COMPARATIVE QUALITY EVALUATION OF CEMENT BRANDS USED IN SOUTH WEST NIGERIA

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Abstract

The quality of common cement brands in Southwest Nigeria was investigated. This is with a view to comparing their properties. Cement brands considered in this study were labeled A, B, C, D and E. Fineness, setting times, chemical composition, compressive and flexural strengths of each of the cement brands were determined in accordance with the relevant BSand ASTM standards. The results showed that all the cement brands contained major oxides in amounts within the acceptable range of valuesas compared to BS EN 196-2 except that the sulphite content of cement E fell outside the range.Strength comparison indicated that cement brand A had the highest flexural and compressive strengths of 7.98 and 35.35 N/mm^{2}respectively, followed by C(6.58 and 33.8 N/mm^2) and then B(6.37 and 31.60 N/mm^2) while D had the lowest compressive strength at 28 days (31.09 N/mm^2). The study has shown that both cements A and C could be adjudged to have met the standard having strength above minimum of 32.5 N/mm^2, while others were marginally below the minimum strength. It was concluded that the choice of cement brand to be used should be based on the expected strength requirements.

Keywords: *Cement brand, compressive strength, flexural strength, southwestern Nigeria.*

1.0 INTRODUCTION

Selection and utilization of suitable materials for any construction work, during design and execution, is pertinent. Failure of concrete structures is usually attributed to incorrect selection of material amongst other factors (McGinley and Choo, 1990).

Cement, a major binding material in making concrete, influences the quality of the concrete so produced with it. Its chemistry dictates the chemistry of concrete (Bhanumathidas and. Kalidas, 2003). Most local construction industries in Southwest 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 mix. For instance, setting behaviour of the cement is not highlighted on the container of these cements. Recently poor quality cement has been implicated as one of the major causes of incessant building collapses in Nigeria (The Nation, 2014). 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.

Therefore, research in this direction is not only timely but may also serve as a basis for many contractors to select appropriate cement for their construction works. However, Yahayah (2009) carried out a similar work, but her work did not consider many of the cement brands found in our study area. In addition, titrimetric/gravimetric method wasused in determining the chemical composition of the cements while X-Ray fluorescence technique was used in this study.

Nigeria being a developing country consumes more cement for its infrastructural development. As at 2009, about 19.5million tonnes of cement were consumed annually with more than 60% imported (Franklin, 2009). In order to meet local the demand, licenses are given to individuals to import cement while local industries are given incentives to support local production. Presently, more than eight brand names of Portland cement are found in different locations in the country with about six of them are common in the Southwestern region.

The quality of cement may differ from plant to plant due to changes in raw material properties, kiln temperatures, as well as fineness upon grinding. These changes can significantly affect the concrete properties, when different cements are used. For example, the tricalcium aluminate (C_3A) and alkali content of cement have been found to have dominant effect on the drying shrinkage of concrete (Johannes *et al.,* 2005). Similarly, Dale *et al.,* (2008) studied the effect of fineness of cement on early strength of concrete. They observed that the coarser cement exhibits compressive strengths well below those of the finer ones at all ages tested with less heat of hydration, which results in a substantially lower semi-adiabatic temperature rise.

Lea (1990) opines that there is an indication that cements with a high content of dicalcium silicate (C_2S) show somewhat higher shrinkage values than those with a high content of tricalcium silicate (C_3S), though the ability to predict shrinkage based on compound composition may not be precise. The ultimate compressive strength and rate of strength development of concrete is strongly influenced by the chemical reactivity of the Portland cement. Varying hydration rates of the different cement compounds can help explain how the relative proportions of these compounds affect the rate of strength gained. Several other researchers have demonstrated the effect of cement content on the properties of concrete produced (Lidstrom and Westerberg (2003), Kelham and Moir (1992), Struble and Hawkins (1994), Zayed (2003), Gazatanga *et al.,* (1997).

The thrust of this study, therefore, is to carry out a comparative quality assessment of common cement brands used in Southwest Nigeria with a view to making appropriate recommendations for the local construction industries that may not have the wherewithal to perform this. It could also be a basis for them to select appropriately the cement to be used for different construction works.

