig. 1 (a) was obtained from the waste yard of a local palm oil producing company in Ibadan in the southwestern region of Nigeria. The sizes of the PKS large aggregates range from 5mm to 15mm. The PKS large aggregate was thoroughly washed to remove earthen impurities and dried. The sun dried PKS large aggregate was crushed to obtain PKS fine aggregate shown in Fig. 1 (b). Sieve analysis was conducted to determine the gradation (particle size distribution) of the PKS fine aggregate. The bulk densities and the water absorptions of the PKS fine aggregate and that of typical normal weight river sand were determined.

(a) PKS large aggregates

(b) Crushed PKS fine aggregate

Fig. 1 PKS Aggregates

The crushed PKS fine aggregate and the normal weight river sand were soaked in water for twenty-four hours to fill the pores with water to obtain PKS fine aggregate and river sand in saturated condition. The saturated PKS fine aggregate and normal weight river sand ware batched by volume and a water-cement ratio of 0.35 based on the weight of cement was employed. Three different mix ratios of 1:3, 1:4 and 1:5 Portland-limestone grade 42.5 cement to saturated crushed PKS fine aggregate were considered. Similarly, three different mix ratios of 1:3, 1:4 and 1:5 Portland-limestone grade 42.5 cement to normal weight river sand were considered. The PKS fine aggregate and the normal weight river sand mortars were mixed manually.

Ten 50mm x 50mm x 500mm each of PKS and normal weight river sand masonry mortar cubes were prepared in accordance with the EN 1996-1-1: 2005 [9] specifications for the three mix ratios considered**.** The typical 50mm x 50mm x 500mm PKS masonry mortar cubes are shown in Fig. 2 (a). The PKS and normal weight river sand masonry mortar cubes were compacted in three layers with 25 blows of tamping rods. The top surface of the cubes were leveled with hand trowel and appropriately labeled. PKS and normal weight river sand masonry mortar cubes were left for 24 hours in the mould and demoulded.

(a)

(b)

Fig. 2 PKS masonry mortar cubes

The PKS and normal weight river sand masonry mortar cubes were cured for 28 days in the same curing tank at ambient temperature of approximately 30 degree centigrade. On the 28th day, the PKS and normal weight river sand masonry mortar cubes were removed from the curing tank and their surfaces were wiped with a piece of cloth and subjected to compressive strength tests. For each of the three mix ratios, five specimens (more than the minimum recommended 3 specimens) of the PKS and normal weight river sand masonry mortar cubes were used for the determination of the dry hardened density of the cubes. The remaining five specimens each of the PKS and normal weight river sand masonry mortar cubes were employed for the compressive strength determinations using the compressive strength test arrangement show in Fig. 2 (b).

III. Result

The average loose bulk densities of the PKS fine aggregate obtained was 743 kg/m^3 while the average loose bulk densities of the of the normal weight river sand obtained is 1564 kg/m^3. The water absorptions of the PKS fine aggregate obtained was 38% while the water absorptions of the normal weight river sand obtained is 18%. The particle size distribution curves for the PKS fine aggregate and the river sand are shown in Fig. 3. The average dry hardened densities of the 1:3, 1:4 and 1:5 PKSMM cubes obtained are 1084kg/m^3, 1141 kg/m^3 and 1202 kg/m^3 respectively. The average dry hardened densities of the 1:3, 1:4 and 1:5 RSMM obtained are 1923kg/m^3, 1863kg/m^3, 1803kg/m^3, The average twenty eight day's compressive strengths of the 1:3, 1:4 and 1:5 PKS masonry mortar cubes obtained are 10N/mm^2, 6 N/mm^2 and 2.6 N/mm^2 respectively.

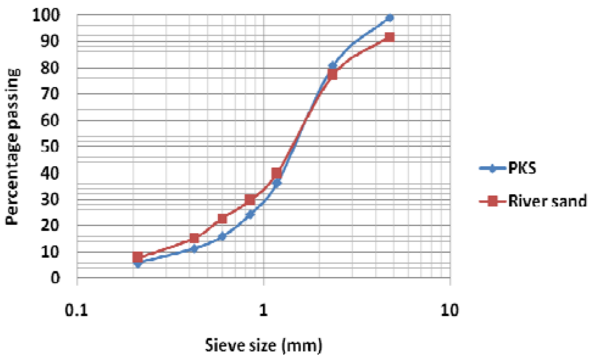

Fig. 3 Particle size distribution curves for PKS and River sand

IV. Discussion

The comparison of the 743 kg/m^3 and 1564 kg/m^3 average bulk densities of the PKS fine aggregate and natural river sand respectively demonstrates that the density of PKS fine aggregate is approximately 47% of the density of the river sand. These results establish that the weight of the PKS fine aggregate is less than half of the weight of the normal weight aggregate. Consequently, the PKS fine aggregate is considerably lighter than the normal river sand. This PKS fine aggregate is considerably lighter than the natural normal weight river sand due to the fact that the PKS contains a lot of voids/pores compared to the natural river sand.

