Applied Journal of Physical Science
Volume 3(2), pages 72-80, April 2021
Article Number: 6410FD274
ISSN: 2756-6684
https://doi.org/10.31248/AJPS2021.051
https://integrityresjournals.org/journal/AJPS
Full Length Research

Evaluation of the impact of chemical admixtures on the compressive strength properties of concrete

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Received 9th April, 2021; Accepted 28th April, 2021

ABSTRACT: This study was carried out to evaluate the effect of chemical admixtures on the compressive strength of concretes. The concretes were produced with the concrete mix ratio of 1:2:4, while water to cement (w/c) ratios of 0.35, 0.4, 0.45, 0.5 and 0.55 were adopted. Different concrete mixtures were produced using two chemical admixtures (hydroxycarboxylic acid and MasterRheobuild 1100) applied at the rate of 1.3% (weight of the cement), during the production process. Laboratory results of the fine aggregate used for the concrete production showed that it was well graded met international standards. All the concretes were produced and tested in accordance to American Society for Testing and Materials (ASTM) standard procedures. Results indicated that the concrete produced with the chemical admixtures showed better concrete performances both in the fresh and hardened state. After 28 days of casting, concrete produced with MasterRheobuild 1100 admixture had the best compressive strength (32 MPa); compared with the compressive strength of the concrete produced with the hydroxycarboxylic acid admixture (28 MPa), and the control concrete samples that had compressive strength of 25 MPa. In addition, the fresh concrete produced with chemical admixtures gave a better slump than the fresh concrete produced without any chemical admixture. Likewise, hydroxycarboxylic acid admixture performs better among the two admixtures used, given a more linear relationship between the slump and water/cement ratio. These results showed the importance of chemical admixtures when higher compressive strength becomes a vital factor in structural constructions.

Keywords: Admixture, coarse aggregate, compressive strength, concrete, fine aggregate.

INTRODUCTION

Concrete composite materials consist of natural aggregate and adhesive cement. It consists of coarse aggregate, fine aggregate, cement (the binder material) which holds the aggregate matrix together, and water combined at the right mix ratio (Lafarge, 2009; Sanjeev et al., 2019). Anything added to concrete to alter its engineering properties is known as an admixture. According to Ramachandran et al. (2002), the most active component of concrete is the cement paste, and the concrete strength performance is highly dependent on the nature of the cement paste. Globally, the use of concrete materials in building and construction industries is twice the total amount of all other building materials (wood, steel, plastic, aluminum, etc.) combined. Data obtained from the Cement Association of Canada (CAC) portal, the annual global concrete production stands at about 4 billion cubic meters, spreading unevenly across about 120 countries (Ecosmart, 2019; Akpokodje et al., 2019). Studies have shown that the use of concrete in structural constructions is increasing globally, pushing cement demand upward, depleting natural aggregates reserves, and causing environmental pollution. Large quantity of CO_2 is produced during cement production, which leads to global warming and environmental pollution (Lafarge, 2009; Sanjeev et al., 2019). In order to avoid an accommodation crisis in the nearest future, it has become necessary to develop sustainable construction materials methods for the building and construction industries.

In order to develop sustainable construction materials methods for the building industries, admixtures are being developed and tested by many researchers. Admixtures are chemicals which are usually added to concrete in order to achieve some beneficial effects; such as better workability, improve strength and durability, acceleration, reduced void volume, improve plasticity, etc. (Ramachandran et al., 2002). According to the European Federation of Concrete Admixture Associations (EFCA), retarding admixtures help to slow down the reaction rate (speed) between the cement and water by affecting the hydration process; thereby, reducing the rate at which water penetrates into the cement particles (Admixture, 2020; EFCA, 2006). Some benefits of concrete admixtures that retard concrete setting time are to; counterpoise the accelerating effect of high ambient environmental temperature, make the fresh concrete workable (prevent cold joints and discontinuities), until it is utilized, and preventing setting of the fresh concrete inside the concrete mixer or transporting equipment if there is delay in the delivering process (American Concrete Institute- ACI, 2004; SINTEF, 2019). However, some admixture has some characteristics including water reduction properties at a wide range of dosages and accelerates compressive properties of the concrete produced when applied at large amounts (SINTEF, 2019). Citing Collepardi (1995), concrete setting time retarding admixtures (retarders) can be organic compounds (lignosulphonates, hydroxycarboxylic acid, phosphonate, etc.) or inorganic compounds (phosphates, borates, lead salts, etc.).