2.0 MATERIALS AND METHODS

2.1 Study Area

Nigeria is made up of six geo-political zones in which southwest zone is a part. This zone has six states namely Ekiti, Ondo, Oyo, Osun, Ogun and Lagos. Figure 1 shows the zone with the six states. The zone is characterized with huge infrastructural development and consumes substantial amount of cement. In the zone, there are two major cement factories: WAPCO Lafarge (Ewekoro and Sagamu plants) and Dangote Cement Plc. (Ibese plant) that produce Elephant and Dangote cement, respectively. Other cement brands found and commonly used in the zone are Gateway, Five Star, Burham, and Purechem Portland cement, all were imported cements. As at the time of this research, Gateway cement was out of the market. Thus, it was not included in the study.

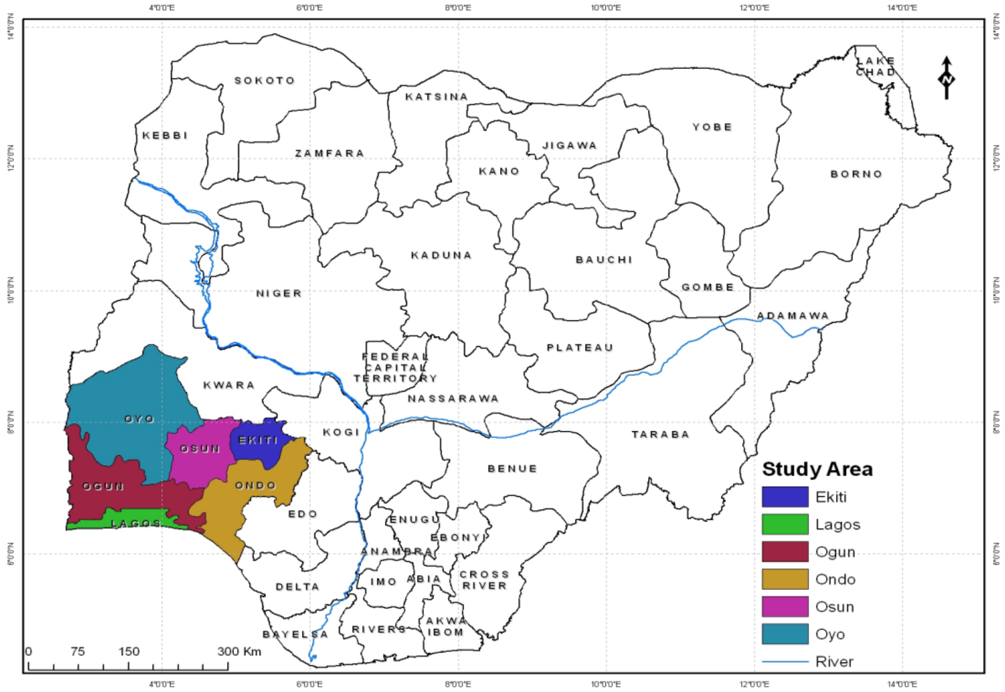


Figure 1: Map of states in the Southwestern Nigeria

2.2 Materials

For this study, five common brand names of Portland cement in the zone used were named A, B, C, D and E. Samples of each of these cement brands were collected from accredited depots of each company that produces these cements in each of the state capitals of the six states in the zone. This is to ensure that samples collected were true representative of what was produced from the factory. River sand was used in producing the mortar, while potable water was used as mixing water.

2.3 Chemical and Mineral Composition of the Cements

Chemical composition of the cement samples were determined using X-ray florescence technique. This was conducted at the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Osun State. Thereafter, the mineral compositions were determined using Bogue's equation (Shetty, 2006). The equations are reproduced as Equations (1) – (4).

$$C_3S = 4.07(CaO) - 7.60(SiO_2) - 6.72(Al_2O_3) - 1.43(Fe_2O_3) - 2.85(SO_3) \quad (1)$$

$$C_2S = 2.87(SiO_2) - 0.754(C_3S) \quad (2)$$

$$C_3A = 2.65(Al_2O_3) - 1.69(Fe_2O_3) \quad (3)$$

$$C_4AF = 3.04(Fe_2O_3) \quad (4)$$

2.4 Fineness Test

A 10g of each brand of cement was weighed approximately to the nearest 0.01g and then sieved through 90µm BS sieve. Weight of cement retained on the sieve was measured and the percentage of weight retained with respect to initial weight was determined. This procedure was in line with the provision of BS 12 - 1991.

2.5 Standard Consistence, Setting Times and Soundness Tests

The standard batch consisting of 650 g of cement for each sample with sufficient water to give a paste of normal consistency in accordance with the procedure described in ASTM C187 was carried out. The soundness of the cement paste made from each sample was conducted, following the procedure highlighted in ASTM C15. Setting times (initial and final) of paste made from each of the samples were investigated as prescribed by ASTM C191.

