Effect of Changing Cement Grade on the Properties of Structural Concrete

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ABSTRACT: Many research efforts have been carried out, in a quest to produce mix design information that will guide the concrete and construction industry on how to achieve different concrete strengths, using the different grades of cement available. This is with a view to arresting the rampant collapse of buildings in Nigeria. The work presented in this paper is the result of investigation carried out to determine effects of changing cement grade, while casting a structural member, on the strength behaviour of the concrete. Two types of cement grades: 32.5 R and 42. 5 R were used for this research. In this investigation, the chemical and physical properties of the cement were determined. Consistency and setting times of mortar specimens from the two cement grades were also determined. Concrete samples made from the two cement grades 32.5 R and 42.5 R were evaluated for workability, density, compressive and tensile strengths at water/cement ratios of 0.40, 0.50 and 0.60. The results showed that the cement grade 42.5 consistently developed higher densities at all the water/cement ratios considered. This may be as a result of unforeseen additional dead load at the design stage, which would now amount to underestimation of dead load and thus design load. The results also showed that at higher water/cement ratios, the cement grade 42.5 R has densities exceeding the 2400 kg/m^3 recommended by BS 8110. Furthermore, the concretes produced with cement grades of 32.5 R and 42.5 R have different strength development pattern and developed different 28-day compressive strength. Thus, it can be concluded that the action of changing the cement grade during concreting, for the same structural member is not supported by the national code, and will not result in safe and durable concrete.

KEYWORDS: Cement grades, Compressive strength, Density, Portland limestone cement, Tensile strength, Workability.

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I. INTRODUCTION

Concrete is the most-used material in the building and construction of civil infrastructures, especially for shelters of many types and usages. However, the concrete industry in Nigeria has attracted sustained attentions in recent times, because of frequent building collapse either during construction, or in service with attendant loss of lives and properties. A graphic picture of this trend can be observed from the results of investigations conducted by Omenihu et al. (2016) as presented in Table 1. Although, their work covered a period of up to 2016, it is obvious from Table 1 that collapse of buildings has been on the increase.

The works of Odeyemi et al. (2019) not only extended to, and including 2019, but also identified the causes of such failures. Their works showed that about 90% of the identified causes are structural in nature. Since most of the buildings were built with concrete, it will not be out of place to investigate the concrete as a material and also question the quality of its individual component. Cement, as the major binder, that contribute in no small measure to the strength of concrete has come under scrutiny for some times on its suitability or otherwise of some grades of cement in the production of structural concrete.

Table 1: Summary of collapse buildings and casualties between 1971 – 2016 in Nigeria (Omenihu et al., 2016).

S/No	Year	Number of Collapse	Number of Lives Lost	% Collapse Occurrence
1	1971 – 1975	2	51	1.14
2	1976 – 1980	8	99	4.57
3	1981 – 1985	14	71	8.00
4	1986 – 1990	15	144	8.57
5	1991– 1995	20	112	11.43
6	1996 – 2000	24	175	13.71
7	2001- 2005	23	235	13.14
8	2006 – 2010	28	324	16.01
9	2011 – 2016	41	244	23.43
	Total	**175**	**1455**	**100**

Presently, two grades of cement (32.5 R and 42.5 R) are sold in Nigerian market, which engineers are expected to use to obtain appropriate concrete mix design for specific work. To remove any doubt in the minds of those raising concerns, the Council for the Regulation of Engineering in Nigeria (COREN, 2016) informed that both grades are suitable. The body however advised that a lot of research is needed to produce mix design information that will guide the

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construction industry on how to achieve different strengths of sandcrete and concrete using the different grades of cement available.

Taking up the gauntlet, Adewole et al. (2015) conducted investigations on appropriate mix design using grade 32.5 R and 42.5 R. They concluded that the strength class C20/25 which is the minimum concrete strength class recommended for the construction of load-bearing building structural members cannot be produced with 1:2:4 mix ratio and 32.5 N grade of cement, but with 42.5 N grade. The work of Joel and Mbapuun (2016), nonetheless showed results in which concrete produced with grade 42.5N developed higher strength than that produced with grade 32.5N. Their results however seemed to contradict that of Adewole et al. (2015), in that concrete produced with 32.5 N grade and 1:2:4 mix developed a compressive strength higher than C20/25. This result is not strange, knowing that strength of concrete does not depend exclusively on the cement grade alone (Neville, 2011 and Gambhir, 2013).

