Suitability of Nigerian Portland-limestone cement grades for building's concrete structural members in various exposure classes

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Abstract

This work investigates the suitability of the Nigerian Portland-limestone cement grades 32.5 and 42.5 for the construction of building structural members in various exposure condition/classes. The investigation was conducted by comparing the 25MPa, 27MPa and 30MPa average cube compressive strengths and the 30MPa, 30Mpa and 31MPa average cube compressive strengths of 1:2:4, 1:1.5:3 and 1:1:2 concretes produced with Portland-limestone cement grades 32.5 and 42.5 respectively with the minimum durability concrete strength requirements for building structural members in Eurocode 2 exposure classes that are obtainable in Nigeria. Investigation revealed that Portland-limestone cement grades 32.5 is only suitable for the construction of superstructure members inside low humidity buildings (class XC1) and is not suitable for the construction of buried building foundations and external building superstructure members. Portland-limestone cement grade 42.5 is only suitable for the construction of superstructure members in exposure classes XC1 and XC2 (building superstructure members subject to long-term water contact) and building foundations buried in non-aggressive natural soils and groundwater. Both cement grades 32.5 and 42.5 are not suitable for the construction of building external superstructure members sheltered from/exposed to rain and subject to high humidity (class XC3) and/or cyclic wet and dry condition (class XC4). Both cement grades are also not suitable for the construction of building

foundations buried in aggressive natural soils and groundwater (exposure classes XA1, XA2 and XA3), and building superstructure members in industrial and coastal areas with airborne, waterborne and/or seawater-borne chlorides (exposure classes XD1, XD2, XD3 and XS1).

Keywords

Building structural members; Concrete durability; Concrete strength class; exposure classes; Nigerian Portland-limestone cement strength class

Introduction

Building concrete structural members can be classified as plain, lightly reinforced, reinforced and pre-stressed concrete structural members [1]. Plain concrete structural members are generally concrete structural members without reinforcement, while lightly reinforced concrete structural members are concrete structural members with reinforcements that are less than the minimum amounts of reinforcement required for reinforced concrete structural members [1]. However, plain concrete structural members also do have steel reinforcement needed to satisfy serviceability and/or durability requirements [1]. Examples of plain and lightly reinforced concrete structural members are members such as walls, columns, and arches that are mainly subjected to compression other than that due to pre-stressing [1]. Other plain and lightly reinforced concrete structural members include strip and pad footings for foundations and retaining walls [1].

The compressive strength of concrete used for the design/construction of building concrete structural elements is governed by the structural/strength and durability requirements. The durability requirement is given a priority where the concrete strength required for durability purposes is higher than that required for structural design [1, 2]. The higher durability strength requirement is meant to prevent the corrosion/degradation of both concrete and reinforcement bars which occurs by a chemical attack on the concrete by substances in the environment (such as liquids stored in the building, carbon dioxides in the air, air-borne and seawater-waterborne chlorides); and by physical attack due to temperature change, abrasion and water penetration [1-3]. The corrosion/degradation of concrete weakens the concrete and makes it more pervious for water and other aggressive substances, leading to

the corrosion of the reinforcement bars and eventual weakening of the building reinforced concrete structural members which could lead to the failure of buildings [4].

In Nigeria, Portland-limestone cement grades 32.5 and 42.5 are used for the construction of building structural members in all exposures conditions/classes without any consideration for the durability concrete strength requirements for the various exposure conditions/classes by the craftsmen who construct about 70% of buildings in Nigeria [5]. Consequently, it is a common occurrence in Nigeria to see cracking/spalling of building structural concrete members due to the expansion of the corroded reinforcement bars, an indication of the weakening of the buildings, which could be responsible for the incessant failure of buildings in service in Nigeria. A typical case is the collapse of an approximately ten years old 5-storey building with a Pent-house located at 11 Aderibigbe Street, Maryland, Lagos, Nigeria on 26 October 2011 [6]. Failure investigation conducted by the Nigerian Building and Road Research Institute (NBRRI) [6], revealed that the occupants of the collapsed building had noticed cracks on the building and reported their observations to their Landlord, who did nothing before the building collapsed.

