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Research Article

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ANALYSIS OF THE PHYSIOMECHANICAL PROPERTIES OF PORTLAND CEMENT BASED ON THE PARTICLE SIZE DISTRIBUTION AND CHEMICAL OXIDE COMPOSITION

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ABSTRACT

The physiomechanical properties of Portland cement mortar paste was studied based on the particle size distribution and the chemical oxide composition using standard experimental procedures. The X-ray florescence (XRF) was used to determine the composition of the chemical oxides. The cement particle sizes of 45, 63, 90, 180 and 212μm were used to produce cement paste and mortar with water-cement ratio of 1:2 and cement-sand ratio of 1:3. The cement paste was subjected to test to determine the setting times and soundness values. The cement mortar was used to produce cement cubic blocks of 40 x 40 x 160mm size which were tested for compressive strength at various aging times of 2, 7 and 28 days. Results obtained showed that the predominant oxides were CaO, SiO_2, Al_2O_3 and FeO_3 which were at the respective percentage compositions of 60.0, 20.6, 5.5, and 3.84%. Other alkali oxides such as K_2O, NaO and MgO were obtained in trace quantities. These values compare well with standard values for Portland cement composition. It was found that particle size distribution and chemical oxide composition have significant effect on setting times and compressive strength. However, soundness was found to be dependent on the chemical oxide composition of the cement. It was therefore concluded that the non-linear relationship obtained between the particle size and the compressive strength shows that the property is function of other multiple factors such as chemical oxide composition, like burning condition or cooling rate affect the strength of cement mortar.

Keywords: cement mortar, paste, compressive strength, setting time, soundness.

INTRODUCTION

Portland cement is the most common type of cement in general use round the world (Bediako and Amankwah, 2015). It is a basic ingredient of concrete and mortar which are useful engineering materials in the construction industries. It is a finely grain material made from clicker (containing calcium trioxocarbonate ($CaCO_3$) mixed with a second material containing clay as source of aluminosilicate and a limited amount of calcium sulphate (gypsum), which control the set time and other minor constituents as allowed by various standards (Chetan, (2008). Portland cement reacts chemically with water to attain setting and hardening properties when used for construction purpose. The chemical composition of Portland cement comprises the major oxides such CaO, SiO_2, Al_2O_3 and Fe_2O_3 while the minor oxides include MgO, SO_3 and some alkali oxides (K_2O and Na_2O and others in trace quantity. Each of the oxide performs specific role to determine the performance of cement mortar or concrete (Bediako and Amankwah, 2015; Punmatharith *et al.*, 2010; Huntzinger and Eatmom, 2009). The particle fineness is determined by the level of grinding of clicker with gypsum in the mill. It is a measure of the surface area or mean diameter of the average cement particle. It has significant effect on strength of cement and is important both in order to achieve desired performance and to control manufacturing cost. Particle size analysis is a practice used in engineering to assess the particle size distribution of a granular material. The size distribution is often of critical importance to the way the material performs in use. With careful selection of the appropriate particle size in a specific engineering application, good physiomechanical properties could be guaranteed. In practical application, the performance requirements which are used to classify and compare Portland cement are durability, strength, fast setting, good finishing and volume stability (Neville, 2000; Shetty, 2005). The cement particle size is key physical parameter which determine the performance of cement mortar and concrete (Nwankwojike *et al.*, 2014). Increased fineness of cement particle size provides more surface area in direct contact with water; hence enhancing hydration rate and the associated strength development are increased. It also provides improved bonding strength which has direct positive impact on the compressive strength and volume expansion of the cement sample. According to literatures (Neville, 2000; Higginson, 1970).particle size has significant effect on strength of cement and the rate of hydration depends on the fineness of the cement particles. Hence, for a rapid development of strength, high fineness is necessary. It was also noted that compressive strength increases with increasing fineness but this increase ceases at higher fineness values. Previous researchers observed that the original size distribution and composition of Portland cement particles have a large influence on hydration, micro structural development, and ultimate properties of cement materials like setting time, shrinkage, capillary porosity and heat released (Bentz and Haecker, 1999). Studies on the effect of particle size of aggregate on properties of porous concrete concluded that increase in voids decreases the compressive strength and smaller particle size exhibits higher compressive strength (Moayed *et al.,* 1986). It was also observed that compressive strength of concrete increases with increase in fineness. However, this increase in strength is prominent up to 3200g/cm^2, after which rate of increase of strength is slowed down. Hence, it was concluded that effect of fineness on strength is greater at early ages but decreases with time as hydration proceeds (Qureshi and Ahmed, 2011). Further work on the effect of particle fineness on the properties of Portland pozzolan cement mortars found that increase in fineness of cement has influence on the mixture strength, final setting time and volume expansion up to 7 days but does not have influence on initial setting time (Ahmet and Sukru, 2009). Inadequate strength and deficiency in other related properties of cement mortar as major material in the construction industry has led to problems like failure of buildings, reduction of lifespan of engineering structures and

