International Journal of Civil Engineering and Technology (IJCIET)
Volume 8, Issue 8, August 2017, pp. 561–571, Article ID: IJCIET_08_08_057
Available online at http://http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=8&IType=8
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

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EFFECT OF CURING TECHNIQUE ON DEVELOPMENT OF HIGH STRENGTH CONCRETE FROM 10MM (3/8) LOCALLY OCCURRING GRAVEL AGGREGATE MATERIALS

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ABSTRACT

This paper reports an effort in achieving high strength concrete from locally occurring 10 mm (3/8") coarse sand abundantly occurring in the Niger Delta Region of Nigeria Several trials mixes were carried out to arrive at different concrete mixes meeting standard requirements for high strength concrete a mix of 1:1.6:2.9 at water-binder content of 0.23 and superplasticizer content of 7.5 liters per cubic metres of concrete adopted in the study. Three curing techniques were adopted: curing in water, curing in moist sand and in curing under thick cellophane membrane. The results are from the laboratory tests on the wet, dry and hardened concrete cubes yielded average values of compressive strength of 80.2N/mm^2, density 2974kg/m^3 and water absorption of 0.03 % after 28 days duration of curing. The results confirm that the developed concrete mix with locally occurring 10 mm (3/8") all-in gravel aggregates represents ultradense high strength concrete with high strength development and minimum porosity. The use of the developed concrete mix in structural applications will lead to value addition to local resources, job creation and economic empowerment.

Key words: high strength concrete and locally occurring oil -in- one gravel aggregate.

Cite this Article: Ephraim M.E and ThankGod O, Effect of Curing Technique on Development of High Strength Concrete from 10mm (3/8) Locally Occurring Gravel Aggregate Materials. *International Journal of Civil Engineering and Technology,* 8(8), 2017, pp. 561–571.
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=8

1. INTRODUCTION

The issue of access to decent and affordable housing is one of the Millennium Development Goals and consequently a major policy thrust in development plans worldwide. Current statistics presented in the Abuja declaration: 7b priorities adopted at UNHABITAT Africa regional conferences held in Abuja, Nigeria on 24 February 2016, revealed that Nigeria has a housing deficit of about 17 million housing units. The major challenges identified at the workshop included the ever increasing high cost of basic construction materials and technology. To address these challenges, calls were made for researches to be embarked upon for identification and development of alternative construction materials to cushion the effect of importation especially in the face present economic realities.

In addition to affordability, modern concrete is expected to satisfy other technical and functional requirements such as high strength, corrosion resistance and enhance thermal insulation and energy efficiency. Concrete remains the most widely used construction material, accounting for about fifty percent of the total built facilities. Concrete basically comprises cement, aggregates, water and admixtures. Thus normal concrete represents a three-phase composite material containing the mortar phase, mortal/aggregates interface and the coarse aggregate phase. The coarse aggregates in normal concrete are mainly from rock fragments characterized by high strength. The strength of the concrete at the interfacial zone essentially depends on the integrity of the cement paste and the nature of the coarse aggregate. The presence of the aggregates size greater than 10 mm predominantly affects the homogeneity and strength development of the concrete. Thus, normal concrete in its basic state is weak on account of the presence of a weak interfacial zone; its failure is manifested in the initiation, development and growth of cracks principally around the cement paste or at the aggregate/cement paste interfacial zone.

The modern strategy for cost savings in concrete construction is the application of high strength concrete which has numerous advantages including, high strength leading to reduced section and dead load; high modulus of elasticity resulting in increased stiffness and longer span as well as reduced creep and shrinkage and associated improved durability among others. The FIP/CIB (1990) state-of-the- art report defines high strength concrete as concrete having a 28-day cylinder compressive strength of 60 MPa and above, Mohammad and Mohammad (2009). Further concluded that in the production of high strength as high as 127MPa, besides the basic requirement in terms of combination of using OPC within the range of (480 – 610kg/m^3) as natural aggregates, use of lower water-binder ratio (0.22-0.29) and superplasticizer is considered along with admixtures as a most vital factor for the production of HSC. The structural properties of high strength high performance concrete based on granite chippings have been reported in numerous works, including Journal of Civil Engineering (IEB) 2009, Russell (1999), and Bickley and Mitchell (2001) and Aitcin, (1998). In recent years, ultra high strength concrete (UHSC), known also as reactive powder concrete (RPC) has been developed with a compressive strength greater than 150 MPa (21,750 psi).

