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Compressive strength of concrete with millet husk ash (MHA) as a partial replacement for cement

Прочность при сжатии бетона с золой лузги проса в качестве частичного заменителя портландцемента

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Ключевые слова: прочность на сжатие; заполнители для бетона; зола лузги проса; заменитель портландцемента

Abstract. A study of compressive strength of concrete with millet husk ash (MHA) as partial replacement for ordinary Portland cement (OPC) is presented. The strength characteristics was investigated by casting and testing 54 specimen cubes sizing 100 mm x 100 mm x 100 mm for varied percentage replacements of cement (0 %, 10 % and 20 %) with water cement ratio of 0.65. These cubes were cured for 7 days, 14 days, 28 days and 35 days to target strength design of 25 N/mm^2 at 35 days crushing. The result shows that at 35 days the compressive strength for 0 %, 10 % and 20 % replacements are 32.00 N/mm^2, 25.56 N/mm^2, and 23.18 N/mm^2, respectively. It is clear that MHA as a pozzolanic material can be incorporated into cement in amounts of no more than 10 % replacement in order to develop a good and hardened concrete.

Аннотация. В статье представлено исследование прочности при сжатии бетона с золой лузги проса, рассматриваемого как частичная замена обычного портландцемента. Прочностные характеристики исследовали методом литья и испытания 54 образцов кубов размерности 100 x 100 x 100 мм для разнообразных процентных замен цемента (0 %, 10 % и 20 %) с водоцементным соотношением 0.65. Эти кубики были выдержаны 7 дней, 14 дней, 28 дней и 35 дней для достижения прочности конструкции 25 Н/мм^2 в возрасте 35 дней. Результат показывает, что в возрасте 35 дней при процентной замене портландцемента на цемент с золой 0 %, 10 % и 20 % прочность при сжатии составляет 32.00 Н/мм^2, 25.56 Н/мм^2, и 23.18 Н/мм^2 соответственно. Очевидно, что для получения бетона удовлетворительного качества зола лузги проса в качестве пуццоланового материала может быть использована в цементе в количестве не более 10 %.

Introduction

Concrete basically consists of cement, fine and coarse aggregates, water for mixing, and sometimes admixtures are added, such as air entraining agents, plasticizers and pozzolans [1].

Many materials are added to a concrete mix to improve its properties in both fresh and hardened states, serving the same purpose as cement and making work with concrete easier while being economically efficient. Other areas that are being explored to attain cost-effectiveness of concrete include the use of recycled solid wastes, agricultural wastes and industrial wastes like fly ash, blast furnace slag, silica fume, rise husk ash, wood ash, etc [2–4].

The use of any particular waste will be tied to its abundance or availability and cost-effectiveness of production. The usage of these environmental wastes as partial replacement for ordinary Portland cement (OPC) in concrete production calls for intensive research into the characteristics of modified concrete. Most of these materials are called pozzolans [5–8].

Neville [8] states that the term pozzolan is used to describe naturally occurring and artificial siliceous or aluminous materials which in themselves possess little or no binding values but within finely divided form and in the presence of moisture will chemically react with calcium oxide at ordinary temperature to form compound possessing binding properties. The pozzolanic reaction may be slower than the rest of the reactions that occur during cement hydration, and thus the short-term strength of concrete made with pozzolans may not be as high as that of concrete made with purely binding materials; conversely, highly reactive pozzolans, such as silica fume and high reactivity metakaolin can produce "high early strength" concrete, which increases the rate at which concrete gains strength with aging [9–12].

Typical natural pozzolana are now so abundant and recognized that some of them, like fly-ash, are covered by code of practice specifications [13]. Other well-known natural pozzolana are granulated blast furnace slag and silica fume which can be used individually with Portland or blended cement or in different combinations as presented by Talero [14]. These pozzolana react with calcium hydroxide ($Ca(OH)_2$) released by the chemical reactions of the tricalcium silicate and dicalcium silicate with water in the cement hydration process to form binding materials. It is for this reason that the materials are of significance in engineering, i.e. they are often added to concrete to produce mixes that are not only economical but also reduce permeability, may increase strength and influence other concrete properties. Neville [9] grouped pozzolana into two main classes, namely, natural and artificial. Though the natural and artificial classes have similar pozzolana activity, they differ greatly from one another in origin, but slightly in chemical and mineralogical constituents.

