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PHYSICO - CHEMICAL PROPERTIES OF SOME LOCALLY AVAILABLE CEMENT IN NIGERIA

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ABSTRACT

Incidences of building collapse in Nigeria are posing serious challenges to all the stakeholders in the building industry. Several causes of building collapse had been attributed to either natural or man-made phenomena. Quality of building materials being among the numerous man-made phenomena and cement, the binding agents in concrete production is very keys in this regards. The aim of this study was to evaluate some physico-chemical properties of four major general purpose cement (AAR, BAR, CAR, DAR) sold in Nigeria market and used on construction sites using standard methods. The results showed that CAR cement recorded the highest CaO content (65%) while the other cement type had the lowest CaO content (64%) however CaO contents are with the specified limits. All the samples have Al_2O_3, SiO_2 and Fe_2O_3 contents within the acceptable limits. The MgO and SO_3 compositions for all cement type were generally below the recommended limit; C_3S content in BAR and CAR cements were above the recommended limit while it was below the standard in AAR Cement. The C_3A, C_4AF contents are above the recommended standards for general purpose cement for AAR and BAR cement respectfully, with the exception of C3A in CAR cement that is below. The longest setting time for the cement samples were recorded in CAR Cement while; LOI and IR were significantly high in all the cement type. AAR and CAR cements had the highest compressive strength of 46.8 and 48.3 N/mm^2 respectively after 28 days. The results indicate that the properties of the four brands of cement are comparable and are all of good quality. Although the cements tested showed variabilities in properties, these variabilities are not enough to cause the collapse of buildings and civil engineering structures.

Keywords: *Cement properties, Good quality, setting time, Physico-chemical, Building collapse.*

INTRODUCTION

Historically cementing materials have played an important role in providing shelter for mankind. The production of cement has played a major role as a construction material throughout the history of civilization. Cement is very important in the construction of buildings, bridges, tunnels, etc. (Faleye*et al.*, 2009; Neville, 2000). In recent times, Nigeria has witnessed frequent cases of collapsed building. The incidences of building collapse in the country's major cities of Lagos, Abuja and Port Harcourt have been alarming. For instance, Lagos, has recorded four cases in 2006 with two of such collapses in Ebute Metta that claimed 37 lives. Adegoroye (2006) reports that on Saturday March 25, the Nigerian Industrial Development Bank's building collapsed killing two persons and injuring 23 others. In November, 2007, a two-storey building collapsed along Okegbogbo Street while another two six-storey buildings along Imam LigaliStreet in Lagos Island collapsed, affecting two other six-storey buildings. The aftermath of the incidence left fifteen persons injured and one dead (Adegoroye, 2010; Adewole 2014). Several causes of building collapse had been attributed to either natural or man-made phenomena. While natural phenomenon may consist of earthquakes and typhoons, man-made phenomena consist of disasters which maybe borne out of man'snegligence in areas such as soil type, building design and planning for extra ordinary loads and stress from strong winds and earthquake for tall buildings, foundation works, strict monitoring of craftsmen, quality of workmanship and quality of building materials. Oloyede*et al.* (2014) reported the use of poor materials as the leading cause of frequent collapse of buildings in Nigeria; and since cement is a major constituent in concrete production thus building construction, focus has been drawn to periodic quality assessment of the product. Recently poor quality cement has been implicated as one of the major causes of incessant building collapses in Nigeria (The Nation, 2014).The need for regular sampling and testing of cement therefore becomes imperative.

Cement, a major binding material in making concrete, influences the quality of the concrete so produced. Cement chemistry dictates the chemistry of the produced concrete (Bhanumathidas and Kalidas, 2003). Most local construction industries in Nigeria rely most often than not, on their experience, availability and cost in selecting the brand of cement to be used in construction, at the expense of quality. More so, that the quality information presently available on the bag of different brands of cement as given by the producers is not adequate to enable an assessment of the behaviour of cement in a concrete mixture. For instance, setting behaviour of the cement is not highlighted on the bags of these cements. Consequently, the Standards Organisation of Nigeria (SON) had to specify different grades of cement to be used for different construction works. This has generated ripples among the stake holders in the construction industry. To eliminate or reduce to the bearest minimum, the collapse of building in Nigeria, the development of quality control and good quality infrastructure in Nigeria are of utmost importance, an issue which is often neglected. Thus, research in this direction is not only timely but may also serve as a basis for many to select appropriate cement for their construction works. This motivates the need for the present study, which is to physically and chemically characterize the various cement used on construction site in the Nigeria and to assess how the cement measure up to BS, ASTM and EN standard.

