STRENGTH CHARACTERISTICS OF REGROUND CAKED CEMENT

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ABSTRACT

The construction climate in Nigeria is fraught with so many problems that lead to projects not being executed as scheduled or eventual abandonment of site. These lead to the storage of purchased cement for times longer than necessary, resulting in their getting caked. Compounding this problem is the activities of some cement traders who re-bag cement after long periods of exposure and the importation of cement, which may have lost their properties due to long period of shipment.

Various tests were conducted on normal and reground-caked ordinary Portland cement (Elephant brand) with a view to determining the effect of long period of storage. The tests included mineralogical composition, consistence, fineness, soundness, setting times and strength performance of mortar and concrete cubes at different ages.

The results of the investigation showed a reduction in the Tricalcium Silicate (C_3S) as well as increase in Dicalcium Silicate (C_2S) contents of the reground-caked cement thus resulting in low strength capacity. The various strengths of mortar and concrete cubes cast with the reground-caked cement were about 10-28% those of the corresponding normal cement. The reground-caked cement is therefore recommended for use in non-load bearing elements and sandcrete blocks for partitions.

INTRODUCTION

Nigeria is a developing country with annual increasing stock of buildings and infrastructure. The main material used for these indices of development is cement. The National Housing Policy of 1980 had as its objective: "housing for all by the year 2000". The Nigerian Building and Road Research Institute (NBBRI) in its 1987 report estimated the nation's housing needs as 20 million new housing units (1).

To achieve this objective, Governments at various levels have carried out the policy of direct intervention by building low cost housing units. These schemes have however failed to satisfy the needs of the population as the population continues to grow especially in urban areas. Compounding this problem is the high cost of cement and other building materials. This has led to the quest for alternative building materials. In this quest therefore, various forms of building materials like burnt clay bricks, soil blocks (2) and timber construction (3) were suggested. These suggestions were based on the availability of raw materials for these forms of construction, in various parts of the country. Introduction of interlocking blocks for walls in housing construction to reduce the use of cement was also proposed (4).

Despite these developments, the use of cement in the construction industry continues to be on the increase due to its versatility and high strength development. Consequently the local production of cement has always been augmented by importation. The Raw Materials Research and Development Council (RMRDC) estimated annual cement requirement in Nigeria at 7.8 million metric tonnes (5).

Out of the 8 cement plants in Nigeria, only 3 are producing satisfactorily. The remaining 5 are either producing below their installed capacity or have shut down; the reasons being lack of spare parts and insufficient power and fuel supply resulting in stoppages during the heat treatment process in the kiln, leading to equipment damage. These result in high production cost, low cement output and low profit which ultimately affect the capital base.

It has been estimated that the total quantity of cement produced in the country in 1990 was 3,053,776 metric tonnes (6). Despite this huge production, other brands of the ordinary Portland cement are imported to augment the shortfall in cement requirement.

Figures obtained from the Cement Manufacturers Association of Nigeria (CMAN) show that the quantity of imported cement amounted to 42%, 52% and 90% of locally produced ones for the years 1996, 1997 and 1998 respectively. The local cement production for those 3 years were 2,530,998 tonnes, 2,519,876 tonnes and 2,206,355 tonnes. This shows continuous drop in local production of cement from the 1990 figure to the1998 figure. This has consequently led to a rise in the quantity of imported cement to augment local production and furthermore created a tendency for usage of ground caked cement in private construction works.

The properties of Portland cement are dependent on the mineralogical composition, its fineness, ambient temperature and duration of storage. Fineness of cement, which reduces with long period of storage on the other hand, determines degree of hydration, water/cement ratio and consequently workability and also rate of development of strength in concrete elements.

Ordinary Portland cement looses its activity, that is, its crushing strength at 28 days, even when stored under most favourable conditions for a long period. After 3 months of storage the loss of activity could be about 20% and after one year it could be up to 40% (7). Imported cements are either imported in bulk and bagged in the country or bagged before importation. With the long period of shipment of imported cement, the possibility of caking and loss of activity particularly for already bagged cement may not be ruled out.