Other factors come into play. Concrete from 1:2:4 and cement grade 42.5 R will not develop any appreciable strength if: (i) aggregate used failed structural specifications, (ii) not properly compacted and (iii) not well-cured. According to Walker and Bloem (1961), Neville (2011) and Gambhir (2013), the strength of a well-compacted concrete results from the strength of the mortar, the bond between the mortar and coarse aggregate (that is, the properties of interfacial zone), and the strength of the coarse aggregate particle (that is, its ability to resist the stresses applied to it). Added to these facts is that, in Nigeria, many of our behaviors that bothers on inadequate planning and lack of professionalism on the part of the construction company (most especially indigenous contractors) can also make the strengths development of structural concrete to be very unpredictable.

For example, in a situation where casting of slab work was started with say, 42.5 R, and mid-way while the concreting is going on, the grade 42.5 R was exhausted, and the supplier brings in 32.5 R to replace it, because grade 42.5 R is no longer available. Thus, the engineer that is in charge of the project is in dilemma in the absence of historic strength development data from the producer (Bamforth et al., 2008), which does not accompany cement that are made in Nigeria. On the other hand, if an engineer is absent, whoever is there will just continue with the casting using the 32.5 R supplied, as if to say that nothing has happened.

This situation was not envisaged by the Code. According to Bamforth et al. (2008), the BS 8110 (1997) assumed that design and construction of concrete will, amongst others: (i) be subject to adequate supervision and quality control procedures, (ii) be carried out by personnel having the appropriate skills and experience, (iii) will involve the use materials and products as specified and (iv) meet the requirements for execution and workmanship as prescribed by relevant code. But there are questions for which answers ought to be provided. Assuming all other concreting conditions remained in place, will concrete produced from both grades develop strength at the same rate? Will concrete produced from these grades be ready for stripping at the same time? Will concrete produced from these grades have the same 28-day compressive strength?

Thus, the aim of this study is to assess the structural implications of changing cement grade during concreting operations on the compressive strength characteristics of structural concrete made from limestone Portland cement grades 32.5 R and 42.5 R, using water/cement ratios of 0.40, 0.50 and 0.60. Specific objectives involve the investigation of workability, density, compressive strength and tensile strength of concrete made with cement grades 32.5 R and 42.5 R at 7, 14, 28, 60 and 90 days of curing.

II. MATERIALS AND METHODS

A. Materials and Mix Proportions

The materials used for this research work were cement, fine aggregate, coarse aggregate and water. Portland limestone cement of grades 32.5 R named Type 1 (in Table 2) and 42.5 R named Type 2 (in Table 2), produced to conform to the requirements of CEM II of NIS 444 (2014), as specified by the manufacturer, were used. The fine aggregate used was river sand. The sand was sun-dried and sieved. The sand material passing through sieve no 4 (4.75 mm) but retained on sieve no 200 (75µm) was collected. The coarse aggregate was naturally-occurring crushed stone obtained from a quarry site in Ikole-Ekiti. To conform with BS 8110 (1997) recommendations for structural concrete, the maximum size was limited to 20 mm. Portable water was used for the mixing of concrete. For the purpose of this investigation, a concrete mix of 1:2:4 and water/cement ratios of 0.4, 0.5 and 0.6 were adopted. The mix proportion on the basis of this is presented in Table 2.

Table 2: Mix proportion for the investigation.

Grade	W/C Ratio	Mix Designation	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water (kg/m^3)
32.5R (Type 1)	0.4	M_{14}	343	686	1372	137
	0.5	M_{15}	343	686	1372	172
	0.6	M_{16}	343	686	1372	206
42.5R (Type 2)	0.4	M_{24}	343	686	1372	137
	0.5	M_{25}	343	686	1372	172
	0.6	M_{26}	343	686	1372	206

Concrete ingredients were batched by weight, and thoroughly mixed following the suggestion of Gambhir (2013). The concrete was cast into moulds of sizes 150 x 150 x 150 mm cube specimens for compression investigation and 150 mm x 300 mm cylinder specimens for tensile strength assessment. The specimens were then compacted manually. The concrete specimens were demoulded after 24 hours and then moist-cured until the date of testing. Specimens were tested at 7, 14, 28, 60 and 90 days of curing.