MATERIALS AND TESTING METHODS

This study selected four common cements in Nigeria, to characterize them in terms of their properties and investigate how they measure up to the standard. Several

physical and chemical tests were carried out in accordance with BS and ASTM standards to characterise the cements and compare their properties with the set values. Characterization, when used in materials science, refers to the broad and general process by which a material's structure and properties are probed and measured. Four locally available cements were tested in this study. The local cements tested are Dangote, Unicem, Elephant and Ibeto. These cements were selected after a desk top survey revealed they are the main cements used on construction site in Nigeria. Each cement sample was given a unique code name to maintain its anonymity. The code names are; AAR, BAR, CAR, DAR.
The tests carried out and methods adopted include:
3 days, 7 days and 28 days compressive strength tests after BS 12: 1971
Standard consistence test in accordance with ASTM c150 1986
Initial and Final Setting time determination in accordance with ASTM C150-07
Soundness test in accordance with ASTM C150-07
Specific surface (Blaine) in accordance with ASTM C150-07
Insoluble residue in accordance with ASTM C150-07
Loss on Ignition in accordance with ASTM C150-07
Sulphate content in accordance with BS 12 1991
Chloride content in accordance with ASTM C150-07
Metal oxides determined via XRF accordance with ASTM

RESULTS AND DISCUSSION

Physical properties

The results of the setting times and expansion and the compressive strength of the different cement samples investigated in this study are presented in Tables 1 and 2 respectively.

Table 1 Setting time in minutes and expansion (mm)

Cement samples	Initial setting time (minutes)	Final setting time (minutes)	Expansion (mm)
AAR	110	185	1.00
BAR	135	200	3.12
CAR	210	285	2.94
DAR	110	190	1.00
ASTMC150-07 Specification	≥ 60	≤ 600	

Table 2 Compressive strength (N/mm^2)

Cement samples	Compressive strength (N/mm^2)		
	Curing periods		
	3 days	7 days	28 days
AAR	21.7	36.8	46.8
BAR	14.1	21.5	32.5
CAR	24.3	37.8	48.3
DAR	18.6	27.5	36.5
BS 12: 1991 Specification	15.20	23.40	47 - 67

The initial setting time for AAR and DAR cements brand were the least when compared to the others, but AAR cement has the fastest final setting time of 185 minutes. Similar results were reported by Sosman and Merwin (1916), and Faleye*et al.*, (2009). This implies that AAR cement brand would exhibit good workability. Increasing compressive strength was consistent over time for AAR and CAR cements and, with the mixtures attaining over 60% of its 28-day strength in 7 day. When this is considered against the background that concrete is expected to attain about 60% of its 28 day strength at 7 day (Nevillle, 1981), its workability is considered good. Nevertheless, the low compressive strength and poor soundness of the BAR cement when compared to others may be due to low CaO content (Ghosh, 1983), though the variations in the physical properties of AAR cement are within the acceptable limit (BSI 1978; and ASTM 1986) for type I (ordinary cement used for general concrete construction). The initial setting time for BAR cement was 135 minutes and 200 minutes for the final setting time which could be attributed to the relatively low gypsum content compared to the low C_3A content (ASTM 1986). The highest compressive strength of 32.5 N/mm^2 and low expansion implies a better workability compared to the other cement brand (Ghosh, 1983). Lower compressive strength may be due to its relatively low C_3A content (See Table 3) which is said to enhance initial strength gain. Compressive strength of 32.5 N/mm^2 recorded is however within the acceptable limit for general purpose cement (BSI, 1978).

CAR cement recorded an initial setting time of 210 minutes and final setting time of 285 minutes, which was longer when compared to the other cement brand while, its high expansion of 3.12 mm implies a poor workability of the product when compared to other cement; this may be responsible for its high compressive strength of 48.3 N/mm^2. Nevertheless, the consistently increasing compressive strength of the product from day 3 to 28 days, with the mixture attaining over 60% of its 28-day strength in 7 day implies good workability (Nevillle, 1981; Faleye*et al.*, 2009). All the stated physical parameters for this cement brand were within the British standard limit for ordinary cement (British Standards Institution (B.S12), 1971). The initial setting time for DAR cement sample was110 minutes while its final setting time was190 minutes, this agrees with the British Standards (BS12), 1971). Comparing the setting time obtained to the other cement brands, it could be attributed to its relatively low sulphur trioxide content and relatively high C_3A content (See Table 3 and 5) (ASTM, 1986). DAR brand recorded low compressive strength with the mixture however, attaining over 60% of its 28-day strength in 7 days; implying good workability of the product (Nevillle, 1981). The low compressive strength may be due to its low silica, CaO contents and relativity low C_3A content (See Table 3 and 5), which enhance the initial setting as well as low expansion of 1.00 mm. All the stated physical properties are within the British specifications (British Standards Institution (B.S12, 1971).

Chemical properties

The results of the mineral composition and the major chemical constituents and Physico-chemical properties for the different cement brand are shown in Tables 3, 4 and 5 respectively.

