ASSESSMENT OF THE HYGROTHERMAL PROPERTIES OF MORTAR USING QUARRY DUST

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ABSTRACT
Assessment of the hygrothermal properties of mortar using quarry dust as fine aggregate was studied. The material used include Ordinary Portland Cement, water and quarry dust. Preliminary test such as particle size distribution, bulk density, moisture content and specific gravity were conducted on the aggregate in accordance to BS EN 1097:6. The mortar was prepared using a mix ratio of 1.4 and cured for 28 days. Water absorption, porosity and sorptivity test were the properties measured. Fineness modulus of 2.94, specific gravity of 2.42 and water absorption of 1.4% was recorded. The porosity and sorptivity were within the limit set by standard but the water absorption capacity was slightly higher that the limit specified. The study concluded that quarry dust can be used in the production of structural mortar.

Keywords: *Hygrothermal Mortar, porosity, quarry dust, sorptivity, water absorption.*

1 INTRODUCTION

Mortar is one of the important component of a building. It has been extensively utilized in masonry works, plastering and repair of damaged structural elements (Skoulikari, 2007). Mortar is defined as a mixture of cement with inactive materials of small granulometric gradation and with treatment liquid, which is usually water (Skoulikari, 2007). Mortar can also be defined as a workable paste used to bind construction blocks together and fill the gaps between them. The word comes from Latin mortarium, meaning crushed. Mortar may be used to bind masonry blocks of stone, brick and cinder blocks (Mehulkumar, 2015). This implies that mortar is made up of two major components; aggregate which offers resistance and cement paste which provides binding properties. Aggregates desirable for mortar production are usually sand with bigger diameter of grain size 4 mm. The attributes of mortar depend on the type of cement used, the type of aggregates and the mix proportion as well as the type of additives and the way of condensation of mortar.

Natural river sand has been conventionally used in the production of mortar for masonry works. The over exploitation of natural river sand has led to degradation of rivers leading to environmental defects such as bank erosion and destruction of aquatic habitat (Appukutty, 2009). The function of fine aggregate is to assist in enhancing workability and uniformity in a mortar mixture. River deposits are the most common source of fine aggregate in Nigeria today. Now-a-days the natural river sand has become scarce and very costly in some parts of Nigeria. Hence the need for alternative materials. Quarry dust has been used in place of river sand fully or partly in the production of concrete and mortar (Mahzuz *et al.*, 2011; Mayank *et. al.*, 2017; Chandana *et. al.*, 2013; Subramanian and Kannan, 2013; Vishal *et. al.*, 2017). This study is therefore aimed at assessing the hygrothermal properties of structural mortar made using quarry dust as aggregate.

The durability of mortar is a very fundamental factor that depends upon the transportation of water and how gases enters and move within it. Moisture transport characteristics has been employed in different construction practices such as the production of damp-proof basement or flat roofs, but the same transport characteristics may also adversely affect the thermal performance and durability of a structure. Moisture transport is always coupled with heat transfer, especially when vapour diffusion and drying processes are involved giving rise to the assessment of the hygrothermal property of mortar used in construction (Lawrence *et al.*, 2004). The basic hygrothermal properties or parameters are porosity, permeability, capillary action, absorption and sorptivity. Permeability is a property that measures the flow of water under pressure. It measures the ability of concrete to move water more concisely with both mechanisms that controls the absorption and transportation of liquid and gaseous substances in concrete (Pitroda and Umrigar 2013). Sorptivity is the ability of material to absorb and transmit water in it by capillary suction (Pitroda and Umrigar, 2013).

2 MATERIALS AND METHODS

2.1 MATERIALS

Materials used in this research and their functions are:

CEMENT: The most widely used cement that is readily available is the Ordinary Portland Cement (OPC). The type of OPC used in this work is the Dangote Portland cement of 42.5R grade. It is manufactured by Dangote

Cement Company Plc. and is in accordance with BS 12 (1996) and ASTM 150 (1994).

FINE AGGREGATE (QUARRY DUST)
Quarry dust was obtained from Usmani Quarry site in Abuja. The quarry dust was passed through sieve size 4.75mm. Organic substances were screened from the dust to obtain a fine grain.

WATER
Water is an important ingredient of mortar as it participates in the chemical reaction with cement. Potable, clean water free from deleterious substances was used as mixing water. The water was obtained from Civil Engineering laboratory and it conforms with BS 3148 (satisfies the required specification in the production of mortar according to BS 3148.

2.2 METHODS

2.2.1 PARTICLE SIZE DISTRIBUTION

The test was done according to BS 1097 (2000). The sieves were arranged in decreasing order of their size. Fine aggregate of air dried sand was introduced into the top sieve and shook vigorously so that finer materials less than 5mm passes through. The mass of each sieve plus its content was determine and the retained sample mass was determine.