It also requires to be emphasized that the construction climate in Nigeria is a very volatile one. Governments at various levels are the biggest spenders in the construction industry. Government construction contracts are however fraught with many problems of bureaucratic bottlenecks and lack of prompt payment to contractors. This results in delay in commencement of construction and in certain cases abandonment of site. The volatile nature could also be ascribed to disagreements between the labour force and their employer resulting in abandonment of construction works. The net effect of this is that purchased cement is stored for a considerable period of time leading to caking and the eventual loss of strength.

Mention also requires to be made of the habits of some cement traders who re-grind and re-bag cement, which had hitherto been exposed to adverse weather effects for a considerable period of time without establishment of their reduced strength. It is pertinent therefore to assess the physical and strength characteristics of re-ground caked cement with a view to providing necessary recommendations for their usage

EXPERIMENTAL PROCEDURE

Elephant brand of ordinary Portland cement obtained from Ewekoro in Ogun State of Nigeria was stored for a period of 3 months until caking took place and then it was reground for 75 minutes to the fineness of 339m^2/kg. This was used for the various tests that were carried out. Normal cement of the same brand was also subjected to the same relevant tests for the purpose of comparison. The coarse aggregate, which is of granite group, was obtained from Abeokuta in Ogun State while sharp river sand was used for fine aggregate. The tests carried out were chemical analysis of the mineralogical composition, consistence, soundness, setting time, fineness as well as mortar and concrete cube compression tests.

The consistence test was performed using the Vicat apparatus with a 10mm diameter plunger fitted into the needle holder. Trial pastes of cement and water were placed in the mould until the penetration of 5-7mm from the bottom of the mould was obtained. This is regarded as a standard paste. The water content of the paste is expressed as a percentage of the dry cement. The same apparatus used for the consistence test was utilized for the determination of the setting times but with different plungers (8).

The soundness test was performed using Le Chatelier apparatus. The procedure involves mixing about 100g of cement with the quantity of water required to give a paste of standard consistence. The mould was placed on one glass plate and filled with the cement paste taking care to keep the split of the mould gently closed while the operation was being performed. The mould was then covered with the other glass plate and the whole arrangement immersed in water at a temperature of about 20^{0}C for the determination of the expansion as outlined in BS4550: Part 3. The permeability apparatus using the manometer and the flowmeter on the other hand was used for the determination of fineness as also described in BS4550: Part 3 (8).

The composition of cement however, was determined using the procedure outlined in the European Standard EN 196 Part 2: 1994 (9). The procedure involves weighing approximately 100g of cement, which was sieved and transferred to a clean dry flask with an airtight closure. This was subsequently used for the various tests that were carried out. 1g of the sample was weighed and used for the determination of loss on ignition.

To determine the oxide constituents of cement, 1g of the sample was further weighed and decomposed with 3g of sodium peroxide. The mixture was then heated to about 500°C. 50ml of concentrated hydrochloric acid (HCl) and 1ml of sulphuric acid were added in the process. This solution was then used for the determination of the oxide composition as outlined in the stated European Standard. The sulphate composition and insoluble residue were determined separately from the other oxide constituents as outlined also in the mentioned European Standard. Bogue's equations were then used to determine the compound composition.

Mortar and concrete cubes were prepared and tested for their compressive strength at 3, 7 and 28 days. For the mortar cubes 1:3 mix proportion of cement to sand was used for casting in 70.7mm steel moulds. For the concrete cubes however 1:2:4 mix proportion of cement:sand:gravel was used. The casting was in 150mm steel moulds. Water/cement ratios of 0.4 and 0.5 were used in both cases. The various tests were performed for both reground caked and normal cements.

TEST RESULTS AND DISCUSSIONS

Chemical Composition

The behaviour of ordinary Portland cement and its strength development is to a large extent influenced by its chemical composition. The oxide and compound compositions for the normal and reground-caked cement are shown in Table 1. The main cementitious compounds in ordinary Portland cement are tricalcium silicate (C_3S) and dicalcium silicate (C_2S). Their percentage compositions affect the rate of hydration and strength development. A higher C_3S indicates faster hydration and rapid strength gain while hi[illegible] C_2S indicates slow gain of strength.

The results showed that the percentage composition of the constituent oxides is nearly the same for the normal and reground-caked cement. The major difference was in the magnesium oxide (MgO) which gave 1.11% and 3.28% for the normal and caked cements respectively. For the silica (SiO_2), there was a mild increase from 18.46% for normal to 19.72% for the reground-caked cement. These differences affected the lime saturation factor reducing it from 95.25% for normal cement to 87.8% for the reground-caked cement. In view of the reduction in the lime saturation factor, the process of hydration was expected to slow down, resulting in low strength in concrete of the reground-caked cement at the various ages tested.