The development of high strength high performance concrete is based on the discovery of a highly ordered crystal nanostructure of amorphous C-S-H gel of concrete internal structure. Among new nanoengineered polymers are highly efficient superplasticizer for concrete and high-strength fibers with exceptional energy absorbing capacity. Nanoparticles, such as silica and fly ash, are effective additives to polymers and concrete and represent the principal technology for achieving high-strength high-performance and self-compacting concrete with improved strength, workability and energy efficiency. However, normal and special materials as well as mixing and curing techniques are used to make and handle these specially designed concretes that must meet a combination of performance requirements. The varieties of methods of producing HSC are summarized in Carrasquillo (1985) and Nagataki and Sakai (1994).

The application of nanaotechnology to concrete is in its primitive stage. It is expected that a better understanding and precise engineering of an extremely complex structure of cement-based materials at the nanolevel will apparently result in a new generation of concrete that is stronger and more durable, with desired stress—strain behavior and possibly possessing a range of newly introduced properties, such as electrical conductivity as well as temperature-, moisture- and stress-sensing abilities Nanobinders or nanoengineered cement based materials with a nanosized cementitious component or other nanosized particles may be the next ground-breaking development.

From the above, it can be seen that aggregate combinations of sand and granite chippings of maximum size of 10 mm has been the most commonly used fractions in high strength concrete. Therefore, in order to further reduce the cost of concrete, there is a serious need to develop cheaper local alternatives for cement and aggregates for incorporation into the high strength concrete system. In addition to granite, basalt chippings and fine river sand, there are other local aggregates used in construction practice in Nigeria. These include of 10 mm (3/8”) coarse sand and laterite rock aggregates. The continued application of 10 mm (3/8”) coarse sand abundantly occurring in the Niger Delta region of Nigeria without adequate documentation of its properties had been recognized in previous studies of Ephraim and ThankGod (2006). On the basis of these studies, some typical mixes with optimum water—cement ratios were recommended for application in mass concrete as well as structural concrete of grades not exceeding 25 N/mm2, particularly design mix of 1:11/2:3 (1:4.5 or 1:1.6:2.9) with cement content of 300kg/m3 and water cement ratio of 0.50. This paper therefore reports an effort in achieving high strength concrete from local 10 mm (3/8”) coarse sand in its natural state abundantly occurring in the Niger Delta Region of Nigeria without the use of granite chippings. The choice of this material is further justified by various recommendations in literature that aggregates for use in the production of high strength should have a maximum size of 8-10mm [1,2,3,4].

2. MATERIAL AND METHODS

The study comprised concrete mix design where the mix proportions for the target strength and quantities of materials determined. The materials included ordinary Portland cement, 10 mm (3/8”) all-in gravel aggregate, water, fly ash, micro silica and superplasticizer. The materials were selected in accordance with ACT 211 .4R-08 (2008) and the following British Standards: aggregates to BS 882 (1992) cement to BS 12 (1996), water to BS 3148 (1980) and admixtures to BS 5075(1982)

2.1. Experimental Plan

Table 1 Experimental program

S/N	Mix	Water-Cement Ratio	Water-Binder Ratio	Superplasticizer Auracast (A200)
1.compressive strength	1:1.6:2.9	0.34	0.23	7.5Litres/m^3

Table 2 Experimental program

F_{cu} (N/mm^2) wet curing (Days)				Wet sand curing Control 150cl of water f_{cu} (N/mm^2)				Dry Curing Strength Rapped with cellophane f_{cu} (N/mmm^2)			
7	14	21	28	7	14	21	28	7	14	21	28
3	3	3	3	3	3	3	3	3	3	3	3
48 cubes											