Engineering properties of concrete are highly influenced by the cement type, nature of fine and coarse aggregates, concentration of the aggregates, quality of water used, type of admixture, and the prevailing environment conductions (mostly temperature) (Ramachandran et al., 2002). Typically, fine aggregate consists of particles with size ranged from 75 µm to 4.75 mm; while coarse aggregate consists of particles with size ranged from 4.75 to 50 mm. Quality of fresh concrete is usually evaluated by the ease and homogeneity it can be mixed, transported and compacted; without an element of excessive bleeding or segregation (Neville, 1995). Bleeding of fresh concrete can be reduced if proper quantities of fine and coarse aggregate are used; while increasing the cement quantity and addition of admixtures also help too.

Previous researches have proved admixtures when added at the right quantity can improve the compressive properties of cement composite materials. Akpokodje and Uguru (2019) observed that the compressive strength of sandcrete block produced from cassava waste water (as admixture) was 39% higher than sandcrete blocks produced from fresh water. Sanjeev et al. (2019) reported that the compressive strength and split tensile strength of concrete blocks were increased after partial replacement of the cement with Fly Ash, Ground Granulated Blast Furnace Slag (GGBS) and Metakaolin. Citing Topçu and Ateşin (2016), the slump flow results of fresh concrete produced with naphthalenesulfonate-based admixture were better (better flowability) when compared with the results obtained from fresh concrete produced with lignosulfonate-based admixture. In another study by Papayianni et al. (2005), they reported that the compressive strengths of concretes produced with modified polycarboxylic ether polymer (admixture) had higher compressive strength compared to concretes produced with modified sulfonated polymer and synthetic polymer, after 28 curing days.

Several researches have been carried out on the utilization of admixtures in concrete production globally. Nevertheless, there is still paucity of information on the impact of hydroxycarboxylic acid and MasterRheobuild 1100 admixtures on the mechanical properties of concretes produced from Nigeria branded Ordinary Portland Cement (OPC). Therefore, the objective of this study is to evaluate the engineering impact of two admixtures (hydroxycarboxylic acid and MasterRheobuild 1100) on some mechanical properties (compressive strength) of concrete produced from Dangote cement, a commonly used OPC in Nigeria.

MATERIALS AND METHODS

Materials

Fine aggregate

River bed sand (sharp sand) was used as the fine aggregate for this study. The sharp sand was collected from one of the tributaries of the Niger River, located in Delta State, Nigeria.

Coarse aggregate

Granite, obtained from local quarry in Ondo State, Nigeria was used for concrete production. The coarse aggregate was sieved with a 20 mm stainless sieve; furthermore, it was manually inspected to make sure it is free from dirt, roots, inorganic materials, etc. The Nigeria Industrial Standard (NIS) recommends that any coarse aggregate which is to be used for concrete production must be free from chemicals or foreign bodies that could lead to deterioration of concrete produced (Akpokodje et al., 2019).

Cement

Ordinary Portland cement (Dangote brand) was used for the casting of the concrete blocks. According to the factory laboratory test result, it was of grade 42.5; which makes it satisfying the Nigeria Industrial Standard (NIS-444, 2003) requirements for cement to be used for concrete production within Nigeria (Esegbuyota et al., 2019).

Water

Borehole water was used for the concrete cubes production. The water was devoid of oily materials, aquatic plants and pH 6.8, making it satisfying the NIS-554 standard recommended of water required for concrete production (NIS-554, 2007).

MasterRheobuild 1100

MasterRheobuild 1100, which was used as admixture for the concrete production, was obtained from an industrial chemical store, located in Onitsha, Anambra State, Nigeria. MasterRheobuild is a strength enhancing admixture, formulated to meet ASTM C 494 requirements, used to produce high compressive strength concrete bodies (Master builder, 2020).

Hydroxycarboxylic acid

Hydroxycarboxylic acid, which was another admixture used for the concrete production, was obtained from an industrial chemical store, located in Onitsha, Anambra State, Nigeria. Hydroxycarboxylic acid which helps to retard Ordinary Portland cement (which is the cement used in this study) hydration. This admixture retards the hydration of the C_3A phase by delaying the conversion of the hexagonal phase to the cubic phase. By applying DTA and XRD, Lorprayoon and Rossington (1981) showed that salicylic acid retards the hydration of C_3A.

Methods

Mixing method

Mechanical mixing method was used for the concrete production. A laboratory concrete mixer was used to mix all the concrete constituents, in order to obtain a homogenous mixture. For the purpose of this study, ten different sets of concrete mixtures with a partial addition of the admixtures (hydroxycarboxylic acid and MasterRheobuild 1100) as shown in Table 1 were produced. For the amended cases, 1.3% (weight of the cement) of the admixture was added to the fresh concrete, during the production process. During the mixing procedure, the cement and the right volume of water and admixture were poured into the mixer and mixed for 10 minutes at an average speed of 10 rpm; then the two remaining constituents (fine and coarse aggregate) were poured into the mixer and mixed for about another 20 minutes at lower average speed of 5 rpm, in order to have a perfect homogenous mixture. This lower speed was adopted, because high speed creates homogeneity imperfection; and to simulate the mixing process in a ready-mix concrete in concrete mixer truck (Mohammed et al., 2017). At regular intervals (5 minutes), concrete sample was taken for slump test, until each concrete mixture had a slump value less than 2 cm.