Although the addition of pozzolana to Portland cement does not contribute to the compressive strength of concrete at early ages, strengths similar to those of ordinary Portland cement can be expected at later ages provided the cement is cured under moist conditions for a sufficient period [15].

Hossain [16] states that the Kenya standard (KS-02-1261) recommends that a good pozzolana for manufacture of pozzolanic cement should have a combination of SiO_2 + Al_2O_3 of at least 70 %. The ASTM C618 [13] on the other hand requires that a good pozzolana should have a combined percentage of SiO_3+Al_2O_3+Fe_2O_3 of more than 70 %. Some of the advantages of using pozzolanic material as partial replacement of cement are listed by Hussain [16] and include improved workability; improved sulphate resistance, particularly in marine environments; improved resistance to freezing and thawing in temperate environments; increased cohesiveness or bonding strength of the concrete; increased long-term strength; reduction in water content of mortar and concrete mixes resulting in less shrinkage and cracking; increased potent advantage in hot weather concreting; decreased permeability and water tightness; and high resistance to alkaline-aggregate reactions.

Table 1. Leading millet producers, 2014 [17]

Country Ranking	Production	
	Quantity in Metric Tons	Percentage (%) total
India	10000	35.2
Nigeria	4800	16.9
Niger	3200	11.3
China	1800	6.3
Mali	1600	5.6
Sudan	1085	3.8
Burkina Faso	1038	3.7
Uganda	820	2.9
Ethiopia	750	2.6
Chad	683	2.4
Others	3419	12.1

One of these pozzolanic materials is the millet husk ash (MHA) which is the focus of this work. Availability of millet production is presented in Table 1. World millet production stands at around 30 million metric tons annually. For millions of people in the semi-arid tropics of Asia and Africa, millets along with Sorghum are the most important staple foods. Around 90 % of this annual figure is utilized in developing countries and only a very tiny fraction is used by developed countries. India, Nigeria, Niger, China, Mali, Sudan, Burkina Faso, Uganda, Ethiopia, and Chad are estimated to account for over 80 % of global millet utilization [17]. As a result of the abundance of this agricultural produce in Nigeria, mostly the husks are not used for any reasonable purpose and are instead burnt or left to decay. This is why this paper focuses on harnessing this agro-waste by assessing the strength property of the MHA when partially replacing cement in concrete.

Materials and methods

The materials used include ordinary Portland cement (OPC) substituted partially with MHA; sharp sand; crushed granite and water. The material preparations took place at the Gidan Kwano campus of Federal University of Technology, Minna, and proceeded with sourcing sharp sand used as a fine aggregate. The binder (cement) used for this project work is partially replaced by MHA. The cement obtained from an open market in Minna was Ordinary Portland Cement (Dangote). While the millet husks were obtained from a Kontangora farm in Niger State and burnt under controlled conditions within the university's premises in Gidan Kwano Campus to obtain the ash. Crushed granite used as coarse aggregates were obtained from a quarry site at Takun Pada, Minna, Niger State, Nigeria.

The methodology included laboratory experiments and this consisted of preparing and testing fresh and hardened concrete specimens of normal concrete and MHA concrete. All the samples were tested based on laboratory preliminary tests with sieve analysis of fine aggregate and coarse aggregate, specific gravity of fine aggregate and coarse aggregate, moisture content of fine aggregate, slump test and compressive strength test carried out according to standard specification.