Table 3 Mineral composition of the different cement samples

Cement samples	Percentage composition (%)			
	C_3S	C_2S	C_3A	C_4AF
AAR	43.56	24.04	13.24	9.14
BAR	62.34	5.69	8.98	13.61
CAR	99.48	28.45	7.80	9.71
DAR	54.65	12.90	8.47	11.23
ASTMC150-07 and BS12 Specification	45-65	7-32	8-12	10-11

Table 4 Percentage composition of major chemical constituents in cement samples

Cement samples	Percentage composition (%)			
	CaO	SiO_2	Al_2O_3	Fe_2O_3
AAR	64	20	5	5
BAR	64	21	5	4
CAR	65	22	5	5
DAR	64	20	4	4
ASTMC150-07 Specification	61-67	19-23	2.5-6.0	0-6.0

Table5Physico-chemical properties and some minor constituents in cement samples

Cement samples	Percentage composition (%)					
	LOI	IR	CaO	SO_3	MgO	K_2O
AAR	9.5	1.8	2.10	1.8	0.6	0.4
BAR	13.5	2.4	1.86	2.0	0.8	0.6
CAR	3.6	3.2	2.03	2.2	0.7	0.4
DAR	9.8	3.0	1.75	1.8	0.6	0.5
BS/ASTMC150-07 Specification	2	5.0		3.3	1.0	1.0

The percentage compositions of calcium oxide in the cement samples: AAR, BAR, CAR and DAR are 64, 64, 65 and 64% respectively as shown in Table 4. This indicates that all the cement type have their calcium oxide content within 61 - 67% specifications of ASTM C 150 and BSI (1978). The result compares well with the mean level of 64.33 ± 0.41% and 65.54 ± 1.48% obtained for cement brands in Ghana and Nigeria (Sam *et al.,* (2013) and Yahaya, (2009)). The percentage of silicon oxide in the cement samples AAR, BAR, CAR and DAR are 20, 21, 22 and 20% respectively following from Table 4. All the samples are within the ASTM C 150 range of 19.0 - 23.0% for general purpose cement. The range obtained in this study conforms closely to the results obtained for Nigerian cement (Akanni*et al.,* (2014)).
From the results of the major chemical composition for the cement brand, the percentage of aluminum oxide in the cement samples AAR, BAR, CAR and DAR are 5, 5, 5 and 4% respectively (Table 4). All the values fall within the ASTM C 150 specification of 2.5 - 6.0% aluminum oxide for general purpose cement (BSI 1978).

The results compare well with the report of Yahaya, 2009 for Nigerian cement. The percentage iron oxide in the cement samples: AAR, BAR, CAR and DAR are 5, 4, 5 and 4% respectively (Table 4). Generally, the values obtained in the studies were below the maximum requirement of 6.0% iron oxide content in common cement as recommended by ASTM C 150. Similarly, Akanni*et al.* (2014) reported mean iron oxide of 3.0 to 5.2% for cement brands sold in South- Western states in Nigeria.
The percentage loss on ignition in the cement samples studied, AAR, BAR, CAR and DAR are 9.5, 13.5, 3.6 and 9.8% respectively as shown in Table 5. The values are generally above the ASTM C 150 maximum limit of 3.0% for type I cement, implying that the cement products are poor in mineral content and high in combustible materials. As presented in Table 5, the percentage insoluble residue content of the cement samples AAR, BAR, CAR and DAR studied are 1.8, 2.4, 3.2 and 3.0% respectively. The values are generally above the 0.75% maximum limit

specified by ASTM C 150 for general purpose cement. Though the result of this study is lower than the range 4.7 – 32.5% reported for Nigerian cement (Faleye*et al.*, (2009)).

As shown in Table 5, the percentage free lime composition in the cement sample AAR, BAR, CAR and DAR are 2.10, 1.86, 2.03 and 1.75% respectively. The values are generally above the 1.00% ASTM C150 limit for type I cement and the 1.30% for type III cement. On the other hand, the study conducted by Sam *et al.*,2013 using EDXRF for cements in Ghana, and that by Akanni*et al.*,2014 for cements in Nigeria indicated higher free CaO of mean value 65%. From the study, the percentage sulphur trioxide in the cement samples AAR, BAR, CAR and DAR are 1.8, 2.0, 2.2 and 1.8% respectively (Table 5). The values are slightly below the 2.9% for some of the cement as recommended limit by ASTM C 150 specification. However, the percentage content of SO_3 is in agreement with Type I and II, though slightly high in comparison to the other cement types. As presented in Table 5, the percentage magnesium oxide in AAR, BAR, CAR and DAR cement are 0.6, 0.8, 0.7 and 0.6 % respectively. These values are generally below the 6.0% maximum limit specified by the American standard (ASTM, 1986). However, the MgO contents conform with the British standard for Ordinary Cement (BSI, 1978). The result is similar to those reported by Yahaya (2009),Ndefo, O. (2013), and Faleye*et al.*, 2009.

CONCLUSION

The major cement brands studied have Al_2O_3, SiO_2 and Fe_2O_3 contents within the acceptable limits, with AAR and DAR cements brand having lower SiO_2content. The cement brands also have MgO and SO_3 being generally below the recommended limit. Also C_3A, C_4AF in all the brands were within the recommended levels except for AAR with 13.24% C_3A and BAR with 13.61% C_4AF content. CAR cement brand has the longest setting time. The highest compressive strength of 46.8 and 48.3 N/mm^2 was recorded in AAR and CAR brands respectively after 28 days. The results indicated that the brands of cement analysed in this study showed some variation in physico-chemical properties, though they all conform to both the American and British standard specifications adopted in Nigeria for general purpose cement.

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