2.6 Compressive and Flexural Strength

Mortar was prepared from each sample in the mix ratio of 1:3 (cement: standard sand) with a water/cement ratio of 0.4, as specified by BS 4550-3.4-1978. The mixtures were cast into 40 × 40 × 160 mm steel mould prisms and then compacted on automated compacting machine. It was allowed to set under room temperature. The steel moulds were removed after 24 hours and weighed. The specimens were cured in water at 20±2℃ temperature. Flexural and compressive strength tests were performed on each specimen at the curing ages of 3,7,14 and 28 days. First, the flexural test with one-point loading was applied at the mid-span of the specimen until failure and the load causing failure was noted. Thereafter, flexural strength was calculated using the relationship given in BS 4550 – 3.4 (1978).

Compressive strength was conducted on each of the remaining halves as specified by the code. The average of three readings was recorded for each test.Plate 1 shows the specimens and set up for flexural strength test.

(a)

(b)

Plate 1: (a) Specimens (b) Set-up for flexural strength test

3.0 RESULTS AND DISCUSSION

3.1 Oxides Composition

The oxide composition of the various Portland cement brands considered as determined from XRF technique is presented Table 1. Oxides of all the cements were found to be within the stipulated limits given by BS EN 196-2 (1995). However, the silica and CaO contents of B, C, and D were slightly lower than what is recommended. Coincidentally, these cements are produced locally while cements A and E are imported.

It could be deduced that the raw materials (calcium carbonate) used in the production of these cements had slightly low CaO and silica content compared to the one used for producing A and E.

Table 1: Chemical and Mineral Composition of the selected Cement Brands

Parameters	OPC Brands					
	A	B	C	D	E	BS EN 196-2
Oxides						
SiO_2	20.48	16.85	17.44	17.00	19.90	18.0 – 24.0
Al_2O_3	5.02	4.67	4.51	4.60	4.60	2.6 – 8.0
Fe_2O_3	3.15	3.07	2.61	2.89	2.94	1.5 – 7.0
CaO	62.45	60.90	61.33	60.39	61.57	61.0 – 69.0
MgO	1.92	1.51	2.25	1.86	1.96	0.5 – 4.0
Na_2O	0.61	0.00	0.00	0.00	0.08	-
K_2O	0.72	0.21	0.19	0.84	0.25	0.2 – 1.0
SO_3	0.18	1.99	2.01	3.13	1.98	0.2 – 4.0
LOI	4.76	9.83	8.51	8.05	6.25	-
Mineral Parameters						
LSF	95.42	108.81	107.29	105.99	95.44	92.0 – 98.0[a]
SR	2.51	2.18	2.45	2.27	2.64	2.0 – 3.0[a]
AR	1.59	1.52	1.73	1.59	1.56	1.0 – 4.0[a]

a –Winter, 2015.
LSF – Lime Saturation Factor; SR – Silica Ratio; AR – Alumina Ratio

Conversely, the values of loss on ignition (LOI) obtained in the case of local cements were higher than their counterpart (imported ones). It should be noted that LOI is a measure of amount of CO_2 and water present in the cement, which are emitted when cement is heated up to 950°C. This shows that cements B, C and D are likely to possess more water and CO_2 that are readily available to evaporate during burning. This may partly be attributed to improper and prolonged storage or adulteration of the cement during transportation or transfer (Hani, 2011).The percentage of sulphite (SO_3) present in all the samples was less than 3.5%, which is the upper limit for SO_3 content. Hence there may be no risk of failure due to heat curing of concrete (Rogers, 2005).