The durability concrete compressive strength class/grade requirements depend on the exposure class, which depends on the ambient environmental conditions of the building concrete structural members [1, 7]. Building plain concrete structural members in all exposures conditions except where there is freeze/thaw, abrasion or chemical attack is classified as being in exposure class X0. Lightly reinforced and reinforced concrete structural members are classified as being in exposure class X0 when the members are in a very dry environment [1]. Exposure class X0 represents the least aggressive exposure condition and can mainly be found inside buildings with very low air humidity (less than about 35%) and in a very dry environment. Exposure class X0 is rarely found in practice, thus, in most practical situations, both the building plain concrete and lightly reinforced concrete structural members are recommended to be classified as being in exposure class XC1, which exists naturally [8].

In most practical situations, building plain concrete, lightly reinforced concrete and reinforced concrete members are at a risk of corrosion by carbonation because they are exposed to the air and moisture. In the practical situations where corrosion of concrete is due to carbonation alone, exposure classes are classified into XC1, XC2, XC3 and XC4 [1]. XC1 represents a dry or permanently wet exposure condition. Building concrete structural members in this exposure class are internal beams, columns, walls and slabs that are inside

buildings with low air humidity (i.e. buildings with well ventilated rooms) and/or concrete structural members that are permanently submerged in non-aggressive water [1, 7]. XC2 represents a wet and rarely dry exposure condition. Building concrete structural members in this exposure class are beams, columns, walls and slabs whose surfaces are subjected to long-term water contact and buried reinforced concrete foundations in a non aggressive soil and/or groundwater chemical environment [1, 7]. XC3 represents a moderately humid exposure condition. Building concrete structural members in this exposure class are internal beams, columns, walls and slabs that are inside buildings with moderate or high air humidity and external beams, slabs, walls and columns sheltered from or exposed to direct rain in a moderate or high air humidity and structural members (beams, columns) beneath waterproofing [1, 7]. XC4 represents a cyclic wet and dry condition. Building reinforced structural members in this exposure class, are external beams, walls, slabs and columns with surfaces sheltered from, or exposed to direct rain which subjects their surfaces to cyclic wet and dry conditions (i.e. wetting by rain, drying up and wetting by rain cycles).

Where building reinforced concrete structural members are at a risk of corrosion by air-borne and/or water-borne chlorides, the exposure conditions are classified as: XD1, XD2 and XD3. XD1 represents a moderately humidity condition with air-borne chlorides. XD2 represents a wet, rarely dry condition with water-borne chlorides, such as obtainable in swimming pools and in industrial areas where concrete surfaces are in contact with waters containing chlorides. XD3 represents a cyclic wet and dry condition containing air-borne chlorides (hydrogen chloride from the burning of fossil fuel by vehicles on the carriageway), an exposure condition obtainable in reinforced structural members within 10m of a carriageway) [1]. Building reinforced concrete structural members near to, or on the coast are susceptible to degradation/corrosion induced by chloride from seawater. The least aggressive near-coast or coastal exposure condition is XS1, which represent an exposure condition in which the building reinforced concrete structural members are exposed to airborne salt but not in direct contact with sea water [1].

Building reinforced concrete structural members in contact with or buried in soils such as foundations and basement retaining walls are susceptible to chemical attacks. The chemical environments of the natural soils and ground water are classified as XA1, XA2 and XA3, which represent slightly aggressive, moderately aggressive and highly aggressive natural soils and ground water chemical environments respectively with groundwater pH of 2.5 to over 5.5 [1].