B. Methods

1.) Materials characterization

Preliminary investigation was conducted to determine the physical properties of aggregate such as the density, specific gravity, water absorption, moisture content, and particle size distribution, for both the fine and coarse aggregate. Chemical analysis was also conducted to determine the oxides composition of the Portland limestone cement.

2.) Consistency test

The consistency test was performed to determine the amount of water required to achieve a paste of standard consistence for mortar specimens containing Portland limestone cement of grades 32.5 R and 42.5 R. The test was conducted in accordance with BS EN 196-3 (2005) using the Vicat apparatus.

3.) Setting time test

The investigation of the initial and final setting times of paste containing Portland limestone cement of grades 32.5 R and 42.5 R, were evaluated by making use of the water required to achieve the standard consistency of cement paste specimens, as determined from the consistency test in accordance to BS EN 196-3 (2005). The setting times – both initial and final – were then determined for the grades of cement (32.5 R and 42.5 R)

4.) Workability test

In order to assess the ease and homogeneity with which freshly mixed concrete with the cements can be mixed, placed, compacted, and finished without segregation and bleeding, slump test was carried out. This property is called workability as per ACI 116R-90 (1994). The experiment was conducted in accordance with the requirements of BS EN 12350: Part 2 (2000).

5.) Density and compressive strength tests

The density and the compressive strength of concrete specimens containing Portland limestone cement of grades 32.5 R and 42.5 R were assessed. 150 x 150 x 150 mm cube specimens were used for both tests. The density test was done in accordance with the provisions of BS 12350: Part 6 (2000). Investigation of the compressive strength was carried out in accordance to the provisions of BS EN 12390-3 (2009). In order to determine the compressive strength of the concrete samples, a computerized 2000 kN WAW-2000B compressive strength machine, with accuracy of ± 1% of test force, was used. At the testing date, three (3) specimens were tested, and their mean strength determined. The weight of each concrete cube was measured before testing. The average density of the concrete cube specimens (in triplicate) was obtained by dividing the obtained weight of the samples by their volumes, which is the volume of the cubes.

6.) Tensile strength

The investigation of the tensile strength of concrete samples with Portland limestone cement of grades 32.5 R and 42.5 R was done with the aid of 150 mm x 300 mm cylinder specimens. The test was carried out as per recommendation of BS 12390: Part 6 (2009). A computerized universal testing machine, 2000 kN WAW-2000B electrohydraulic servo, with accuracy of ± 1% of test force. Eqn (1) was used to compute the splitting tensile strength.

$$T_s = \frac{2P}{\pi l d} \qquad (1)$$

In eqn (1), T_s is the splitting tensile strength (N/mm^2), P is the maximum applied load (in Newtons) by the testing machine, l is the length of the specimen (mm), and d is the diameter of the specimen (mm).

III. RESULTS AND DISCUSSION

A. Materials Characterization

The properties of the aggregates are shown in Table 3. From the table, it can be seen that the specific gravities of sand and gravel are 2.63 and 2.67 respectively. According to Gambhir (2013), the average specific gravity of majority of natural aggregate lie between 2.5 and 2.8. Thus, both the sand and gravel used in this investigation can be considered as natural aggregate. Also, the bulk density, water absorption and the moisture content of both the sand and gravel fell between the ranges used in normal concrete (ACI, 1999). These values are 1280 to 1920 kg/m^3 for density, 0 to 8% for water absorption, and 0 – 2% for sand and 0 - 10% for gravel. Also, the coefficient of curvature for both are close to 1, thus indicating that both are well-graded, while the coefficient of uniformity of less than or equal to 4 recorded for both sand and gravel suggest that both are uniformly graded (Iowa, 2020). Overall conclusion of all of these is that the materials are good for concrete production.

Table 3: The physical properties of the aggregates.

Properties	Sand	Gravel
Specific Gravity	2.63	2.67
Bulk Density (kg/m^3)	1666.67	1641.67
Water Absorption (%)	2.00	2.00
Moisture Content (%)	0.00	0.00
Coefficient of curvature (Cc)	0.88	0.98
Coefficient of uniformity (Cu)	3.00	2.43

B. Chemical Analysis

The chemical analysis of the cement grade 32.5 R and 42. 5 R are shown in Table 4. From the table, it can be seen that both 32.5 R and 42.5 R have high CaO in relation to other oxides. The overall oxides composition is in line with similar limestone Portland cement reported by Tosun et al. (2009). The limits of oxides (CaO, SiO_2, Al_2O_3, Fe_2O_3) in the Table were according to Neville (2011), as no limits were specified by

Table 4: Oxides composition and compounds of grades of cement.

