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Determination of appropriate mix ratios for concrete grades using Nigerian Portland-limestone grades 32.5 and 42.5

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Abstract

The construction of buildings by incompetent craftsmen and the use of low quality building materials, including low quality concrete have been identified in the literature as two of the major reasons for the incessant collapse of building in Nigeria. The roadside craftsmen/artisans usually/generally construct buildings using 1:2:4 cement-fine aggregate-large aggregate mix ratio irrespective of the cement strength class. In this paper, the investigation conducted to determine the appropriate concrete mix ratios required to produce Class 20/25 and Class 25/30 concretes commonly used for design of building structural members using the Portland-limestone cement grades 32.5 and 42.5 that are available in the Nigerian open market is presented. Investigation revealed that the cube compressive strength of 1:2:4 concrete produced with Portland-limestone cement grade 32.5 is less than the minimum 25MPa required for concrete Class 20/25 and a richer 1:1.5:3 concrete produced with Portland-limestone cement grade 32.5 may be needed to produce concrete Class 20/25. Investigation also revealed that Portland-limestone cement grade 32.5 may not be suitable for the production of concrete class 25/30 with cube compressive strength of 30MPa as the cube compressive strength of 1:1:2 concrete produced with Portland-limestone cement grade 32.5 may not attain 30MPa. Concrete strength classes 20/25 and class 25/30 can be produced with Portland-limestone cement grade 42.5 using

1:2:4 and 1:1.5:3 mix ratios respectively. To produce concrete with strength class C20/25 which is the minimum concrete strength class recommended for the construction of the load-bearing building structural members using the 1:2:4 mix ratio, Portland-limestone cement grade 42.5 is required.

Keywords

Cement grades, Concrete grade, Compressive strength, Portland-limestone cement

Introduction

In the Nigerian urban areas, concrete is widely used for the construction of building structural elements [1]. With the exception of buildings owned by the Nigerian and foreign governments, corporate organisations such as banks and industries, educated and wealthy individuals, which are designed and constructed by professionals, all other buildings are constructed by roadside craftsmen. These incompetent roadside craftsmen do not carry out any quality assurance tests on the concrete they use for building construction [1]. Since most buildings in Nigeria are owned by common individuals who cannot afford to engage the qualified professionals for the construction of their buildings, most building (conservatively about 70%) in Nigeria are constructed by the roadside craftsmen. These roadside craftsmen construct building ranging from one to three/four storeys. The incessant collapse of building is a common occurrence in Nigeria. A survey conducted by [1] revealed that building experts have identified the use of low quality building materials, the use of incompetent artisans/craftsmen and lack of supervision of building construction works by qualified professionals as the main three reasons for the incessant collapse of building in Nigeria. The concrete production, placement and other activities involved in concreting used for the construction of most buildings in Nigeria are done by the roadside bricklayers/masons without the supervision by the qualified professionals. This explains why the incessant collapse of buildings is more common in building construction works owned by individuals that are constructed by the roadside craftsmen.

Unlike in the buildings constructed by the professionals, in which, trial mixes to obtain the appropriate mix ratios to achieve the required concrete grades/strength class and

concrete quality assurance tests are conducted, the roadside craftsmen neither conduct any trial mix nor any quality assurance tests on concrete. They generally use 1:2:4 cement-fine aggregate-coarse aggregate mix ratio irrespective of the strength class/grade of the cement as they are unaware of the presence of different cement grades in Nigeria and their effects on concrete strength. The roadside bricklayers have been using 1:2:4 mix ratio as a rule of thumb before the introduction of the different cement strength classes into the Nigerian open market and are still using the same 1:2:4 concrete for the construction of the load-bearing building structural members till date irrespective of the cement strength classes.

It is not only the roadside bricklayers that are unaware of the presence of different cement grades/strength classes in Nigeria, many of the professionals, academics and researchers in Nigeria are also unaware of the presence of cement of different grades/strength classes in Nigeria. This explains why the authors of the published work on concrete in Nigeria such as [2 - 11] amongst others did not indicate the grade/strength class of the cement they used for their researches. Nigerians generally are only aware of the different cement brand names and they buy and use cement based on brand names rather than cement grades/strength classes. In the Nigerian open market, the two cement grades/strength classes that are available and which are used for building construction are cement grade 32.5 and cement grade 42.5. Generally, cement grade 42.5 represents a higher strength cement than cement grade 32.5.