3. EXPERIMENTAL PROCEDURES

Several trial mixes were carried out to arrive at different concrete mixes meeting standard requirements for high strength concrete and a mix of 1:1.6:2.9 at water-binder content of 0.23 and superplasticizer content of 7.5 liters per cubic metre of concrete was adopted in the study. A total of forty-eight 150 x 150 x 150mm British standard cubes were produced from the adopted mix and subjected to compressive strength tests at ages of 3, 7, 14, 21and 28 days duration of curing. Other tests included particle size distribution, slump workability and water absorption tests. Mixing of fresh concrete was done using the electric pan concrete mixer.

Three curing techniques were adopted, namely: curing in water, curing in wet sand and curing of specimens wrapped in thick cellophane membrane.

All tests were conducted in the Civil Engineering Laboratory in the Rivers State University, Port Harcourt, Nigeria and in accordance with the relevant international standards. The process of casting and curing are depicted in plates 1.

Plate 1 (a) Freshly Cast samples

Plate 1 (b) Wet curing (WC)

Plate 1 (c) Wet sand curing (WSC)

Plate 1 (d) Cellophane curing (CC)

Figure 1

4. ANALYSIS AND DISCUSSION OF RESULTS

The preliminary results of the cube tested on the adopted mix are presented in this section . Results and discussion are presented in tables including plates and graphical representation values for compressive strength, average water absorption and density of all in one gravel aggregate concrete are presented in various subheads below;

4.1. Particle Size Distribution of 10 mm (3/8") all-in Gravel Aggregate

The particle size distribution test results for the washed 10mm (3/8) all —in gravel are in table 1 below

Table 1 Total weight of sample taken for dry grading-985g

Sieve Size	Mass Retained	Total Mass retained	Total mass passing	Total percentage passing
14mm			985.00	100.00
10mm	16.85	16.85	968..15	98.29
6.3mm	152.25	169.10	815.90	82.83
5mm	204.55	373.65	611.35	62.06
2.362mm	211.25	584.90	400.10	40.61
1.18mm	109.25	694.15	290.85	29.53
600 micron	142.35	836.50	148.50	15.08
300 micron	104.75	941.25	43.75	4.44
150 micron	37.15	978.40	6.60	0.67
63 micron	6.60	985.00	-	
Total				

From table 1, it can be seen that the washed aggregates, the material consists of 2% of fine, 26% of medium and 72% coarse sand fractions. The proportional ratio of the fine to coarse is 1:3, The BS882 (1992) delineates four zones of sand for the production of structural concrete. The plots show that 10mm washed gravel plot outside the grading limits or enveloped for zone A, representing coarse sand. The uniformity coefficient C_U averaged 8.4 while the coefficient of curvature C_U had the value of 1.0. The material is well graded [C_U> 4.0] and uniform [C_U> 1.0). This resulted in a designed mix proportion of 1:1.6:2.9 in its natural state, compared to the reference concrete mix of 1:1.6:2.9 based on Ephraim and Ode (2006).

4.2. Workability of Fresh Concrete

Aggregate size, shape, texture and grading significantly influence concrete workability. Irregularly shaped and poorly graded aggregates typically have a lower packing density than well graded aggregate, resulting in more paste being required to fill the voids between aggregates. As the excess volume of paste needed to fill the voids is reduced, the mobility of the paste must be increased to maintain a given workability level. The all- in gravel aggregate in its natural state is poorly shaped and graded and as such exhibits increased inter particles variation which results in reducing workability with higher water and cementitious material requirement. The proper selection of aggregates or good aggregate combination can minimize the additional water and cementitious material content needed to ensure adequate workability. The concrete yielded l5omm-l8Omm sheared slump in its fresh state. Against the control mix use by Ephraim and Ode (2006) of water cement ratio of 0.35 that gives zero slump, dry concrete mix. This change was a result of introduction of Auracast 200 superplasticizer of 7.5Liter/ M^3 to the Mix. The workability of the concrete is unique, plastic in fresh state and mobile and self compacting. The process of slump test is shown in Plate 2.