On the basis of the various exposure classes specified in [1] and [7], the various exposure classes building obtainable in Nigeria are as follows: Building concrete superstructure members in Nigeria exist in environments where corrosion induced by: carbonation (exposure classes XC1 to XC4); airborne and waterborne chloride (exposure classes XD1, XD2 and XD3 in chloride releasing industries such as bleach, chloride salts, fertilizers, dyes, textiles industries); and chloride in seawater (XS1 in coastal areas). However, in Nigeria, most building internal concrete structural members (slabs, beams, columns, and walls) exist in exposure class XC3, a moderately humid exposure condition; while most building external concrete structural members exist in the exposure class XC4, especially during rainy season when they are subjected to cyclic wet and dry conditions. Building reinforced concrete foundations in Nigeria also exist in natural soil and groundwater with chemical environment classes XA1, XA2 and XA3, as the pH values of groundwater reported by various authors [8-12] for various regions of Nigeria which ranges from 5.5 to 8.3 is within the 2.5 to more than 5.5 specified for the XA1, XA2 and XA3 natural soil and groundwater exposure classes.

For structural requirements, C16/20 is the minimum/lowest concrete grade/strength class recommended for the construction of building plain concrete structural members [13]. However, for durability requirements to prevent damage and corrosion of concrete, concrete grade/strength class C20/25 is the minimum/lowest concrete grade recommended for the construction of building plain and lightly reinforced concrete structural members in the least aggressive practical/obtainable exposure condition, exposure class XC1 [1]. The minimum/lowest concrete strength class to be used for the construction of building reinforced concrete structural members in exposure conditions XC1 and XC2 are concrete classes C20/25 and C25/30 respectively. The minimum/lowest concrete strength class required for the construction of building reinforced concrete structural members in exposure conditions: XC3, XC4, XD1, XD2, XS1, XA1 and XA2; and XA3 are C30/37 and C35/45 respectively. The minimum cylinder compressive strengths for C20/25, C25/30 C30/37 and C35/45 concretes are 20MPa, 25Mpa, 30Mpa and 35MPa respectively, while their minimum cube compressive strengths are 20MPa, 25Mpa, 30Mpa, 37MPa and 45MPa respectively [1].

In Nigeria, Portland-limestone cement grades 32.5 and 42.5 are used for the construction of building concrete structural members: slabs, beams, columns, basement walls, and foundations in all exposure classes obtainable in Nigeria [5]. This is due to the fact that

most Nigerians, particularly, the roadside craftsmen who construct most of the privately owned buildings, which is about 70% of the buildings in Nigeria are neither aware of the different grades of cement and their areas of applications; nor the need to use different concrete grades/classes for different exposure conditions/classes [5]. This explains why in the work of [14-16] amongst others, the grade/strength class of the cement they used for their work on concrete was not stated. The lack of awareness of the different grades of cement in the Nigerian open market is due to the inadequate public enlightenment by the Standards organization of Nigeria, the agency in charge of standardization and quality assurance of cement in Nigeria. This work is aimed at the establishing the suitability of the Nigerian Portland-limestone cement grades 32.5 and 42.5 for use in the construction of building plain and reinforced concrete structural members in the various exposure conditions obtainable in Nigeria.

Material and method

The concrete cubes were produced with 20mm crushed granites and river sand (generally known as sharp sand in Nigeria) that are commonly used for the construction of building concrete structural members in Nigeria. Sieve analysis was conducted to determine the gradation of the river sand. Ten 150×150×150mm 1:2:4, 1:1.5:3 and 1:1:2 concrete cubes each batched by weight with 0.5 water cement ratio were moulded with Portland-limestone cement grades 32.5 and 42.5 in accordance with [17]. The concrete cubes were cured for 28 days and subjected to compressive strength testing. The algorithm of the experimental procedure is as follows:

River sand ⟶ Sieve analysis ⟶ well graded sand + Cement + 20mm size granite + water batched by weight ⟶ cast into 150x150x150mm 1:2:4, 1:1.5:3 and 1:1:2 concrete cubes ⟶ left for 24 hours ⟶ cured for 28 days ⟶ subjected to compressive strength test.