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substandard service delivery. The performance Portland cement used for construction cannot be fully established without detailed explanations on the process factors which have direct influence on the behavior of the cement product. Hence, this study sought to investigate how some physiomechanical properties of Portland cement is related to the particle size distribution and the chemical oxide composition. This will help to develop better product with improved properties that guarantee impressive performance with combination of durability, fast setting, good finishing and volume stability in our construction industries.

MATERIALS AND METHODS

Materials

Materials used in this study include 5kg weight of clinker and 3% weight of gypsum supplied from Dangote cement factory Obajana, Kogi State Nigeria, sand and water.

Equipment

The equipment used were XRF machine, disc grinder, digital weighing machine, sieve, mortar mixer, compacting machine, humidity cabinet, curing tank, vicat apparatus and compressive strength testing machine.

Methods

The chemical compositions of the sample materials were determined using XRF machine. Details on the procedure of the experiment for this test is given in Folorunso, *et al.,* (2014).Clinker of 5kg with 3% weight of gypsum were both inter ground using disc grinder and thereafter sieved using sieve machine comprising sizes of (212, 180, 90, 63 and 45) µm. The experiment was conducted with a definite cement-sand mixture of 1:3 and water cement ratio of 0.5 using prism mould of (40 x 40 x 160) mm size as specified by European Standard (EN197). The five different particle sizes of the cement sample were used to produce different specimen test samples. The experimental atmospheric humidity was maintained at 90% while the curing temperature of 20^{0}C was maintained for 24 hours. This was to avoid abnormal fast drying and shrinkage due to evaporation at early stage which could lead to increase in tensile stresses at the time it has not yet gained significant strength. The cement mixtures were used to produce mortar and paste from which test samples were developed. These samples were tested for compressive strength at different ageing time, initial and final setting time and soundness.

The initial setting time was tested by lowering the vicat needle gently and bringing it in contact with the surface of the cement paste test sample and quickly releasing it to observe the lost in plasticity of the test sample. The initial setting time was determined as time taken for the needle to penetrate the sample to a depth of 35mm from the surface. The final setting was determined using a circular attachment on the same equipment.

The final setting time was taken as the time taken for the center needle to make an impression on the sample. This was considered as the time taken for the paste to attain hardness that the center needle could not penetrate the paste more than 0.5mm.

The volume expansion was determined using a small cylindrical split of 30mm diameter and 30mm high with two indicator arms of 165 lengths attached to either side of the pointed end. The paste was gauged as in the previous cases and was left on a covered glass plate immersed in water at a temperature of 27^{0}C for 24 hours after which the distance between the two indicator points was taken and thereafter the set up was heated to boiling point for 30 minutes and left for 3 hours. The mould was later removed and allowed to cool and the same distance point of the sample was measured. The difference between the two measurements represented the expansion of the cement paste.

The cement samples of various particle sizes were used to produce cement prism block from which the compressive strength was tested using compressive strength testing machine. The maximum load at fracture with the cross sectional area were determine while the compressive strength was calculated using the mathematical formula shown in equation 1.

$$\text{Compressive Strenght} = \frac{L}{A}\ (N/mm^2) \quad \text{------------ (1)}$$

where L is the load impact at fracture and A is the cross-sectional area of the specimen.

RESULTS AND DISCUSSIONS

Results

Results obtained in the chemical oxide analysis tests are shown in Tables 1A and 2for cement and clicker samples respectively. A comparative assessment of the chemical oxide composition of the cement sample with those of standard sample from other authors was shown in Table 1B. The results obtained in the tests for compressive strength and setting time with volume expansion tests are shown in Table 3 and 4 respectively.

Table 1A: Chemical Oxide Composition of Cement Sample

Oxide	SiO_2	AlO_3	FeO_3	CaO	SO_3	K_2O	NaO	Cl	MgO	LO1	IR	Total
Composition	20.60	5.50	3.84	60.23	1.80	0.18	0.24	0.02	0.10	6.76	1.23	99.27

Table 1B: Chemical Oxide Composition of the Cement Sample shown by Other Authors(Dunuweera and Rajapakse, 2018) for Minimum, Average and Maximum Values.