Figure 2 Plate 2 Slump workability Tests process

There was no segregation / bleeding of concrete from the mortar/aggregate. The fresh characteristics of the concrete give an indication of high strength concrete.

It is expected that further investigations into trial mixes with of 6.5 and 5.5 litres of superplasticizer content would lead to reduced slump of this concrete and even better strength properties.

4.3. Compressive Strength of 10mm (3/8") of all-in Gravel Concrete

Plate 1 shows three different type of curing. It was observed for wet curing method (WC) that the material exhibited rapid increase in strength to about 78 N/mm^2. About 96 percent of the 28-day strength was achieved after 14 days of wet curing after which no appreciable growth in strength was observed. In the case of curing in moist sand, a gradual strength development was observed to the age of2l days at which the concrete achieved about 94 percent of its 28-day strength of 80.2 N/mm2. The curing in cellophane bags presented an interesting phenomenon, characterized by formation of vapour and water trapped in the cellophane bag which gradually disappeared in the course of hydration. The 28-day strength had the least value of 70 N/mm2. However, the strength development was most rapid with the specimen attaining about 70 and 91 percent of the 28-day strength at the age of 3 and 14 days respectively followed by a slight drop. The maximum strength of about 75 N/mm2 was recorded after 21 days of dry curing under thick membrane.

Table 2 Compressive Strength of all in 10 mm 3I8' gravel aggregate concrete methods for various curing

Type of Curing		Average values of compressive strength in N/mm^2 for various duration of curing			
		7 days	14 days	21 days	28 days
WSC	Wet Sand Curing	36.4	50.7	75.1	80.2
WC	Wet Curing	36	74.6	76	78
CC	Dry Curing in Cellophane bag	64	72	75	70

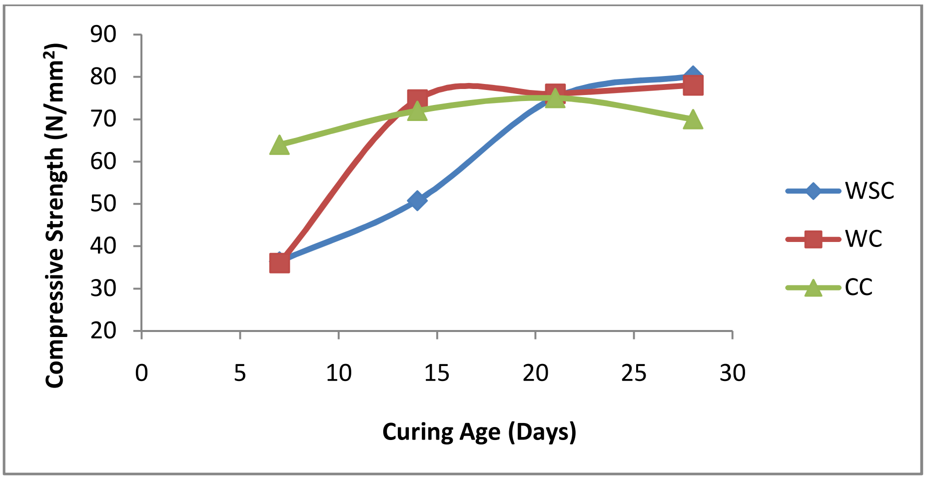

Figure 3 Variation of Compressive strength various duration and type of curing

The compressive strength of concrete depends on the water-cement ratio, cement/binder-aggregate ratio, degree of compaction, bond between mortar and aggregate as well as grading, shape, strength and size of the aggregates. The study has shown a tremendous strength development from 25 N/mm2 reported in Ephraim and ThankGod (2006) to 80.2N/mm2. The addition of 9% and 23% silica fumes and steel slag respectively to 10 mm (3/8") all-in gravel concrete mix at 0.23 water/binder ratio resulted to a tremendous increase in compressive strength up to 80.2 N/mm2 after 28 days wet curing. These results are in agreement with findings from previous studies on high strength concrete based on crushed granite, sand and cement enhancers such as microsilica and steel slag [1, 2, 3, 4, 5, 6, and 7]. The strength development for the concrete does not follow a steady growth, rather zig-zag growth that called for proper aggregate combination technique in further works to be carried out. This can be seen in the heterogeneous nature of its sizes as different scoops do not represent the true nature of the bulk aggregate size representation in the natural occurring state.