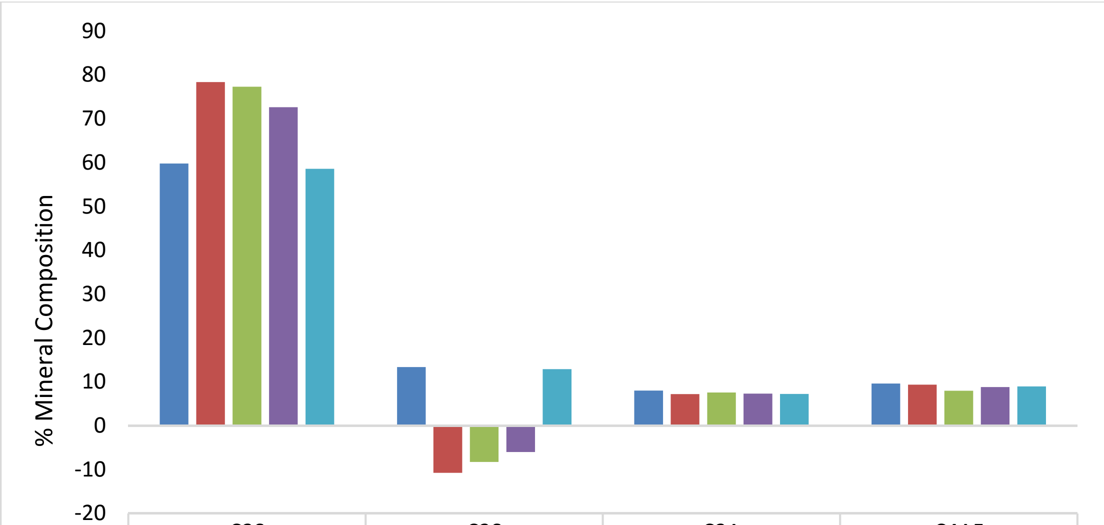
3.2 Mineral Composition

Mineral composition of cement is more useful in determining performance of cement than its oxide composition (Winter, 2015). The mineral composition of the corresponding oxide composition for each of the cements is also summarized in Table 1. The standardized Bogue's equations given in ASTM C 150 were used to compute mineral compositions. Though limitations of Bogues' equations have been identified, it is still considered as approximate representation of the mineral composition (Taylor, 1990). Other advanced methods such scanning electron microscopy (SEM) instrument would give more accurate values but the technique requires a significant amount of time and more importantly the instrument is not readily available in the country. However, Bogue's equation could give reasonable level of accuracy.

The mineral compositions of the cements varied from one to another (Figure 2). Surprisingly, negative values were obtained as dicalcium silicate (C_2S) contents in the cements (B, C and D). The reason for these values may not be easily explained, but the likely interpretation for these seemingly strange values could be that content of calcium oxide (CaO) and silica (SiO_2)slightly fell short of the recommended minimum (Table 1). Possibly during heating of clinker some C_2S may have been converted to C_3S (Graeme, 2003). However, C_3A and tetracalciumaluminaferrite (C_4AF) values for all the cements were not significantly different ($p>0.05$), indicating that difference in the performance of the cements could not have been influenced by these minerals. Though C_3A and C_4AF minerals also hydrate, but the products that are formed contribute little to the properties of the cement paste (Shetty, 2013).

Of particular interest is the quantity of C_3S, which was above 50% for all the cements with relatively higher values obtained for B, C and D (78.33, 77.28 and 72.59% respectively). The higher values obtained for these cements could be due to higher lime saturation factor, LSF (Table 1). Winter (2015) suggests that the C_3S content of the final clinker is influenced not only by the raw mill LSF, but also by the quantity and chemistry of the ash from the fuel(s), as well as the quantity and chemistry of any additional AFR material streams (e.g. spent cell liner) which have a significant SiO_2, Al_2O_3, Fe_2O_3 or CaO content. Our results were comparable to what Faleye *et al.,* (2009) reported but marginally higher than those obtained by Yahyah (2009). The slight difference between our results and that of other researchers may be due to the methods adopted. We used XRF technique while they use volumetric analyses.

The two calcium silicate minerals, C_3S and C_2S, are largely responsible for the early strength development and the long-term structural and durability properties of hydrated cement (Graeme, 2003). The combined values of C_3S and C_2S for B, C and D were 67.56, 69 and 66.58%, respectively while those of A and E were higher (73.1 and 71.44 % respectively). It is important to mention that only cements A and E had values within the prescribed range of 70 – 75% (Graeme, 2003). These results were similar to what Faleye *et al.,* (2009) reported but marginally higher than those obtained by Yahyah (2009). Similar reason of different methods might be responsible for the slight differences. These results may possibly suggest that A and E are likely to develop early and late strength than others.