The investigation of the suitability of the Nigerian Portland-limestone cement grades 32.5 and 42.5 for use in the construction of building plain and reinforced concrete structural members in the various exposure conditions obtainable in Nigeria was conducted by comparing the cube compressive strengths of 1:2:4, 1:1.5:3 and 1:1:2 concrete produced with Portland-limestone cement grades 32.5 and 42.5 with the minimum durability concrete

compressive strength requirements for building concrete structural members in various exposure conditions/classes that are obtainable in Nigeria.

Results and discussions

Figure 1 shows the particle size distribution curve for the river sand. The average compressive strengths for the 1:2:4, 1:1.5:3 and 1:1:2 concrete cubes produced with Portland-limestone cement grades 32.5 and 42.5 are presented in Table 1.

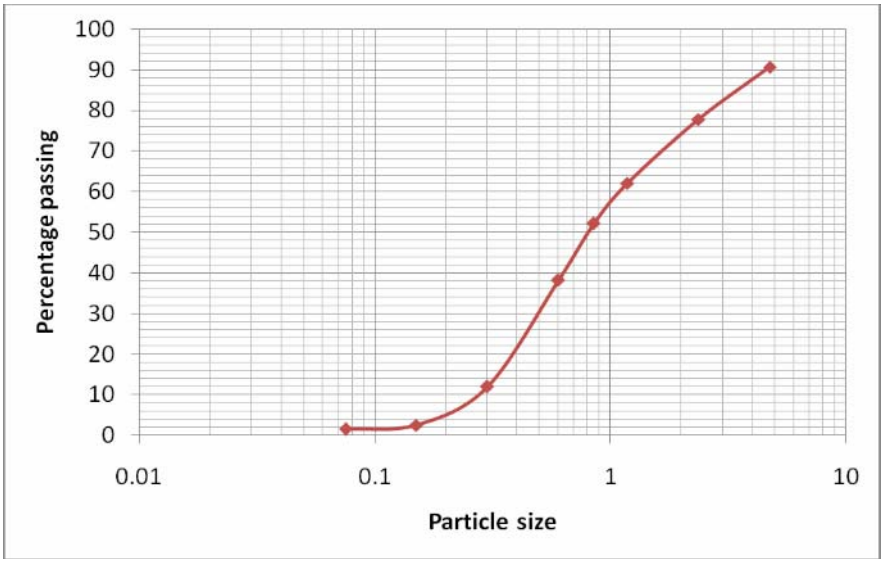

Figure 1. *Fine aggregate particle size distribution curve*

Table 1. 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

The distribution curve of the particle size for the river sand used for this work shown in Figure 1 demonstrates that the sand is well graded. From Table 1, the average compressive strength of 24.5Mpa for the 1:2:4 concrete cubes molded with cement grade 32.5 compares well with the 23.8MPa reported by [11]. From Table 1, the 24.5MPa cube compressive strength of the 1:2:4 concrete produced with the Portland-limestone cement grade 32.5 is approximately equal to the 25MPa minimum cube compressive strength required for the

construction of building concrete beams, columns, walls and slabs in exposure class XC1 (members permanently submerged in non-aggressive water and/or inside well ventilated buildings with low air humidity). This result demonstrates that the concrete produced with Portland-limestone cement grade 32.5 using the 1:2:4 concrete mix ratio which is the commonly used concrete mix ratio in Nigeria is only suitable for the construction of building internal beams, columns, walls and slabs that are inside well ventilated buildings with low air humidity and building concrete structural members that are permanently submerged in non-aggressive water. The result also demonstrates that the 1:2:4 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of building beams, columns, slabs and walls that are in a permanently wet and rarely dried condition (XC2), building external beams, columns, slabs and walls that are exposed to, or sheltered from rain (XC3 and XC4) with a minimum durability concrete cube strength requirements of 30MPa (for XC2) and 37MPa (for XC3 and XC4). The result also demonstrates that the 1:2:4 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of buried building foundations that are buried in soils, be it nonaggressive (XC2), slightly aggressive (XA1), moderately aggressive (XA2) or highly aggressive (XA3) natural soils and groundwater with minimum durability concrete cube strength requirements of 30MPa, 37MPa, 37Mpa and 45MPa respectively.