In the compound composition, the C_3S reduced from 53.54% for the normal cement to 36.98% for the reground-caked cement; a decrease of 31%. The C_2S consequently increased sharply with more than 100%, from 12.61% in the normal cement to 28.71% in the reground-caked cement. During the initial period of hardening (up to 28 days) the C_2S strength gain is small and amounts to about 15% of that of C_3S. The increase of C_2S in the reground-caked cement will definitely reduce the strength of the concrete produced. The comparatively higher tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF) in the reground-caked cement may be indications of higher expansion and greater susceptibility to sulphate attack.

Table 1: Oxide and Compound Compositions of Normal and Reground-caked Cement

Constituent (oxide/compound)	Percentage composition (%)		Composition limits (10 and 11)
Oxide composition	Normal Cement	Reground Caked Cement	
CaO	58.12	58.23	60-67
SiO_2	18.46	19.72	17 - 25
Al_2O_3	4.73	5.60	3 - 8
Fe_2O_3	2.94	3.51	0.5 – 6
MgO	1.11	3.28	0.1 - 4.0
SO_3	2.36	2.63	1 - 3
Insoluble residue	0.48	0.49	≤1.5
Lime Saturation Factor	95.25	87.8	66-102
Compound Composition			
C_3S	53.54	36.98	
C_2S	12.61	28.71	
C_3A	7.57	8.9	
C_4AF	8.94	10.67	

PHYSICAL PROPERTIES

The results of the physical properties of the normal and reground-caked cement are tabulated in Table 2. Physical and chemical analyses were not performed on the aggregates, as they were not expected to have any deleterious effect on the concrete. Furthermore, since the same aggregates were used for the normal and reground-caked cement, they would not unduely influence the strength comparison.

The rate of hydration depends on the chemical composition and the total surface area of cement available to react with water. Specific surface area therefore contributes to the initial and final setting times as well as to early development of strength, to a certain extent. The fineness of the normal cement obtained was 456m²/kg while reground-caked cement had the fineness of 339m²/kg. This shows that the normal cement will develop strength and generate heat quicker than the caked cement. It is also an indication that the normal cement will improve the cohesiveness of fresh concrete and can be effective in reducing the risk of bleeding. The normal cement produced a standard consistence with the water/cement ratio of 0.32 while the ratio for that of reground-caked cement was 0.27. The higher ratio for the normal cement was not unexpected because the reground-caked cement would have undergone a certain degree of hydration due to an initial exposure to humidity before regrinding. This exposure gradually lowered the activity of the cement. Apart from the effect of humidity on the caked cement, the higher water/cement ratio that produced standard consistence in the case of the normal cement would also be ascribed to its higher fineness, which presented a larger surface area for the hydration process.

Table 2: Physical Properties of Normal and Reground-Caked Cement

Physical Property	Normal cement	Caked cement	BS 12 Values (10)
Consistence (%)	32	27	26-33
Fineness (m²/kg)	456	339	225
Soundness (expansion, mm)	0.6	0.3	10
Initial setting time (minutes)	195	202	> 45
Final setting time (minutes)	260	338	< 600

In the soundness test a lower expansion value was obtained for the caked cement than that obtained for the normal cement. The normal cement has a larger surface area, which presented a larger medium of hydration, which resulted in a bigger expansion. The higher expansion would also be ascribed to the higher Lime Saturation Factor (LSF) as indicated in Table 1 above. Though the reground-caked cement had a higher C_3A composition its lower expansion cement would on the other hand be ascribed to a less active hydration process, a higher C_2S composition and a lower LSF. The two types of cement are sound based on their relatively low expansion values (0.3 – 0.6mm) compared to the BS12 recommended value of 10mm. Generally, the effect of unsound cement may not be apparent for some considerable period of time but normally manifest itself in cracking and disintegration of the surface of the concrete

Setting and hardening of cement paste are the main physical characteristics associated with hydration of cement. Hydration results in the formation of a gel around each of the cement particles and in time these layers of gel grow to the extent that they come into contact with each other and the cement paste begins to loose its fluidity resulting in setting. The initial and final setting times of the normal cement was 195 and 260 minutes respectively compared to the 202 and 338 minutes obtained for the reground-caked cement. This shows that for the same water/cement ratio, the reground-caked cement takes a longer period of time to achieve its final setting time. This may not be unconnected with the higher fineness of the normal cement compared to the reground-caked cement.