	C3S	C2S	C3A	C4AF
A	59.74	13.36	7.98	9.59
B	78.33	-10.77	7.18	9.34
C	77.28	-8.28	7.54	7.94
D	72.59	-6.01	7.3	8.79
E	58.55	12.89	7.22	8.95

Figure 2: Mineral composition of cement brands

3.3 Cement Control Parameters

Other parameters that were determined were Lime Saturation Factor (LSF), Silica Ratio (SR) and Alumina to Iron ratio (AF). Each of these parameters also influences performance of cement in a way and is often used for control purposes (Taylor, 1990). The LSF controls the ratio of alite (C_3S) to belite (C_2S) in the clinker. A clinker with a higher LSF will have a higher proportion of alite to belite than will a clinker with a low LSF (Winter, 2015). This assertion is evident in our results presented in Table 1. For instance, C had higher LSF (107.29) than what was obtained for cement A (95.42) so the proportion of C_3S to C_2S in cement C was 77.28 to -8.28 while those of cement A were 59.74 to 13.36. These results further showed that cements B, C and D might have surplus free lime that could not combine with other constituents as indicated by their LSF values being greater than 100% (Winter, 2015). Nonetheless, the values of SR and AR of the cements considered in this study are within the specified provision (ASTM C 150 -1992). More importantly, SR and AR values of cement brands did not deviate significantly from others. This observation would seem to indicate that the calcium silicates and aluminate in the cements are within the acceptable limits.

3.4 Standard consistence, fineness, soundness and setting times of cement samples

Table 2 summarizes the results of tests on the standard consistence, fineness, soundness and setting times of the cements studied. The results indicated that cement A would likely required more water to obtain consistence mix than others for having highest standard consistency value of 37.5% followed by C (36.5%) and then B (35.2%). This performance is in agreement with the corresponding fineness values shown in Table 2. Since fineness is a measure of surface area, material with higher surface area would be expected to take more water during hydration process and react faster. For instance, A whose fineness was 13% (i.e. 13% of the material was retained on 90μm sieve) had highest standard consistency value (37.5%). Another possible implication of higher fineness is possible increase in the rate at which cement hydrates and thus accelerates strength development.

As for the soundness, the results suggested that all the cements had zero expansion during thermal curing. Thus, the cements could be said to have met the standard. Furthermore, setting behaviour is another most important property of cement, which is greatly influenced by clinker reactivity and by cement fineness (Graeme, 2003). The setting times of the cements, shown in Table 2, suggested that E would likely had delay in initial setting by about 12 minutes when compared with that of A. Similar trend was observed in case of final setting, while other cements fell in the range of 129 – 134 and 298 – 306 minutes for initial and final setting times, respectively. Generally, the changes observed in setting times could be attributed to changes in their fineness and clinker composition.

Table 2: Setting Times and Physical Properties of the Selected Cement Brands

Properties	Cement Samples				
	A	B	C	D	E
Standard Consistency (%)	37.5	35.2	36.5	33.5	33.7
Fineness (%)	13.0	15.7	14.5	15.8	15.9
Soundness	0.0	0.0	0.0	0.0	0.0
Setting Times					
Initial (min)	126.0	132.0	129.0	134.0	138.0
Final (min)	300.6	306.0	304.2	298.0	311.4

3.5 Compressive and Flexural Strengths

The compressive and flexural strengths of each of the cements were determined at different curing ages; the results are shown in Table 3.Apart from A and C cements that had compressive strength of 35 and 33.88 N/mm^2, the 28-day strength of all other cements was not different significantly. Furthermore, the results indicated that about 50% of the 28-day strength was attained at early age of 3 days for all the cements. Similar patterns were noticed in the case of their flexural strengths. The better performance of A cement, in term of strength, could be partly attributed to its mineral composition and fineness.

Furthermore, the strength development of all the cements showed that the strength increased with curing ages. Nevertheless, the rate at which strength developed differed.

Table 3: Compressive and Flexural Strength of the Cements at different Curing Ages

Sample	Compressive				Flexural			
	Curing Ages (Days)				Curing Ages (Days)			
	3	7	14	28	3	7	14	28
A	17.50	29.45	30.35	35.35	3.75	4.57	6.30	7.98
B	16.35	26.92	27.63	31.60	2.98	3.86	5.98	6.37
C	16.75	28.56	28.13	33.88	3.39	3.86	5.83	6.58
D	14.25	25.96	26.03	31.09	3.23	3.27	5.67	6.34
E	15.97	26.34	27.21	31.67	2.78	3.45	5.56	6.01

This can be possibly expressed by the graph of log of their compressive strength against log of time (curing ages) shown in Figure 3. While the gradient indicates the rate of strength development, the intercept would indicate *latent strength* of the cement mortar that does not depend upon time.

Generally, the consistency of the graph could be acceptable with the Pearson residuals squared, R^2,ranges between 0.825 and 0.85.

It is observed that cement A had the highest latent strength followed by cements C and then B (Figure 3a - c). Although cement D had the lowest latent strength but its rate of strength development was the highest. Other cements had marginal difference in their rate of strength development.