In addition to the lack of awareness of the different cement grades in Nigeria, most Nigerian craftsmen and professional engineers as well as academics and researchers still believe that the bagged Portland-limestone cement, the only cement type in the Nigerian open market is the same Ordinary Portland Cement (OPC) they used in the past. They are not aware that the OPC, which was the only cement type allowed to be produced in Nigeria by the old Nigerian industrial standards for cement: NIS 11: 1974 [12] and NIS 439:2000 [13] no longer exist in the bagged form in Nigeria. In Nigeria, OPC is only produced in bulk on request by the big construction companies handling big government projects. The lack of awareness of the fact that the bagged cement in the Nigerian open market is Portland-limestone cement explains why the ten Nigerian authors cited earlier amongst others indicated that they used OPC in their research instead of Portland-limestone cement they bought from the Nigerian open market. Cement manufacturers in Nigeria started producing Portland-limestone cement following the adoption and implementation of the current Nigerian

Industrial Standards for cement, NIS 444-1:2003[14]. From 2003 till date, Portland-limestone cement is the only bagged cement in the Nigerian open market.

Concrete grades or strength classes are specified in terms of the minimum 150 mm diameter by 300 mm compressive cylinder strength and the minimum 150 mm cube compressive strength. Concrete grades or strength classes denotes the compressive strength of concrete which is taken as the 28 days crushing strength of concrete cubes or cylinders [15]. A few of the concrete strength classes recommended for the construction of load-bearing building structural members and their associated cylinder and cube strengths obtained from [15] are presented in Table 1. In Table 1, the letter "C" is used to designate strength class.

Table 1. Concrete strength classes and their cylinder and cube strengths

Concrete strength class (C)	Concrete compressive strength (MPa)	
	Cylinder strength	Cube strength
C16/20	16	20
C20/25	20	25
C25/30	25	30
C30/37	30	37
C35/45	35	45

From Table 1, for all the concrete grades/strength classes, the cylinder strengths are higher than the cube strengths. For example, the concrete grade/strength class C20/25 concrete is expected to have a minimum cylinder crushing strength of 20MPa and the same C20/25 concrete is expected to have a minimum cube crushing strength of 25MPa. Concrete grade/strength class C16/20 with a minimum cylinder strength of 16MPa or a minimum cube strength of 20MPa is the minimum concrete grade/strength class recommended for use in plain concrete construction [16]. Concrete grade/strength class C20/25 with a minimum cylinder strength of 20MPa and a minimum cube strength 25MPa is the minimum concrete grade/strength class recommended for the construction of the reinforced load-bearing building structural members such as columns, beams and slabs in mild exposure condition [16]. However, higher concrete grades/strength classes such as concrete grades/strength classes: C25/30, C30/37, C35/45 are recommended to be used for reinforced concrete foundations and other reinforced concrete structural members [15].

This paper presents the investigation conducted to determine the appropriate concrete mix ratios required to obtain concrete strength classes C20/25 and C25/30 concrete commonly

used for design of buildings and other civil engineering structures using the Portland-limestone cement grades 32.5 and 42.5 that are available in the Nigerian open market. The investigation was conducted to establish if the 1:2:4 mix ratio, that is generally used by the roadside bricklayers for the construction of load-bearing building structural members in Nigeria irrespective of the cement strength class, is suitable for the production of C20/25 concrete (the recommended minimum concrete strength class for reinforced concrete structures).

Material and method

The Portland-limestone cement grades 32.5 and 42.5 employed for this research were bought from the depots of the cement manufacturers certified by the Standards Organisation of Nigeria (SON), the agency in charge of standardisation in Nigeria, which guaranteed that good quality cements were used for the research. The other materials used for the production of the concrete used for this work were river sand (commonly called sharp sand), 20mm crushed granites (commonly used for concrete production in Nigeria) and water of drinkable quality. The particle size distribution of the river sand was determined using sieve analysis. For each cement grade, ten 150×150×150mm concrete cubes were moulded with 1:2:4, 1:1.5:3 and 1:1:2 cement- sand - crushed granite mix ratios and 0.5 water-cement ratio batched by weight. The cubes were cured in accordance with [17] and subjected to compressive strength test in accordance with [18] at 28 days.