Strength Characteristics

The results of the compressive strength of the mortar cubes from the normal and reground-caked cements, expressed in Table 3, showed that with increase in the water/cement ratio from 0.4 to 0.5, there was corresponding decrease in strength for all the ages tested. This may be as a result of the availability of excess water beyond that required for the hydration process. The consistencies of the normal and reground-caked cements were 32% and 27% respectively, showing the affinity of more water in the normal cement mortar.

The strength at 28 days for the reground-caked cement mortar cubes was more than 1½ times the values at 7 days while in the normal cement mortar cubes, the strength at 28 days was greater than those at 7 days by not more than 20%. This shows a delay in the strength development in the reground-caked cement mortar compared to the normal cement where more than 75% of the 28-days strength was developed at 7 days.

Table 3: Compressive Strength of Mortar Cubes

Age (days)	Compressive Strength (N/mm²)				BS Value N/mm² (10)
	Water/cement ratio of 0.4		Water/cement ratio of 0.5		
	Normal cement	Reground-caked cement	Normal cement	Reground-caked cement	
3	8.05	1.90	7.02	1.60	**23.0**
7	21.52	2.20	20.11	2.17	**-**
28	25.50	3.98	25.28	3.81	**41**

The caked cement mortar cubes with water/cement ratios of 0.4 and 0.5 exhibited low strength values of 3.98N/mm² and 3.81N/mm² at 28 days respectively compared to those of the corresponding normal cement mortar cubes of 25.50N/mm² and 25.28N/mm²

The effect of the water/cement ratio on the strength of the cement mortar was pronounced in the normal cement while in the case of the reground-caked cement there was no distinction between the growth of strength in the water/cement ratio of 0.4 and 0.5. Figure 1 shows the compressive strength-time characteristic of the mortar cubes with the different water/cement ratios.

The compressive strength of concrete cubes from the normal and reground-caked cement as shown in Table 4 gave higher results compared to the corresponding mortar cubes. At 28 days, the concrete cubes from the normal cement exhibited strength of 35.56N/mm² compared to the reground-caked cement concrete cube strength of 5.69N/mm² with the water/cement ratio of 0.4. Apart from the reduced tricalcium silicate (C_3S) composition and fineness of the reground-caked cement, the comparatively low strength could be ascribed to the initial hydration process of the cement as a result of exposure to humidity prior to its use.

Table 4: Compressive Strength of Concrete Cubes

Age (days)	Compressive Strength (N/mm²)				BS Value N/mm² (10)
	Water/cement ratio of 0.4		Water/cement ratio of 0.5		
	Normal cement	Reground-caked cement	Normal cement	Reground-caked cement	
3	18.46	3.24	15.79	3.24	**13**
7	22.80	5.50	22.31	6.32	**-**
28	35.56	5.69	35.56	9.31	**29**

For water/cement ratios of 0.4 and 0.5, the normal cement concrete cubes showed the same growth in strength from 7 days to 28 days as seen in figure 2 with increase of about 55%. Conversely, that of the reground-caked cement showed no significant strength difference between the 7 days (5.5N/mm^2) and 28 days (5.69N/mm^2). This may be as a result of the reduced activity of the reground-caked cement. However an increase in strength of the reground-caked cement concrete cubes of about 50% was observed for the same period for water/cement ratio of 0.5. This may be as a result of the level of compactness of the cubes facilitated by the higher water/cement ratio especially with the presence of the coarse aggregate.