The 27MPa cube compressive strength of the 1:1.5:3 concrete produced with Portland-limestone cement grade 32.5 is less than the 30MPa minimum cube compressive strengths required for the construction of building external beams, columns, slabs, walls and buried building foundations. This result demonstrates that the 1:1.5:3 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of building beams, columns, slabs and walls that are in a permanently wet and rarely dried condition (XC2), and those exposed to or sheltered from rain (XC3 and XC4) with a minimum durability concrete cube strength requirements of 30MPa (for XC2) and 37MPa (for XC3 and XC4). The result also demonstrates that the 1:1.5:3 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of buried building foundations that are buried in nonaggressive (XC2), slightly aggressive (XA1), moderately aggressive (XA2) or highly aggressive (XA3) natural soils and groundwater with minimum durability concrete cube strength requirements of 30MPa, 37MPa, 37Mpa and 45MPa respectively.

The 29.6MPa (≈30MPa) cube compressive strength of the 1:1:2 concrete produced

with Portland-limestone cement grade 32.5 is approximately equal to the 30MPa minimum cube compressive strengths required for the construction of building beams, columns, slabs and walls in a permanently wet and rarely dried exposure condition (XC2). However, the 29.6MPa(≈ 30MPa) cube compressive strength of the 1:1:2 concrete produced with Portland-limestone cement grade 32.5 is less than the 37MPa minimum cube compressive strength required for building external beams, columns, slabs and walls that are exposed to or sheltered from rain (XC3 and XC4) as well as building foundations in XA1, XA2 and XA3 exposure classes. This result demonstrates that the 1:1.5:3 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of building external beams, columns, slabs and walls that are exposed to or sheltered from rain with a minimum durability concrete strength requirements of 37MPa (for exposure classes XC3 and XC4). The result also demonstrates that the 1:1.5:3 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of building foundations that are buried in slightly aggressive (XA1), moderately aggressive (XA2) or highly aggressive (XA3) natural soils and groundwater with minimum durability concrete strength requirements of 37MPa, 37Mpa and 45MPa respectively.

From Table 1, the 29.8MPa(≈30MPa), 30.1MPa(≈30MPa), and 30.6MPa (≈ 31MPa) cube compressive strengths of the 1:2:4, 1:1.5:3, and 1:1:2 concretes produced with the Portland-limestone cement grade 42.5 are more than the 25MPa and the 30MPa minimum cube compressive strengths required for the construction of building concrete beams, columns, walls and slabs in exposure classes XC1 and XC2 respectively. This result demonstrates that the concrete produced with Portland-limestone cement grade 42.5 using the 1:2:4 concrete mix ratio which is the commonly used concrete mix ratio in Nigeria is only suitable for the construction of building internal beams, columns, walls and slabs that: are inside well ventilated buildings with low air humidity (XC1); and/or are permanently submerged in non-aggressive water (XC2). The results also demonstrate that the 1:2:4, 1:1.5:3 and 1:1:2 concretes produced with Portland-limestone cement grade 42.5 are only suitable for the construction of building foundations in a nonaggressive natural soils and groundwater (exposure class XC2) with a minimum durability concrete strength requirements of 30MPa.

The result also demonstrates that the 1:2:4 concrete produced with Portland-limestone cement grade 42.5 is not suitable for the construction of building external beams, columns, slabs and walls that are exposed to or sheltered from rain (XC3 and XC4) with a minimum

durability concrete strength requirements of 37MPa. The 1:2:4, 1:1.5:3 and 1:1:2 concretes produced with Portland-limestone cement grade 42.5 are also not suitable for the construction of building foundations that are buried in slightly aggressive (XA1), moderately aggressive(XA2) and highly aggressive (XA3) natural soils and groundwater with a minimum durability concrete strength requirements of 37MPa and 45MPa respectively.