Results and discussions

The sieve analysis particle size distribution obtained for the sand used in this work is presented in Figure 1. The typical fracture or failure shape exhibited by all the concrete cubes tested in this work is shown in Figure 2. The average compressive strengths with the standard deviations for the concrete cubes made with grade 32.5 cement and grade 42.5 cement for all the mix ratios considered are presented in the second and third columns of Table 2.

From Table 2, the 24.5MPa average strength of the 1:2:4 concrete cubes moulded with cement grade 32.5 compares well with the 23.8MPa reported by [19] who evaluated the

compressive strength of concrete used in typical construction sites in Nigeria. Variation of test results between different concrete cubes was small with a maximum range (maximum difference between the least and the highest cube compressive strength) of 4.5MPa and a maximum standards deviation of approximately 4.3 as shown in Table 2.

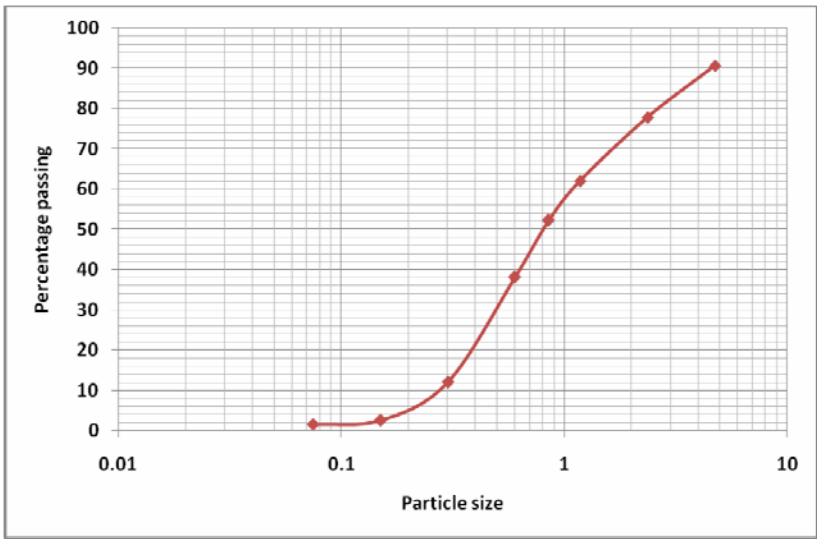

Figure 1: *Fine aggregate particle size distribution curve*

Figure 2. *Fractured concrete cube specimen*

Table 2. Concrete cube compressive strength

Mix ratio	Average Strength (N/mm^2)	
	Cement grade 42.5	Cement grade 32.5
1:2:4	29.8 ± 2.6	24.5 ± 5.4
1: 1½: 3	30.1 ± 3.2	27.0 ± 5.8
1:1:2	30.6 ± 5.2	29.6 ± 3.2

From Table 2, the compressive strength of the 1:2:4 concrete cubes produced with Portland-limestone cement grade 32.5 is 16.5Mpa which is less than the minimum

compressive strength of 25Mpa required for concrete with the strength class C20/25. This result indicates that concrete with the strength class C20/25 which is the minimum concrete strength class recommended for the construction of reinforced load-bearing building structural members cannot be produced with the Nigerian Portland-limestone cement grade 32.5 using the 1:2:4 mix ratio that is usually/generally used by the roadside craftsmen/artisan in Nigeria. The 27.0MPa compressive strength of the 1:1.5:3 concrete cubes produced with the Nigerian Portland-limestone cement grade 32.5 is more than the minimum compressive strength of 25Mpa required for concrete with the strength class C20/25. This result indicates that concrete with the strength class C20/25 can be produced with Portland-limestone cement grade 32.5 using the 1:1.5:3 mix ratio. The 29.6MPa compressive strength of the 1:1.2 concrete cubes produced with cement grade 32.5 is less than the minimum compressive strength of 30Mpa required for concrete with the strength class C25/30. This result indicates that concrete with the strength class C25/30 cannot be produced with Portland-limestone cement grade 32.5 as producing concrete with C25/30 strength class will require using concrete mixes richer than 1:1:2 which will be uneconomical.