2.2.3 SPECIFIC GRAVITY TEST

The test was carried out in order to obtain the specific gravity of the fine aggregate (river sand) according to BS 1097 (2000). The specific gravity was calculate using equation 3.1

$$Gs = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \tag{3.1}$$

where

M_1 mass of empty flask
M_2 mass of flask and sample
M_3 mass of flask, sample and water
M_4 mass of flask and water

2.2.4 BULK DENSITY TEST

Bulk density test was carried out on the fine aggregate according to BS EN 1079 (2000). The British Standard recognises two degree of compaction which are the loose (uncompacted) and dense (compacted) degrees. The test was performed in a metal cylinder container of 1 litre capacity. The bulk density was estimated using equation 3.2

$$\text{Bulk density} = \frac{Weight\ of\ Material}{Volume\ of\ Cylinder} \tag{3.2}$$

2.2.5 WATER ABSORPTION TEST

The test was carried out in order to measure the rate at which the fine aggregate absorbs water. The water absorption was calculated using the formula.

$$\text{Water Absorption} = \frac{M_3 - M_4}{M_2 - M_1} \times 100\% \tag{3.3}$$

where M_1 mass of can
M_2 mass of can and sample
M_3 mass of can, sample and water
M_4 mass of can, sample and water (after 24hours)

2.2.6 PREPARATION OF SAMPLES

From the preliminary test that was carried out, selection of the right proportion of mortar constituents was done. For this research, mix design ratio of 1:4 was used. Mixing was carried out manually and a total of 30 50x50x50 mm mortar cubes were cast. The mould were oil smeared on the inside to avoid sticking, compaction was done manually using tamping rod to remove entrapped void and the mortar was left in the mould for 24 hours after casting before there were removed from the mould. The mortar cubes were prepared for porosity, water absorption and sorptivity test. The mortar cubes were cured in a water curing tank for 7, 14, 21, and 28 days respectively.

2.2.7 WATER ABSORPTION COEFFICIENT DUE TO CAPILLARY ACTION

The water absorption coefficient due to capillary action is measured using mortar cubes specimens under prescribed conditions at atmospheric pressure. Coefficient of water absorption due to capillary action was calculated from formula

$$water\ absorption = \frac{M2 - M1}{M1} x100\% \qquad 3.5$$

2.2.8 POROSITY TEST METHOD

This method covers the determination of the porosity of hardened mortar according to ASTM, C 20 (2000). The porosity was calculated using the formula given by:

$$P = \left[1 - \frac{WD - WS}{\frac{pW}{VT}}\right] \times 100 \tag{3.6}$$

where
P = Porosity in %
W_D = Oven dried weight (g)

W_S = Submerged weight (g)
pW = Density of water (g/cm^3)
V_T = Volume of the cube

2.2.9 SORPTIVITY TEST METHOD

Sorptivity (S) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillary suction (Pitroda, & Umrigar 2013). The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t). Sorptivity was calculated using equation 3.7.

$$S = \frac{I}{t^{1/2}} \quad (3.7)$$

where,
S = sorptivity
t = elapsed time (minutes)
I = Aw/Ad
Aw= W_2- W_1 (change in weight)
W_1 = Oven dried weight of the cube (g)
W_2 = Weight of the cubes after 30 minutes capillary suction of water (g)
A= Surface area of the cube
d= Density of water
t= Elapsed time

3 RESULTS AND DISCUSSION

3.1 PARTICLE SIZE DISTRIBUTION

Figure 3.1 shows the result of particle size distribution analysis. Total mass of dry sample used was 500g, but summing the masses of the retained sand we have 499.8. The reduction is due to losses mainly from small quantities of sand that gets stuck in the meshes of the sieves. The fineness modulus of fine aggregate was 2.94. It means that the average value of aggregate is between 2nd and 3th sieves. Thus the fineness modulus obtained suggested that the aggregate used had an approximate average size of 0.15mm to 0.30mm. Therefore, the quarry dust is fine in nature and adequate for use in mortar production (Vishal *et al.,* 2004).

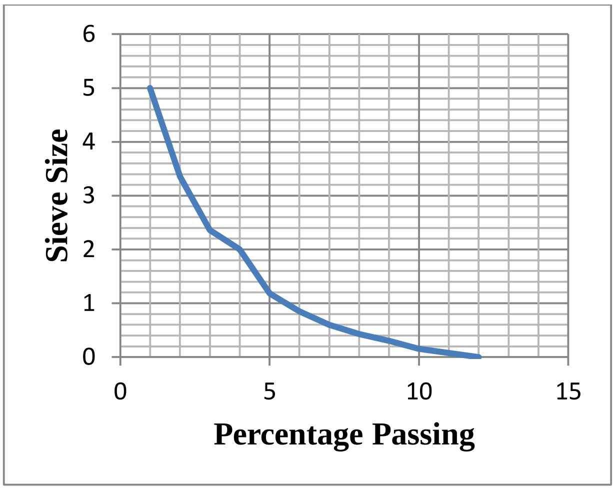

FIGURE 3.1: GRAPH OF PARTICLE SIZE DISTRIBUTION

3.2 SPECIFIC GRAVITY

Table 3.1 shows the result for the specific gravity of quarry dust. The specific gravity obtained fro the quarry dust was 2.42. This indicates that the aggregate used for the study was within the accepted specified values of 2.0 to 2.6 in accordance to BS-EN 1097 -6 (2000).