Oxides	Cement Type		BS EN 197-1(2000) (%)
	32.5R (%)	42.5R (%)	
CaO	64.20	65.55	63
SiO_2	18.92	17.89	20
Al_2O_3	5.08	4.78	6
F_2O_3	3.30	3.72	3
MgO	0.92	0.85	
Na_2O	0.19	0.30	0.00 – 5.00
K_2O	0.42	0.42	
Mn_2O	0.02	0.01	
SO_3	2.16	1.97	3.50
LOI	2.08	1.97	5.0
Insoluble Residue	0.34	0.25	5.0

BS EN 197-1 (2000) in respect of those oxides. In addition, it can be observed from Table 4 that the chemical compositions conform to the following requirement of BS EN 197-1 (2000), namely: SO_3 less than 4.0%; loss on ignition of less than 5% and insoluble residue of less than 5.0%

C. Physical Properties of Portland Limestone Cement and Mortar

The physical properties of the grades of cement and that of their mortars are presented in Table 5. It can be observed from this table that both grades of cement have similar the specific gravity and fineness. However, grade 42.5 R has a higher consistency. This means higher amount of water is required by grade 42.5 R to achieve a standard consistency. Also, the initial setting times of 170 and 175 minutes for 32.5 R and 42.5 R respectively, are higher than 60 minutes stipulated by BS EN 197-1 (2000). In relation to the final setting time, both the BS 12 (196) and EN 197-1 (2000) have to limits or recommendations. This is in agreement with Neville (2011) who observed that limits on the final setting time no longer appear in the European or ASTM standards. It can thus be concluded that the final setting times obtained for both 32.5 R and 42.5 R are acceptable.

Table 5: Some physical properties of portland limestone cement and mortar.

Properties	32.5 R	42.5 R
Specific Gravity	3.14	3.12
Fineness (%)	90	90
Consistency (%)	29.5	33
Initial Setting Time (minutes)	170	175
Final Setting Time (minutes)	362	342

D. Workability

Workability, according to Neville and Brooks (1987), is required for maximum compaction necessary for the development of compressive strength, and it is vital to achieve a maximum possible density. The slump characteristics of concrete specimens with different grades of Portland limestone cement, at different water/cement ratios are presented in Table 6.

Table 6: Effect of cement grades on workability of concrete.

Cement grade	Water/cement ratios		
	0.40	0.50	0.60
32.5 R	0.0	5 mm	20 mm
42.5 R	0.0	5 mm	20 mm

For both grades of cement the slump increased with water/cement ratio. Also, both grades of cement have similar values in slump, and exhibited true slump. For the slump values of between 0 and 20 mm recorded at the considered water/cement ratios, the workability of both cement grades is to be considered as low (Neville, 2011 and Gambhir, 2013).

E. Density of Concrete Specimens made with Different Grades of Portland Limestone Cement

The pattern of density development of concrete made with 32.5 R and 42.5 R at all the water/cement ratios is shown in Figure 1 for density of concrete at water/cement ratio of 0.40. At all the water/cement ratios, the cement grade 42.5 R consistently developed higher densities at all the curing days. The implication of this is that if there is change in cement grade during concreting operations for the casting of a structural element, two types of densities will result.

The BS 8110 (1997) governing design of structural concrete in Nigeria does not envisage this situation. Only one type of density is in view when using the BS 8110 (1997). Also, looking at the numerical values of the densities (in kg/m^3, with standard deviations of between 28.33 to 33.21 kg/m^3) developed at all the water/cement ratios as shown in Tables 7 – 9, some developments are worthy of attention. The obtained densities increased with water/cement ratios, especially for cement grade of 42.5 R, exceeding the limit of concrete density for normal concrete.

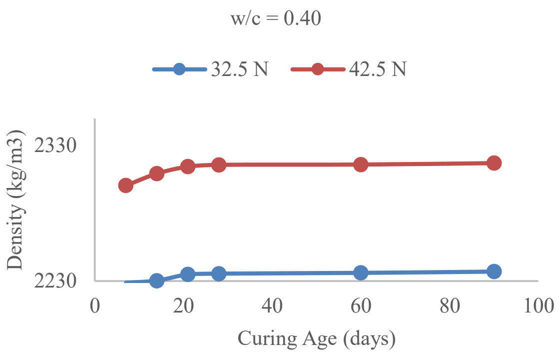

Figure 1: A Typical Density development of Concrete Specimens made with Cement grades 32.5 R and 42. 5 R.