The 40% and 10% water absorptions of the PKS fine aggregate and that of the normal weight river sand demonstrates that PKF fine aggregate absorbs water four times than amount of water absorbed by the natural sand. This PKS fine aggregate absorbs more water than the natural normal weight river sand due to the fact that the PKS contains a lot of voids/pores compared to the natural normal weight river sand. The lower density of the PKS fine aggregate demonstrate that its thermal conductivity will be lower than that of river sand since the thermal conductivity of concrete/mortar has been established to be proportional to the density of the concrete/mortar. Similarly, the presence of substantial pores in the PKS fine aggregate more than the pores in the normal weight river sand demonstrate that the thermal conductivity of the PKS fine aggregate will be lower than that of normal weight river sand since the thermal conductivity of concrete/mortar has been established to be proportional to the porosity/void ratio of the concrete/mortar. Also the thermal conductivity of voids is lower than that of solid.

The 10 N/mm^2 28 days average compressive strengths of the 1:3 PKSMM cubes demonstrates that the PKSMM with Portland cement to sand ratio of 1:3 can be employed for the bonding of masonry units in severe exposure conditions such as the external walls of buildings as specified by [13]. The 6N/mm^2 and 3N/mm^2 28 days average compressive strengths of the 1:4 and 1:5 PKSMM cubes demonstrates that the PKSMM with Portland cement to sand ratios of 1:4 and 1:5 can be employed for the bonding of masonry units in mild exposure conditions such as the internal walls of buildings as specified by [13].

V. Conclusion

This study presents the development of PKS masonry mortar for bonding of masonry units (bricks and blocks) for building walls construction. The study covers the production, testing and comparison of the PKS fine aggregate and normal weight river sand masonry mortar cubes. The various stages of the PKS fine aggregate production covering the washing, sun drying and crushing of the large PKS aggregate are presented The details of the sieve analysis conducted to establish the gradations of the PKS fine aggregate and normal weight river sand are also presented. Also presented are the details of the conditioning of the PKS fine aggregate and the normal weight river sand which involved the soaking of the PKS fine aggregates and the normal weight river sand in water for 24 hours to fill all the pores in both aggregate types with water in order to obtain saturated PKS fine aggregate and normal weight river sand aggregate. Saturated PKS fine aggregate was employed in this work to prevent the PKS fine aggregate from absorbing the water meant to give the PKS mortar the required workability and the water meant for the hydration of the Portland cement at the chosen water-cement ratio of 0.35. Saturated normal weight river sand was employed in this work to ensure that the same water-cement ratio was employed for the productions of both the PKS fine aggregate and normal weight river sand mortars for good caparisons of the two mortar types. Furthermore, the details of the batching (done by volume), mixing, casting, demoulding, and curing of the PKS fine aggregate and normal weight river sand masonry mortar cubes are also presented. The detailed procedures employed for the batching, mixing, casting, demoulding and curing of the PKS fine aggregate and natural river sand mortars are also presented. The details of the physical test (density determination) and laboratory tests (compressive strength and water absorption tests) conducted on the PKS fine aggregate and normal weight river sand masonry mortar cubes are equally presented.

The study demonstrates that PKS fine aggregate can be used for the production of lightweight PKS masonry mortar. The use of lightweight PKS masonry mortar has the potential to reduce the cost of building by reducing the weight of wall and thus the size and strength requirements of the structural elements such as beams, columns and foundations supporting the walls. Also, due to the porous nature of the PKS fine aggregate, the use of lightweight PKS masonry mortar has the potential to reduce the thermal conductivity of building walls thereby reducing the thermal efficiency of buildings. Furthermore, the recycling and application of PKS waste as fine aggregate for masonry mortar production represents an effective utilization of waste, thereby reducing the consumption of mined/quarried fine aggregate. This will encourage sustainability in terms of efficient waste management through the reuse/recycling of PKS and reduction of the consumption of virgin river sand aggregates commonly used for masonry mortar production.

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