A total of 72 concrete samples of 100 x 100 x 100 mm dimensions were cast. The percentage of substituting the cement with MHA varied at 0 %, 10 % and 20 % of cement and values of their respective compressive strengths were taken at 7 days, 21 days, 28 days, and 35 days of hydration periods [18]. The conventional procedure at 14 days was be skipped and replaced with crushing at 35 days because studies have shown that pozzolanic materials result in concrete of lower strength in the early ages and that strength similar to those of ordinary Portland cement can be expected at later ages provided the cement is cured under moist conditions for a sufficient period [10–13, 15]. The compressive strength of the samples was determined after the specified curing periods and demoulding according to the standards specification [18–20].

Results and discusion

Results of the tests carried out, such as sieve analysis, specific gravity, natural moisture content, bulk density, workability test, and compressive strength, are presented in Tables 2, 3, 4 and Figures 1 and 2, respectively. The result of sieve analysis for sharp sand as presented in Figure 1 was carried out in accordance to BS [21] with a fineness modulus of 3.03 classified as finely graded. The fineness modulus for crushed granite rock gives 2.87 from the sieve analysis presented in Figure 2. The characteristics of the fine and coarse aggregates are given in Table 2 and 4, respectively. These components are: specific gravity; bulk density; moisture content; and fineness modulus for sharp sand all within specifications of the standards [22–25].

The characteristics of MHA concrete are presented in Table 4. It is evident that with an increase in percentage of MHA replacement, there is a decrease of slum indicating a reduction of workability. However, all values of slum fall within 10 mm to 30 mm [26], which can be classified as medium workability, even though the workability decreases with an increase in MHA replacement concrete. The maximum compressive strength of 32.0 N/mm^2 was obtained after a 35 days curing period for 0 % MHA replacement and 25.56 N/mm^2 at 10 %, but 23.18 N/mm^2 was obtained at 20 % replacement (Figure 3).

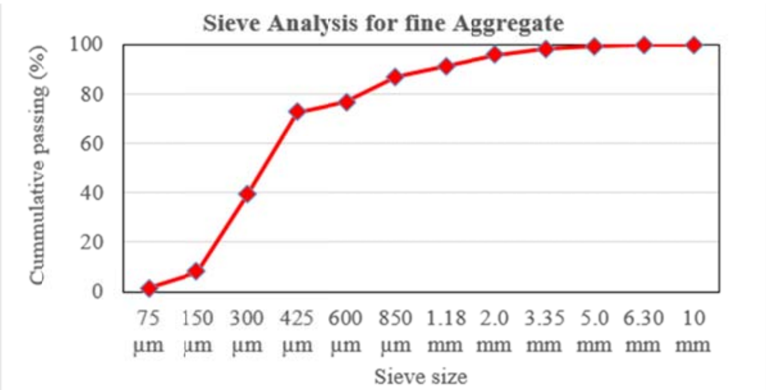

Figure 1. Particle size distributions for fine aggregate (sharp sand)

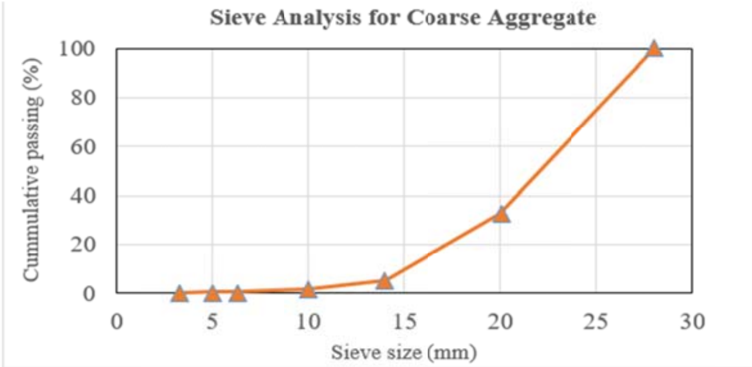

Figure 2. Particle size distribution for coarse aggregate (crushed granite)