Table 7: Density of concrete specimens made with cement grades at w/c ratio = 0.40.

Cement grade	7	14	21	28	60	90
32.5R	2228.57	2230.23	2234.87	2235.45	2236.03	2236.97
42.5R	2300.46	2309.29	2314.43	2315.76	2315.98	2317.02

Table 8: Density of concrete specimens made with cement grades at w/c ratio = 0.50.

Cement grade	7	14	21	28	60	90
32.5R	2373.44	2378.29	2381.77	2387.39	2392.99	2400.47
42.5R	2406.64	2409.23	2411.62	2415.81	2420.83	2422.05

Table 9: Density of concrete specimens made with cement grades at w/c ratio = 0.60.

Cement Grade	7	14	21	28	60	90
32.5R	2390.04	2390.89	2392.06	2435.87	2439.05	2441.78
42.5R	2473.03	2477.49	2480.05	2482.97	2483.01	2483.89

The British standard BS 8110 (1997) which governs the design of structural concrete recommends a density of 2400 kg/m^3. This value is used for estimation of dead loads to obtain the design loads. Thus, using a density of 2400 kg/m^3, while the actual density is in excess of 2400 kg/m^3 will lead to underestimation of design loads. The effects could be catastrophic. Within the same grade of concrete, the developed densities increased with water/cement ratios. This can be seen in Figures 2 and 3.

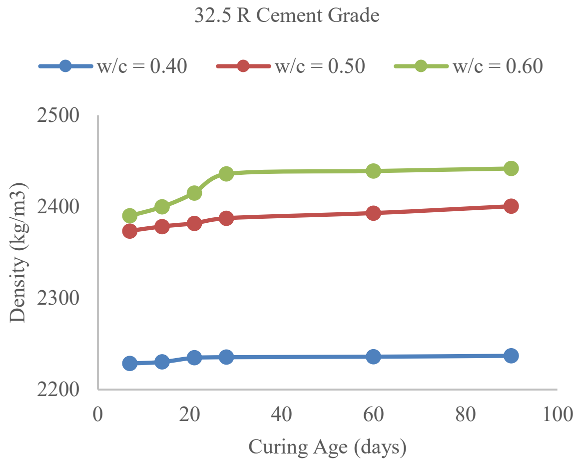

Figure 2: Effects of water/cement ratios on density of the concrete samples.

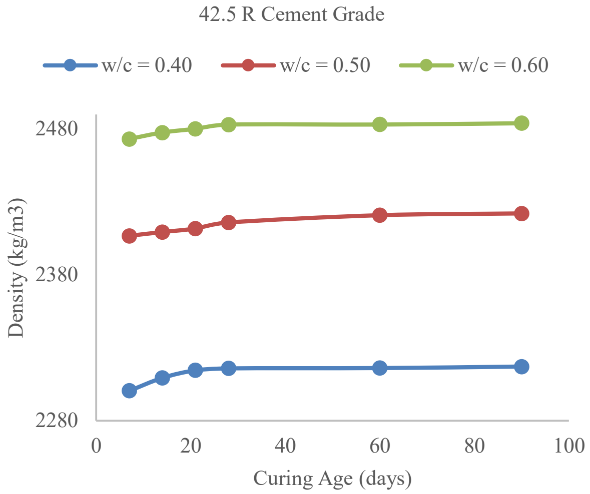

Figure 3: Effects of water/cement ratios on density of the concrete samples.

The increased density may not be unconnected with the fact of increasing workability at higher water/cement ratios (Table 6). According to Neville and Brooks (1987) sufficient workability makes full compaction possible leading to increased density. The increase in density can also be due to the removal of entrapped air in the concrete mix, governed by the grading of the fine aggregate in the mix. The presence of water makes it possible and easier for the voids to be expelled from wet mix than dry one (Neville and Brooks, 1987; Neville, 2011, and Gambhir, 2013).