Concrete cubes production

A mix proportion of 1:2:4 (cement:fine aggregate:coarse aggregate) by a weight was used for the production of concrete. The following water to cement ratios (w/c) of 0.3, 0.4 and 0.5 were strictly adopted for the concrete production. During the weight, a digital weighing balance with sensitivity 0.01 kg was used. Also, caution was taken to ensure that the accurate weight of the individual components (cement, fine aggregate and coarse aggregate) was used. The concrete cubes (samples) were produced in accordance to ASTM standard size (150 mm by 150 mm by 150 mm) and procedures. Before the casting of the concrete cubes, all the moulds were oiled with thin film of motor engine oil, to facilitate the release of the cubes from the moulds during the de-moulding process. During the concrete production (casting), each already prepared (oiled) mould was filled (up to half volume) with premixed cement composite (fine aggregate, coarse, aggregate and cement) and rammed 36 times to remove all air bubbles tapped within the mixture; after which the mould was filled to the top and rammed again 36 times. Then the mould was smoothed with a flat stainless steel trowel to obtain a flat surface.

Curing of the concrete cubes

After the casting of all the concrete cubes, they were covered with black polythene sheet for the first 24 hours (initial curing) to prevent moisture loss. After 24 hours, cast concrete cubes were demoulded, and the cubes were cured by total immersion in water at ambient laboratory temperature for 28 days. This is necessary for the concrete cubes as it facilitates proper hydration of the concrete produced.

Laboratory tests

Two major laboratory tests were carried out in this study. Firstly, physical characteristics (moisture content, specific gravity, absorption capacity and sieve analysis) of fine aggregate used for the concrete production were tested in accordance with AOAC recommended procedures. Secondly, mechanical properties (compressive strength) of the concrete cube produced from the two admixtures and the control were tested in accordance with ASTM recommended procedures. All the laboratory tests were carried out at the Department of Civil Engineering Technology's concrete laboratory, Delta State Polytechnic, Ozoro, Nigeria, under ambient environmental conditions (24±4°C).

Table 1. Concrete mixture proportion.

Sample	Admixture type	Admixture dosage (% wt. of cement)	W/C
C_1(control)	-	-	0.35
C_2	-	-	0.40
C_3	-	-	0.45
C_4	-	-	0.50
C_5	-	-	0.55
H_1	Hydroxycarboxylic acid	1.3	0.35
H_2	Hydroxycarboxylic acid	1.3	0.40
H_3	Hydroxycarboxylic acid	1.3	0.45
H_4	Hydroxycarboxylic acid	1.3	0.50
H_5	Hydroxycarboxylic acid	1.3	0.55
M_1	MasterRheobuild 1100	1.3	0.35
M_2	MasterRheobuild 1100	1.3	0.40
M_3	MasterRheobuild 1100	1.3	0.45
M_4	MasterRheobuild 1100	1.3	0.50
M_5	MasterRheobuild 1100	1.3	0.55

Moisture content of the fine aggregate: Moisture content of the fine aggregate used for the concrete cubes production was determined through the approved gravimetrical method approved by AOAC, as described by Akpokodje et al. (2018) and calculated using equation 1.

$$Mc\ (wet\ basis) = \frac{W_1 - W_2}{W_1} \times 100 \qquad (1)$$

W_1 = weight of wet sample and W_2 = weight of dry sample.

Specific gravity of the fine aggregate: Specific gravity of the fine aggregate (sharp sand) used for the concrete production was determined using standard procedures recommended by AOAC (2019), and calculated using equation 2.

$$s_g = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \qquad (2)$$

Where: W_1 = Weight of the empty bottle and W_2 = Weight of the bottle filled sharp sand.

Absorption capacity of the fine aggregate: The absorption capacity of the sharp sand used for the concrete production was determined using standard procedures recommended by AOAC (2019), and calculated using equation 3.

$$AC = \frac{W_{SSD} - W_{OD}}{W_{OD}} \times 100 \qquad (3)$$

Where: W_{OD} = Wight of oven-dry soil sample; that is all moisture has been removed, and W_{SSD} = Weight of saturated-surface-dry soil sample; that is all internal pores are full, but no film of water on the surface.