TABLE 3.1: SPECIFIC GRAVITY OF FINE AGGREGATE

Trial	1	2	3
Weight of Cylinder: M_1 (g)	116.7	116.7	116.7
Weight of Cylinder + Dry Sample: M_2 (g)	171.8	211.0	197.0
Weight of Cylinder + Dry Sample + Water: M_3(g)	344.3	342.4	351.7
Weight of Cylinder + Water: M_4 (g)	309.0	303.9	300.1
M_2-M_1 (g)	55.1	94.3	80.3
M_4-M_1 (g)	192.3	187.2	183.4
M_3-M_2 (g)	172.5	131.4	154.7
G_S	2.7828	1.6899	2.7979
Average G_S		2.42	

3.3 BULK DENSITY

Table 4.3 shows the results of compacted and uncompacted bulk density of quarry dust. From the result obtained it shows that the quarry dust has a high bulk density of 1471.70 kg/m^3 as compared to standard for the uncompacted bulk density and a low bulk density of 1671.25kg/m^3 as compared to standard for compacted bulk density.

3.4 WATER ABSORPTION

Table 3.2 shows the result of water absorption testWater absorption is the ability of a porous material to retain water. The water absorption for the sand used was 1.4%, which is below the specification limit of 2% according to BS 882. This explains that, much of the water used for mixing the mortar will be absorbed by the aggregate to keep it at the saturated surface-dry state and the rest of the rest for mixing the mortar and hydration of cement.

TABLE 3.2: WATER ABSORPTION OF FINE AGGREGATE

Trial	1	2	3
Weight of empty can: M_1 (g)	24.1	23.6	24.7
Weight of can + Dry sample: M_2 (g)	124.7	120.8	130.0
Weight of can + Sample + Water: M_3 (g)	194.7	195.7	195.7
Weight of can + Sample + Water(after 24 hours):M_4 (g)	192.6	193.7	193.8
Decrease in mass: M_3-M_4 (g)	1.01	2.00	1.19
Weight of initial dry sample: M_2-M_1 (g)	100.6	97.2	105.3
% Water Absorption	1.00	2.06	1.13
% Mean Water Absorption		1.4	

3.5 HYGROTHERMAL PROPERTIES TEST RESULTS

3.5.1 POROSITY OF MORTAR

The result of mortar porosity is shown in table 3.3. The result shows clearly that the mortar is highly porous in nature, thus this mortar cannot be subjected to water and any other adverse weather condition, because mortar with larger pores permits larger water absorption in saturated condition and larger evaporation of water in drying process accordingly. This shows consistent result with previous research work carried out on mortar, for every increase in the w/c ratio (additional water content) from 0.45 to 0.60, porosity goes up to 150% and compressive strength is reduced.

TABLE 3.3: POROSITY

Trails	Dry Weight W_D (g)	Submerged Weight W_S (g)	Bulk Porosity (%)
Specimen 1	245.6	257.7	100.00
Specimen 2	228.3	239.9	100.00
Specimen 3	258.3	274.6	100.00
Specimen 4	268.9	285.8	100.00
Average			100.00

3.5.2 WATER ABSORPTION

Table 3.4 shows the result of water absorption, the difference in the value of percentage water absorption is due to the variation in mass of each specimen. The result obtained indicates that the mortar has large void spaces having a finest modulus of which are interconnected that allow rapid ingress and flow of water through it. From the average result (9.78%) obtained it shows that the fine aggregate used is of lightweight (low density river sand) as low density relatively have high absorption capacity, thereby affecting the durability of the mortar. According to BS 8002, it is stated that the higher (>8%) the water absorption by mortar the less durable it becomes.

TABLE 3.4: WATER ABSORPTION

Trails	Dry Weight W1 (g)	Wet Weight W2 (g)	Water Absorption (%)
Specimen 1	226.3	247.8	9.50
Specimen 2	247.9	270.8	9.16
Specimen 3	265.9	283.4	6.58
Specimen 4	256.6	292.2	13.87
Average			9.78

3.5.3 SORPTIVITY

Table 4.7 shows the result of sorptivity of cement mortar cured for 28 days. For determining the sorptivity of the specimens, it was decided to base the observation on the first 30 minutes of elapse test time. For all specimen tested, this duration of time produces a linear relationship which ranges from 0.051 to 0.058. The average value obtained correlates with the minimum range of 0.0358 g/cm^2/min$^{1/2}$.

TABLE 3.5: SORPTIVITY

Trails	Dry Weight W1 (g)	Wet Weight W2 (g)	Sorptivity Value (g/cm^2/min$^{1/2}$)
Specimen 1	261.5	269.5	0.058
Specimen 2	213.6	220.6	0.051
Specimen 3	260.1	267.8	0.056
Specimen 4	269.6	277.1	0.055
Average			0.055

4 CONCLUSION

Hygrothermal properties of mortar produced using quarry dust was investigated. The properties of the quarry dust were determined and found to conform with specifications. The hygrothermal properties measured were within the specified limit recommended by several standards except for water absorption which was high that the specified limit. The study therefore concluded that quarry dust can be used to produce mortar for structural use

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