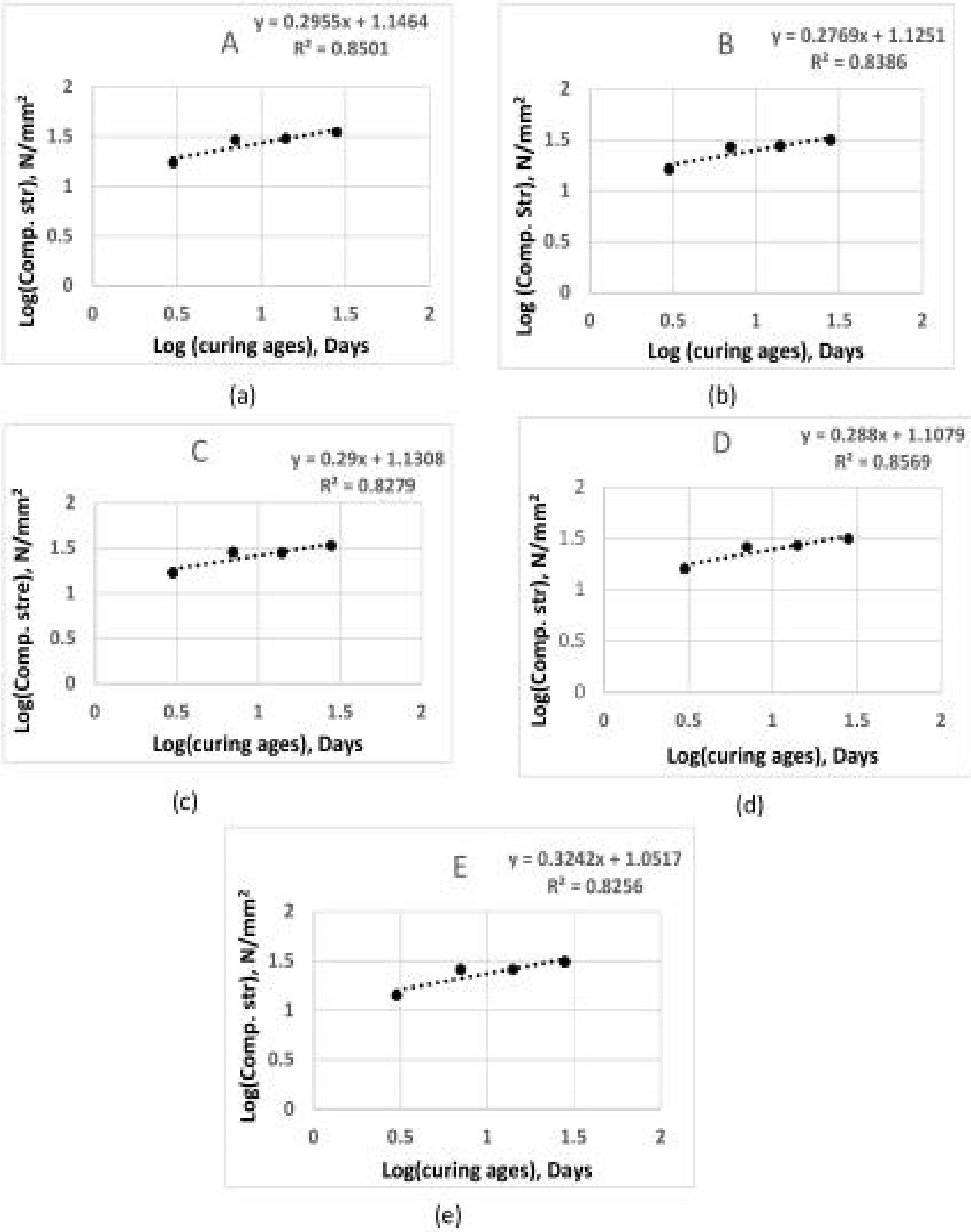


Figure 3: Rate of strength development for various cement brands

4.0 CONCLUSION

The chemical and physical properties as well structural properties of five Portland cements commonly used in Southwest Nigerian were investigated. The following could be concluded from the study:

i The chemical compositions of locally made cements (B, C and D) were slightly different from the imported ones (A and E). Particularly, the CaO and silica content were lower than the Standards.

ii. Setting times of the cements did not differ significantly, only that cement E set earlier than others.

iii. At 28 days, cement A had highest compressive strength with low rate of strength development, while cement Dhad lowest compressive strength with high rate of strength development.

iv. All the cements could be acceptable for normal construction works, where strength is paramount cement A and C could be given preference.

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