Generally it was observed that the 3 and 28 days strength of the concrete cubes produced from the normal cement satisfied the recommended values of the British Standard values of 13N/mm^2 and 29N/mm^2 respectively (10) while those from the caked cement fell far short of the standard. However, the values for the caked cement mortar and concrete cubes exceed the minimum recommended strength for sandcrete blocks (3.5N/mm^2)

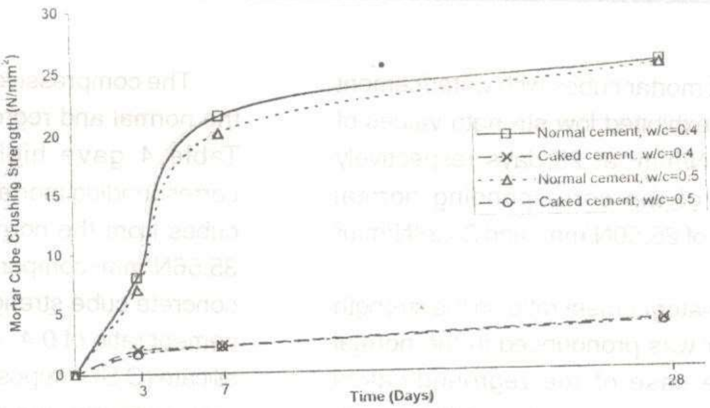

Figure 1: Compressive Strength-Time Characteristics of Mortar Cubes from Normal and Reground-Caked Cement with Water/Cement Ratios of 0.4 and 0.5

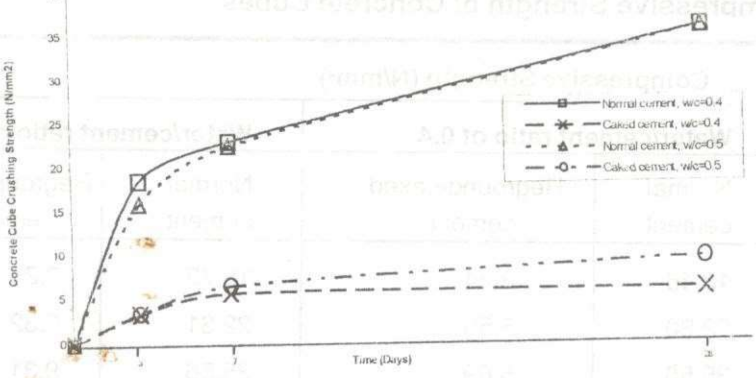

Figure 2 : Compressive Strength-Time Characteristics of Concrete Cubes from Normal and Reground-Caked Cement with Water/Cement Ratios of 0.4 and 0.5

CONCLUSIONS AND RECOMMENDATIONS

The consistence, fineness, expansion, initial and final setting times of the normal and reground-caked cement both met the recommendations of the British Standard. While the concrete cubes produced with the normal cement met the requirement of BS 12, the mortar cubes produced from this cement fell short of the requirement. The reground-caked cement with maximum 28 days concrete cube strength of 9.31N/mm^2 and minimum mortar cube strength of 3.81N/mm^2 as would be expected fell very short of the appropriate British Standard requirements. The minimum mortar cube strength at 28 days however exceeds the recommended strength for sandcrete blocks.

The water/cement ratio that produced standard consistence for the caked cement was lower than the ratio for the normal cement. In the soundness test however, the caked cement produced less expansion due to its loss of activity as a result of the initial hydration process, which would have taken place in the presence of humidity. Higher initial and final setting times were also observed in the reground-caked cement compared to the normal cement.

The results of the investigation showed that the percentage composition of the constituent oxides are nearly the same for the normal and reground-caked cement while the tricalcium silicate (C_3S) content in the compound composition showed a reduction from 53.54% in the normal cement to 36.98% in the reground-caked cement. Conversely an increase in the dicalcium silicate (C_2S) content was noticed in the reground-caked cement from the 12.61% in the normal cement to 28.71% for the caked cement.

The mortar and concrete cube crushing strength of the reground-caked cement fell far below British Standard recommendations due the tremendous loss of activity in the cement. The various strengths obtained were between 10 and 28% of the corresponding strength of the normal cement. Though the mortar cube crushing strengths for the normal cement fell short of the expected British Standard recommendation, the requirements were met for the concrete cubes.

It is recommended that proper storage of cement on site should be carried out to ensure it does not lose activity. Cement should also be used in the order it is delivered to site. This practice will ensure cement quality and reduced possibility of caking. Lumpy cement should not be used without regrinding to appropriate fineness.

Though caked cement as the results show, cannot be used for structural concrete, it could find other uses like the construction of non-load bearing walls and moulding of sancrete blocks for partitions. Further investigation could be carried out on different brands of caked cement by storing normal cement under varied conditions for various duration of time.

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