From Table 2, the 29.8MPa compressive strength of the 1:2:4 concrete cubes produced with cement grade 42.5 is more than the minimum compressive strength of 25Mpa required for concrete with the strength class C20/25. This result indicates that concrete with the strength class C20/25 can be produced with Portland-limestone cement grade 42.5 using the 1:2:4 mix ratio that is usually/generally used by the roadside craftsmen/artisan in Nigeria. The 30.1MPa compressive strength of the 1:1.5:3 concrete cubes produced with cement grade 42.5 is more than the minimum compressive strength of 30Mpa required for concrete with the strength class C25/30. This result indicates that concrete with the strength class C25/30 can be produced with Portland-limestone cement grade 42.5 using the 1:1.5:3 mix ratio. The strength of the 1:1:2 concrete cubes produced with Portland-limestone cement grade 42.5 is marginally more than the minimum compressive strength of 30Mpa required for concrete with the strength class C25/30 but far less than minimum 37MPa required for the concrete with the strength class C30/37. This result indicates that concrete with the strength class C30/37 cannot be produced with the Nigerian Portland-limestone cement grade 42.5 as producing concrete with C30/37 strength class will require using concrete mixes richer than 1:1:2 which will be uneconomical.

Concrete with the strength class C20/25 can be produced with the Nigerian Portland-limestone cement grade 42.5 using the 1:2:4 mix ration that is usually/generally used by the roadside craftsmen/artisan in Nigeria for the construction of load-bearing building structural elements. Also concrete with the strength class C25/30 with a minimum cube compressive strength of 30MPa can be produced with the Nigerian Portland-limestone cement grade 42.5 using 1:1.5:3 mix ratio. Concrete with the strength class C28/35 with a minimum cube compressive strength of 35MPa cannot be produced with the Nigerian Portland-limestone cement grade 42.5 as the 30.6MPa compressive strength of 1:1:2 concrete produced with Nigerian Portland-limestone cement grade 42.5 is far less than minimum 35MPa required for concrete with the strength class C25/30. Thus producing concrete class with the strength class C28/35 will require using a concrete mix richer than 1:1:2 mix which will be uneconomical.

While concrete with strength class C20/25 which is the minimum concrete strength class recommended for the construction of the load-bearing building structural members can be produced with the Nigerian Portland-limestone cement grade 32.5 using the 1:1.5:3 mix ratio, it is uneconomical as more Nigerian Portland-limestone cement grade 32.5 is required. Consequently, to produce concrete with strength class C20/25 using the 1:2:4 mix ratio that is generally used by the roadside craftsmen/artisans, Portland-limestone cement grade 42.5 is should be used. The use of the Nigerian Portland-limestone cement grade 42.5 for the production of 1:2:4 concrete with the strength class of C20/25 rather than using Nigerian Portland-limestone cement grade 32.5 for the production of 1:1.5:3 concrete with the same strength class of C20/25 is more economical considering the fact that the price of the two cement grades are approximately the same in the Nigerian open market. While the ideal approach to determine the appropriate mix ratios for the required concrete grade/strength classes is through trial mix designs, the appropriate mix ratios specified in this paper if adopted by the craftsmen/artisans who construct most buildings in Nigeria will ensure that stronger concrete are used for building construction and reduce the incessant collapse of building in Nigeria.

Conclusions

This work demonstrates that concrete with the strength class C20/25 with a minimum cube compressive strength of 25MPa which is the minimum concrete strength class

recommended for the construction of load-bearing building structural members cannot be produced with the Nigerian Portland-limestone cement grade 32.5 using the 1:2:4 mix ratio that is usually/generally used by the roadside craftsmen/artisan in Nigeria. This work also demonstrates that to produce concrete with the strength class C20/25 with the Nigerian Portland-limestone cement grade 32.5, a mix ratio of 1:1.5:3 which is richer than the 1:2:4 mix ratio that is usually/generally used by the roadside craftsmen/artisan is required. Investigation also revealed that concrete class C25/30 with a minimum cube compressive strength of 30MPa cannot be produced with the Nigerian Portland-limestone cement grade 32.5 as the 29.6MPa compressive strength of 1:1:2 concrete produced with Nigerian Portland-limestone cement grade 32.5 is less than the minimum 30MPa required for concrete class C25/30. Thus producing concrete class C25/30 will require using a concrete mix richer than 1:1:2 mix ratio which will be uneconomical.

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