F. Compressive Strength of Concrete Specimens made with Different Grades of Portland Limestone Cement

The pattern of compressive strength development of concrete specimens with grades of cement for water/cement ratios of 0.40, 0.50 and 0.60 are shown in Figures 4 – 6. Careful observation of the Figures shows a pattern of slow early strength development and higher rate of late strengths.

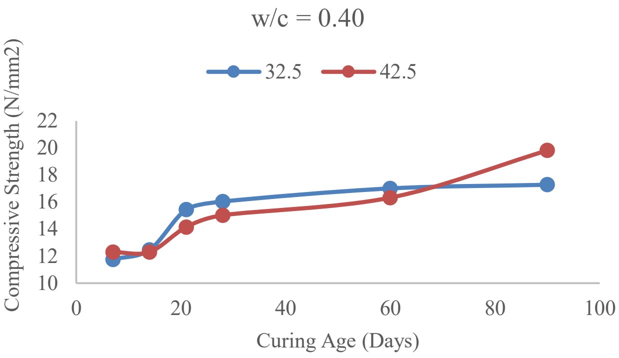

Figure 4: Strength Development for Concrete made from cement of 32.5R and 42.5R at w/c ratio of 0.40.

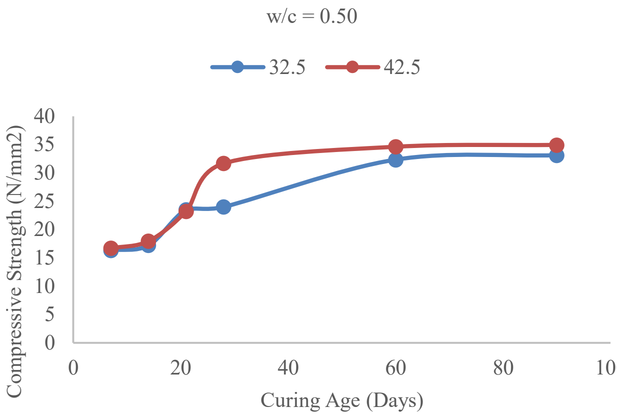

Figure 5: Strength Development for Concrete made from cement of 32.5R and 42.5R at w/c ratio of 0.50.

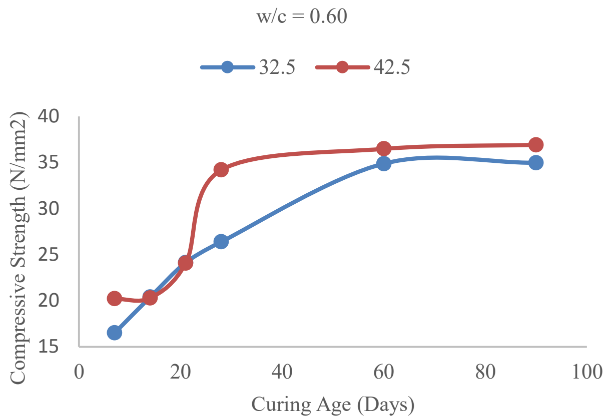

Figure 6: Strength Development for Concrete made from cement of 32.5R and 42.5R at w/c ratio of 0.60.

However, the concrete specimens with cement grade 32.5R perform better than concrete made with 42. 5R at all the curing ages up to 60 days, at water/cement ratio of 0.40. This may be due to the fact that the 32.5 R grade of cement requires a lower amount of water to achieve a standard consistency (Table 5). This, ultimately translates to lower water/cement ratio, setting the stage for higher strength development. Cement grade 32.5 R also sets earlier than 42. 5 R. The combined effects of these seems to have a greater influence on strength at lower water/cement ratio. However, concrete with cement grade 42.5 R developed higher strength at latter days.

At higher water/cement ratios of 0.50 and 0.60, concrete specimens made with grade 42.5 developed higher compressive strengths at all the curing days. The numerical values of 28-day compressive strength, being the relevant strength in the design of structural concrete, are shown in Table 10. It can be seen from Table 10 that concrete specimens made with grades 32. 5 R and 42.5 R cement did not have the same 28-day strength. Apart from the fact that specimens with grades 32. 5 R developed higher 28-day strength at water/ratio of 0.40, concrete with 42.5 R cement have higher 28-day compressive strengths at higher water/cement ratios of 0.50 and 0.60. This can be as a results of the fact 42.5 R is finer than 32.5 R (Table 5) because it has more specific surface hence it set earlier and thus attained both early and higher strength. This is an indication that concrete produced from 32.5 R and 42.5 R will not have the same 28-day compressive strength.