4.4. Effect of Supplementary Cementious Material (SCM)

The addition of 9% and 23% silica fumes and steel slag respectively to 10mm (3/8) all- in gravel concrete mix at 0.23 water/binder ratio resulted to a tremendous increase in compressive strength up to 80%N/mm2 after 28 days wet curing. According to Muhammed Ismael, (2009) silica fume contributes to both short and long tension properties of the concrete, whereas steel slag shows its beneficial effect on a relatively longer time. The results obtained for 10mm (3/8") all –in gravel concrete are in agreement with findings of Muhammed Ismeil (2009)

4.5. Failure Mechanism of 10 mm (3/8") all -in Gravel Aggregate Concrete

Several standard cubes specimens of 10 mm (3 /8") all in one gravel aggregate concrete were subjected to compression strength tests at various ages. The crushing of the cubes was characterized by formation of wide axial tensile cracks at the earlier ages which was thereafter dominated by a considerably explosive failure at the age of 28 days. The failed pieces depicted the observed failure mechanism are vividly shown in Plates 3. The observed failure mechanism is characteristic of the behaviour of high strength concrete with clearly visible fracture process zone and the effective critical crack-trip opening displacement reported in previous studies.

Figure 4 Plates 3 Failure Characteristics of HSHP under Compressive load

4.6. Density of 10mm (3/8") all-in Gravel Aggregate Concrete

Table 2 and figure 3 show the average experimental values of density of high strength concrete based on 10 mm (3/8") all-in gravel aggregates. Three cubes were tested after 3, 7, 14, 21 and 28 days curing by the three methods adopted.

Table 3 Average Density of all in gravel aggregate concrete at various duration of curing

Type of Curing		Average densities in Kg/m³ for various duration of curing			
		7 days	14 days	21 days	28 days
WSC	Average Density sampleA kg/m³	2637	2800	2874	2962
WC	Average Density sample B kg/m³	2687	2850	2884	2974
CC	Average Density sample C kg/m³	2677	2866	2878	2955

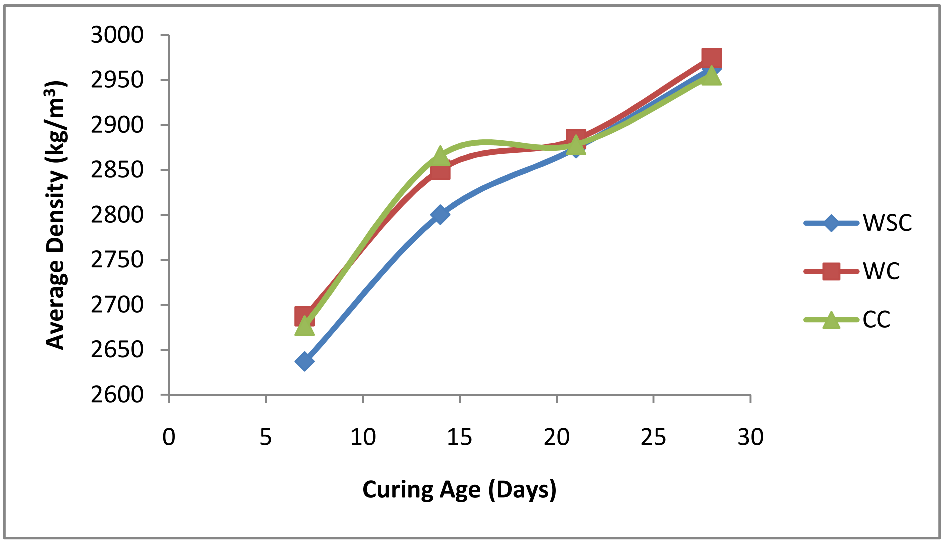

Figure 5 Average Density at various ages and types of curing

A steady increase in density was observed throughout the duration of curing for each method. The density range of 2600 to 2980 kg/m3 is characteristic of ultra-dense, high strength concrete resulting from the reaction of the admixtures. These densities are typical of high strength concrete.