Oxide	SiO_2	AlO_3	FeO_3	CaO	SO_3	K_2O	NaO	Cl	MgO	LO1	IR	Total
Composition												
Minimum	18.4	3.10	0.16	58.1	0.0	0.04	0.00		0.02			
Average	21.02	5.04	2.85	64.18	2.58	0.70	0.24		1.67.			
Maximum	24.05	7.56	5.04.	68.00	5.35	1.66	0.78		7.10			

Table 2: Chemical Oxide Composition of Clicker Sample

Oxide	SiO_2	AlO_3	FeO_3	CaO	SO_3	K_2O	NaO	MgO	LO1	IR	Total
Composition	21.02	5.61	3.86	64.47	0.65	0.56	0.25	1.00	6.76	1.23	99.27

Table 3: Compressive Strength (N/mm^2) of Cement Mortar of Different Particle Sizes at Varied Time

Ageing Time (days)	B.S.12:1971	Particle Sizes (µm)				
		212	180	90	63	45
2	15.20	2	2.90	3.20	3.60	12.20
7	23.40	7	7.50	9.20	13.10	21.20
28	47 - 67	20.0	30.80	31.00	32.00	36.10

Table 4: Analysis of the Physiochemical Properties

Particle Sizes (µm)	Soundness(min)	Initial setting time	Final setting time (min)
212	1.2	193	217
150	1.0	167	194
75	0.5	150	172
ASTM C 150-07 Specification		›60	Not more than600

DISCUSSION

From the result obtained in the chemical oxide analysis presented in Tables 1A and 2, it was found that the predominant oxides in the cement sample were CaO, SiO_2, Al_2O_3 and FeO_3. Other alkali oxides such as K_2O, NaO and MgO were obtained in trace quantities. The percentage composition of these respective oxides presented in Table 1 compare well with the result shown in other literatures as standard values for oxide composition of ordinary Portland cement in Table 1B(Bediako and Amankwah, 2015; Lea, 1970). The respective chemical oxide at various percentage compositions played different roles in cement hydration process. When cement hydrated, oxides such as CaO, SiO_2, Al_2O_3 and FeO_3enhanced hardening process due to the formation of calcium aluminosilicates and aluminoferrite hydrate as observed by Bediako and Amankwah, (2015).The percentage composition of SO_3 was found as 1.8%. This value is adequate based on ASTC C618 and Indian standards which limited the composition of SO_3 to less than 5% and 2.75% respectively. It has been reported that higher percentage composition of SO_3 cause unsoundness of cement (Bediako and Amankwah, 2015). Hence, the composition of the oxide in the cement sample is assumed to have contributed to good soundness values presented in Table 4. It was also noted from the result of the chemical oxide analysis that the Calcium oxide content of 60.23% was within the minimum value as shown by Bediako and Amankwah, (2015). High lime content is reported to enhance high strength attainment mostly in early days which is utilized in where formwork is to be remove early. More also, Matschai., *et al.,* (2007)observed that hardening of cement is traceable to the formation of $CaCO_3$ when atmospheric$CO_2$is absorbed by CaO. Hence, increase in CaO enhances $CaCO_3$ formation even at early stage which yields rapid hardening. This postulation correlates with the results obtained for the compressive strength at early stage which showed a limited strength growth at the early stage when compared to higher days. However, alkalis at higher composition and in the presence of moisture gives rise to reaction that aids expansion and crack development as observed by Bediako and Amankwah, (2015). The initial and final setting times of the cement sample were found within the respective ranges of 150 – 193 and 172 – 217 minutes for the particle size range of 75 – 212µm. The initial setting time of the cement is the period between the time water was first added to the cement and when the paste began to stiffen considerably. Also, the final setting time was considered from the time when water was added to the time when the cement has developed sufficient strength to withstand load. From the results obtained in these tests, it was found that the particle size of the cement affected the rate of hydration and compressive strength significantly. Finer particle size of the cement yielded more impressive properties than coarser particle size. Notwithstanding, it has been noted that though finer cement particle performs better for rapid strength development, yet it is susceptible to air set and early deterioration (Shetty, 2005). Therefore, it is expected that the initial setting time of cement should not be too soon and the final setting time should not be too late to enable adequate strength development which is required in construction.

CONCLUSION

From the findings made in this study, the following conclusions were drawn: The non-linear relationship established between the particle size and the compressive strength shows that other multiple factors such as chemical oxide composition, burning condition or cooling rate affect the strength of cement mortar. The cement setting time is a function of particle size and chemical oxide composition. Soundness which relates to the volume stability is slightly affected by particle size variation but depends mostly on the chemical oxide composition of the cement sample.

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