Table 10: 28th day strength development of the concrete samples.

W/C Ratio	Compressive Strength (N/mm^2)	
	32.5 R	42.5 R
0.40	16.04	15.02
0.50	23.99	31.67
0.60	26.40	34.20

The overall picture is that concrete produced with different cement grade will have differential strength developments, and most importantly, differential 28-day compressive strength. The implication of changing the cement grade during concreting operation to construct the same structural element are many. First, the stripping time for formwork will be different. Thus, if the formwork is stripped at the same time, the portion of the structural member with insufficient strength will collapse. This may spread to other portion of the structure, and the whole structure may collapse. Secondly, the stiffness (κ) of any structural member that is used in structural analysis and design is defined as:

$$\kappa = \frac{EI}{L} \qquad \textbf{(2)}$$

where E = Youngs Modulus of elasticity, I = second moment of area of the cross section about the centroidal axis, and L = the length of the structural member. But the Young modulus E is a function of the compressive strength. Table 11 (Mosley et al., 2013) shows typical values (cylinder/cube compressive strengths) of E.

Table 11: Values of modulus of elasticity of concrete.

Concrete Cube Strength (N/mm^2)	Modulus of Elasticity (kN/mm^2)
20/25	30
25/30	31
30/37	33
35/45	35
40/50	36
50/60	37

Thus, mixing cement grades, which are bound to develop two different compressive strengths, to construct the same structural element will result in two different stiffnesses which are not foreseen by any standard, when it is not a composite construction. This is a dangerous situation. Finally, there is differential stress-strain relationship because of incompatibility of deformations. This will lead formation and propagation of crack in the structural element. Collapse will ultimately result.

Also, the results presented and analyses above did not agree with the conclusion made by (Adewole et al., 2015) that a load-bearing building structural members cannot be produced with 1:2:4 mix ratio and 32.5 N grade of cement. The results presented here show that at water cement/cement ratios of 0.5 and 0.60, concrete produced with grade 32. 5R using mix proportion of 1: 2: 4 can develop compressive strength for structural application. This agrees with COREN (2019) that, a specified grade of concrete can be produced using any strength class of cement provided the mix design procedure is followed, and backed by adherence to governing standard or code, during production.

Thus, changing of cement grade during concreting operation for the same structural member is not envisage by the code, and will not results in safe and durable structure.

G. *Splitting Tensile Strength of Concrete Specimens made with Different Grades of Portland Limestone Cement*

The tensile strength is an important mechanical parameter that allows the determination of degree of susceptibility of concrete to cracks. The pattern of tensile strength, evaluated through splitting tensile strength experiment is similar to that of the compressive strength as discussed above in section 3.6. With reference to the discussions of results presented in section 3.6 on compressive strengths pattern, the concrete produced with 42.5 R developed higher splitting tensile strengths than that concrete produced from 32.5 R at all the water/cement ratios and at all the curing ages. Also, splitting tensile strength of the specimens increased with water/cement ratios for all the samples.

IV. CONCLUSION

From the results and discussions, the followings can be concluded:

1) The cement grade 42.5 R consistently developed higher densities at all the water/cement ratios considered. This may be tantamount to unforeseen additional dead load at the design stage, which would now amount to underestimation of dead load and thus design load.
2) At higher water/cement ratios, the cement grade 42.5 R has densities exceeding the 2400 kg/m^3 recommended by BS 8110.
3) The concrete specimens produced with cement grades of 32.5 R and 42.5 R have different strength development pattern.
4) The concrete specimens produced with cement grades of 32.5 R and 42.5 R developed different 28-day compressive strength.
5) The splitting tensile strength of the specimens followed the pattern of the compressive strength for all the curing days and at all the water cement ratios.
6) Changing the cement grade during concreting for the same structural member is not supported by the national code, and will not result in safe and durable concrete.

Among many parameters and circumstance of usage, this paper presented some relevant structural implications of changing cement grades during concreting. This is with a view to present empirical data that will aid structural decision-making process of the technical team or personnel involved in the construction of building and concrete structures. In Nigeria, there are still other parameters that are yet to be investigated in relation to cement grades that are available in Nigeria. They include: strength relations, equations for strength prediction and durability studies of concrete made with 32.5 R and 42.5 R, and many more others. They are thus, recommended for future works.

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