From Table 1, the cube compressive strengths of the 1:2:4, 1:1.5:3, and 1:1:2 concretes produced with the Portland-limestone cement grades 32.5 and 42.5 are all less than the 37MPa and 45MPa durability minimum cube compressive strength requirements for building structural members in environment with airborne, waterborne and/or seawater-borne chlorides (exposure classes XD1, XD2 and XD3). These results demonstrate that both Nigerian Portland-limestone cement grades 32.5 and 42.5 are not suitable for the construction of buildings structural members in industrial and coastal areas (such as bar beach areas in Lagos) with airborne, waterborne and/or seawater-borne chlorides.

In this work, the suitability of the Nigerian Portland-limestone cement grades 32.5 and 42.5 for the construction of building structural members in various exposure conditions is investigated. The study identified Eurocode 2 classified exposure classes XC1, XC2, XC3, XC4, XD1, XD2, XD3 and XS1 as the commonly obtainable building concrete superstructure members exposure conditions and identified Eurocode 2 classified exposure classes XC2, XA1, XA2 and XA3 as the commonly obtainable foundations exposure conditions/classes in Nigeria.

The study revealed the following: The concrete produced with Portland-limestone cement grade 32.5 using the 1:2:4 concrete mix ratio which is the commonly used concrete mix ratio in Nigeria is only suitable for the construction of building internal beams, columns, walls and slabs that are inside well ventilated buildings with low air humidity and building concrete structural members that are permanently submerged in non-aggressive water (exposure class XC1). The 1:2:4 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of building beams, columns, slabs and walls that are in a permanently wet and rarely dried condition (exposure class XC2), and building external beams, columns, slabs and walls that are exposed to, or sheltered from rain (exposure classes XC3 and XC4) with a minimum durability concrete strength requirements of 30MPa (for XC2) and 37MPa (for XC3 and XC4). The result also demonstrates that the 1:2:4 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of

buried building foundations that are buried in soils, be it nonaggressive (XC2), slightly aggressive (XA1), moderately aggressive (XA2) or highly aggressive (XA3) natural soils and groundwater with minimum durability concrete strength requirements of 30MPa, 37MPa, 37Mpa and 45MPa respectively.

The 1:1.5:3 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of building beams, columns, slabs and walls that are in a permanently wet and rarely dried condition (XC2), and building external beams, columns, slabs and walls that are exposed to or sheltered from rain (XC3 and XC4) with a minimum durability concrete strength requirements of 30MPa (for XC2) and 37MPa (for XC3 and XC4). The 1:1.5:3 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of buried building foundations that are buried in nonaggressive (XC2), slightly aggressive (XA1), moderately aggressive (XA2) or highly aggressive (XA3) natural soils and groundwater with minimum durability concrete strength requirements of 30MPa, 37MPa, 37Mpa and 45MPa respectively. The 1:1.5:3 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of building external beams, columns, slabs and walls that are exposed to or sheltered from rain with a minimum durability concrete strength requirements of 37MPa (for exposure classes XC3 and XC4). The result also demonstrates that the 1:1.5:3 concrete produced with Portland-limestone cement grade 32.5 is not suitable for the construction of building foundations that are buried in slightly aggressive (XA1), moderately aggressive (XA2) or highly aggressive (XA3) natural soils and groundwater with minimum durability concrete strength requirements of 37MPa, 37Mpa and 45MPa respectively.