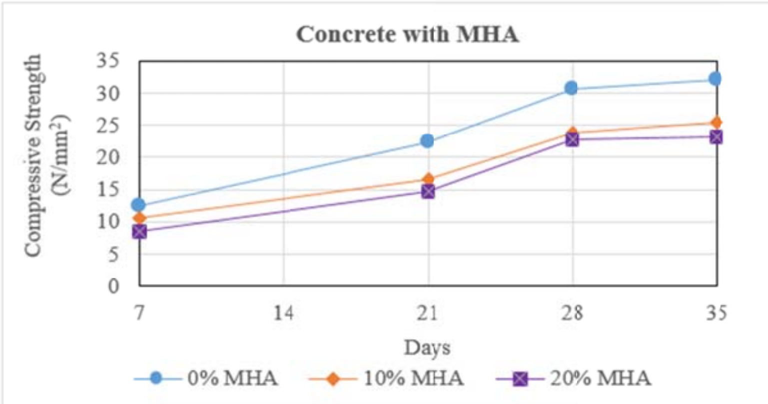

Figure 3. Variation of compressive strength with percentage MHA content

Table 2. Characteristics of Fine Aggregate

No.	Test	Result	BS requirement
1	Specific Gravity	2.53	2.6…3.0 [22]
2	Bulk Density (kg/m^3)	1368.0	1300…1700 [23]
3	Moisture Content (%)	8.40	5…15 [24]
4	Fineness Modulus (FM) from standard sieves only.	3.03	2.0…3.3 [25]

Table 3. Characteristics of Coarse Aggregate

No.	Test	Result	BS requirement
1	Specific Gravity	2.80	2.4…2.8 [22]
2	Bulk Density (kg/m^3)	1570.31	1300…1800 [23]
3	Moisture Content (%)	1.76	1…5 [24]
4	Fineness Modulus (FM) from standard sieves only	2.87	5.5…8.0 [25]

Table 4. Characteristics of MHA Concrete

No.	Test		% of MHA replacement Result		
			0 %	10 %	20 %
1	Mix Proportion, Cement/MHA: fine aggregate: coarse aggregate		1:2:4	1:2:4	1:2:4
2	Water cement ratio (w/c)		0.65	0.65	0.65
3	Slum in (mm)		28.5	22.4	18.7
4	Number of cubes cast	7 days	6	6	6
		21 days	6	6	6
		28 days	6	6	6
		35 days	6	6	6

No.	Test		% of MHA replacement Result		
			0 %	10 %	20 %
5	Compressive strength (N/mm^2)	7 days	12.36	10.67	8.48
		21 days	22.38	16.68	14.68
		28 days	30.71	23.86	22.73
		35 days	32.00	25.56	23.18

The average compressive strengths at 7 days, 21 days, 28 days and 35 days for 0 % MHA replacement are as represented in Table 4. The result shows that with an increase in days of curing, the compressive strength of various replacements percentages generally increases. It is also observed that the more the replacement percentage of MHA, the lesser the strength of the concrete irrespective of the hydration periods. However, the design strength of 25 N/mm^2 was achieved for a much later hydration period, as evident and attained in the curing period of 35 days with 10 % MHA replacement, thus giving a compressive strength of 25.56 N/mm^2.

Conclusions

This work has presented the compressive strength study of concrete with MHA as partial replacement for cement at 25.56 N/mm^2 with a 10 % replacement. By this study, one vital ways of harnessing naturally abundant agricultural waste in the form of Millet Husk which otherwise could have been, environmentally, hazardous has been achieved. Rather than lay wasted, it could be transformed into useful building material especially, where MH material is readily available and in abundance. The following conclusions can be drawn: it is feasible to use MHA as an alternative pozzolanic material alongside with conventional cement; MHA can be blended in small amounts between 0 % and 10 % replacement by weight or volume of cement in concrete production and concrete works; we recommend that MHA replacement should not be greater than 10 %, especially for major concrete works and the replacement should be strictly supervised; a replacement of cement with 20 % MHA is not advisable for major concrete work, since the percentage drop in concrete strength is great; further work can be carried out to include curing periods up to 90 days, re-vibration of MHA concrete and some other physical properties in order to standardize its application in the construction industry. In addition, cost analysis can be incorporated for MHA and OPC concrete to ascertain concrete production with a lower cost.

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