4.7. Water absorption of 10mm (3/8) all-in-one Gravel Aggregate Concrete

The results of water absorption tests on the 10mm (3/8) all-in-one gravel aggregate concrete are presented in Table 4 and plotted in Figure 4. The rate of absorption decreased by about 40 percent 14 days and about 95 percent at 28 days of curing using the methods adopted in this study.

Table 4 Average Water Absorption from all -in-aggregate concrete at Different curing Age [Days]

Type of Curing		Average value of water absorption in percentages for various duration of curing			
		7 days	14 days	21 days	28 days
WSC	A.W.A sample A %	1.11	0.66	0.94	0.06
WC	A.W.A sample B %	1.16	0.64	0.84	0.09
CC	A.W.A sample C %	1.1	0.63	0.92	0.03

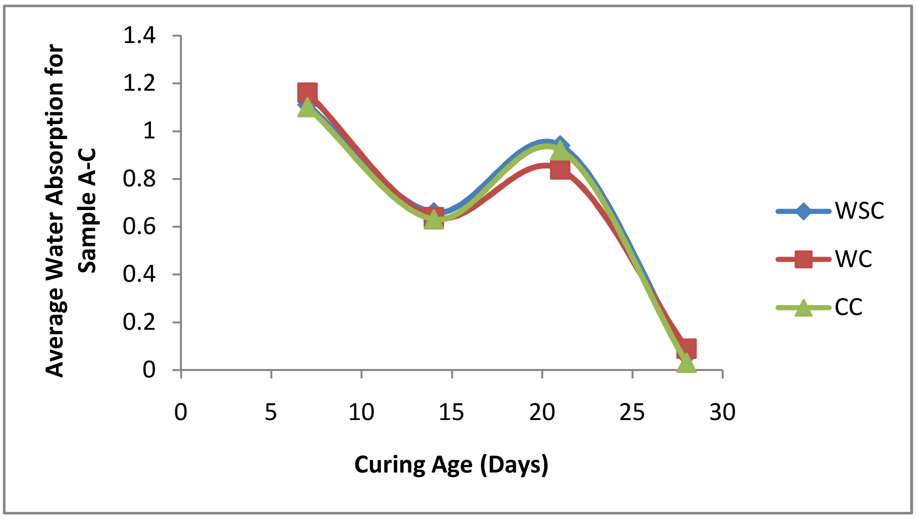

Figure 3 Average Water Absorption at Different Curing Age (Days)

5. CONCLUSIONS

The low water absorption correlates with high density and low permeability as characteristic of high strength concrete. From the result of the water absorption and strength development of the dry curing method adopted, it clearly indicates that the concrete needs only its water of crystallization to complete 80% of its process of hydration.

6. RECOMMENDATIONS

- We recommend that the aggregate in its natural state should be sieve alongside with good aggregate combination technique. Aggregate more than 10mm should discard in high strength concrete production.
- An aggregate combination should be used to improved on the strength from 80.2-100Nmm^2 by removing size of aggregate that are not required for production of high strength concrete.
- Other mixes of should also be adopted with maximum size of 10mm aggregate to optimize the compressive strength.

- It is recommended that achieving high strength concrete using locally aggregate, admixtures should be added in the concrete production of high strength using local occurring 3/8 grave aggregate.
- A range of water-binders ratio of (0.2 – 0.35) should be tried for different range of cement content of (400 – 650)kg/m^3 to optimize the cement visa-avis the grade of concrete alongside the percentage of SF and FA to be used for the same aggregate.
- To adopt a special curing technique that provide for covering of samples with cellophane within the first 48hours before adopting the wet curing method.
- Investigate the early strength development of the concrete to further document the mechanical properties of 3/8 all-in one gravel aggregate concrete.

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