The concrete produced with Portland-limestone cement grade 42.5 using the 1:2:4 concrete mix ratio which is the commonly used concrete mix ratio in Nigeria is only suitable for the construction of building internal beams, columns, walls and slabs that: are inside well ventilated buildings with low air humidity (XC1); and/or are permanently submerged in non-aggressive water (XC2). The 1:2:4, 1:1.5:3 and 1:1:2 concretes produced with Portland-limestone cement grade 42.5 are only suitable for the construction of building foundations in a nonaggressive natural soils and groundwater (exposure class XC2) with a minimum durability concrete strength requirement of 30MPa. The 1:2:4 concrete produced with Portland-limestone cement grade 42.5 is not suitable for the construction of building external beams, columns, slabs and walls that are exposed to or sheltered from rain (XC3 and XC4)

with a minimum durability concrete strength requirements of 37MPa. The 1:2:4, 1:1.5:3 and 1:1:2 concretes produced with Portland-limestone cement grade 42.5 are also not suitable for the construction of building foundations that are buried in slightly aggressive (XA1), moderately aggressive(XA2) and highly aggressive natural soils and groundwater with a minimum durability concrete strength requirements of 37MPa and 45MPa respectively. These results demonstrate that both Nigerian Portland-limestone cement grades 32.5 and 42.5 are not suitable for the construction of buildings structural members in industrial and coastal areas with airborne, waterborne and/or seawater-borne chlorides (exposure classes XD1, XD2 and XD3).

Recommendations

The Standards Organisation of Nigeria (SON) should create effective grassroots awareness for all Nigerians, particularly, the homeowners and roadside craftsmen who construct most of the privately owned buildings in Nigeria that:

(a) The compressive strength of concrete used for the design/construction of building concrete structural elements is governed by the structural/strength and durability requirements, and the durability concrete strength requirements shall be given a priority where the concrete strength required for durability purposes is higher than that required for structural design.

(b) For durability purposes, the concrete strength to be used for the construction of various building structural concrete elements such as beams, slabs, columns and walls depends on the exposure conditions and the concrete to be used shall meet the durability concrete strength requirements for the appropriate exposure classes.

(c) If Portland limestone cement grade 32.5 is to be used for any structural applications, such as for the construction of building reinforced concrete superstructure members (slabs, beams, walls, columns) and foundations, then, 1:1:2 concrete mix ratio which is richer than the commonly used 1:2:4 mix ratio should be used. However, using 1:1:2 mix ratios is expensive as it requires more cement, consequently, it is advisable not to use Portland limestone cement grade 32.5 for the construction of building structural members to satisfy the durability concrete strength requirements.

(d) Only Portland limestone cement grade 42.5 or the newly introduced grade 52.5 shall be

used for structural application, such as for the construction of building reinforced concrete superstructure members (slabs, beams, walls, columns) and foundations to satisfy the durability concrete strength requirements in the identified aggressive exposure classes.

(e) Concrete mix ratio of 1:1.5:3 or richer concrete mixes should be used for the construction of building foundations.

(f) Concrete mix ratio of 1:1.5:3 or richer concrete mixes should be used for the construction of building external reinforced concrete superstructure members (slabs, beams, walls, columns) that are exposed to rain, and cyclic dry and wet conditions.

(g) The information on the suitability and the minimum mix ratios for the various structural elements in various exposure conditions should be on the cement bags in English and in the major Nigerian languages.

(h) The production of grade 52.5 cement should be mandated since the compressive strengths of concrete produced with the Portland limestone cement grades 32.5 and 42.5 at the economical and commonly used mix ratios of 1:1.5:3 or 1:2:4 respectively are less than the 37MPa and 45MPa minimum cube compressive strengths required for:

(i) foundations that are buried in moderately aggressive (XA2) and highly aggressive(XA3) natural soils and groundwater;

(ii) building superstructure members exposed to, or sheltered from rain with cyclic wet and dry conditions (exposure classes XC3 and XC4);

(iii) building superstructure members in industrial and coastal areas with airborne, waterborne and/or seawater-borne chlorides (exposure classes XD1, XD2 and XD3);

(iv) If Portland limestone cement grade 32.5 cannot be phased out in Nigeria as it has been phased out in many developed countries and India, then, the Standards Organisation of Nigeria (SON) should encourage/ensure that more of Portland limestone cement grades 42.5 and 52.5, which are suitable for both structural and non-structural applications in all exposure classes obtainable in Nigeria are produced and made available in the open market instead of selective production of high strength cement for multinationals.

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