Sieve analysis of the fine aggregate: The sieve analysis of the fine aggregate (sharp sand) used for the concrete production was carried in accordance with recommendation procedures approved by NIS-87. The sharp sand was dried in the laboratory under ambient temperature (24±4°C) for one week. 1 kg of sharp sand was taken from the dried sand and then poured onto an already pre-arranged stainless sieves set (arranged in descending order). Then, the set was carefully inserted into a mechanical sieve shaker, and ran for twenty minutes. After this, each sieve was removed from the set (starting from the topmost one), and the sharp sand retained in each sieve was weighed and recorded (Esegbuyota et al., 2019).

Cumulative weight of the sharp sand that passed through each sieve was calculated as a percentage of the total sharp sand weight. A particle size distribution curve was developed from the sieve analysis, and the coefficient of uniformity (C_u) of the fine aggregate was calculated with equation 4, as approved by Unified Soil Classification System (USCS, 2015).

$$C_u = \frac{D_{60}}{D_{10}} \qquad (4)$$

Where C_u = uniformity coefficient (ASTM D2487), D_{60} = Diameter corresponding to 60% finer in the grain size distribution, and D_{10} = Diameter corresponding to 10% finer in the grain size distribution.

Concrete slump test: Concrete samples from all the mix ratio and mix design were subjected to slump test in accordance with standard procedures recommended by ASTM C143, and described by Mohammed et al. (2017).

Compressive strength test: Compressive strength test of the concrete cubes produced was carried out in full compliance with NIS and ASTM standard recommendations. Concrete Compression Testing Machine (STYE 2000), manufactured in China was used to carry out the compressive test. During the test, individual concrete cube was clamped between the two flat plates of the machine, and loaded axially at constant speed until failure occurred. The compressive force of the block at failure point was displayed on the screen of the machine, from where it was read from. Compressive strength of each concrete cube was calculated using equation 5. All the laboratory tests were carried out under ambient laboratory temperature (24±4°C).

$$\text{Compress strength} = \frac{\text{crushing force (N)}}{\text{Net area of block } (mm^2)} \qquad (5)$$

Effective area of the concrete cube = 150 mm x 150 mm = 22500 mm^2

Statistical analysis

The data obtained from this research were statistically analyzed using the MS Excel 2010 (Microsoft Corporation Redmond, WA 98052). The summary of the readings was plotted in Microsoft Excel 2010.

RESULTS AND DISCUSSION

Physical Characteristics of the aggregate

Laboratory results obtained for the physical characteristics of the sharp sand used for the concrete production are presented in Table 2 and Figure 1. The physical characteristics of the sharp sand showed that the sharp sand used for the concrete production was well graded and met NIS, ASTM and USCS recommended standards. The moisture content of the sharp sand was 8.15%, which is below the maximum value of 12% moisture content of sand recommended by the Nigeria Industrial Standard for concrete production.

Figure 1 shows the sieve analysis curve of the sharp sand, with silt content (fines) of 4% and C_u of 7.18. According to USCS (ASTM D2487-11), a sand (fine aggregate) is poorly graded (P) if C_u is less than 6 (C_u<6) and fines particles are less than 5% (fines< 5%). While a sand is well graded (W) if C_u is greater than 6 ($C_u \geq 6$) and the fines particles are less than 5% (fines < 5%). According to NIS recommendation, the permissible maximum value of 6% silt content is allowed for fine aggregate to be used for concrete production. Silt content (from aggregate) usually lowered the compressive strength of concrete produced from it. According to Cho (2013), compressive strength of concrete block declined from 5 to 3 MPa, as the silt content of the fine aggregate inclined from 7 to 9%.

Fresh concrete slump property

The addition of the chemical admixtures greatly influenced the slump and workability of the fresh concrete (Figure 2). In all water/cement ratio cases, the fresh concrete containing admixture gives a better slump than the fresh concrete without chemical admixture. The hydroxycarboxylic acid admixture performs better among the two admixtures used, given a more linear relationship between the slump and water/cement ratio. Concrete slump (workability) is the ease with which fresh concrete produced can be transported, compacted and finished without separation of the individual constituents. Good workability is required to produce concrete that is both economical and high in quality. According to concrete guidelines stated by JSCE, 2007), for normal weight ready-mix concrete, the minimum slump requirement at the unloading point should be maximum of 8 cm. This is because, concrete with very high-slump value usually experience excessive bleeding, shrinkage, cracking, and dusting of the hardened concrete (Mishra, 2019). In addition to type and volume of admixture used, the slump of concrete is dependent on type of cement, w/c ratio and temperature (Ramachandran et al., 2002).

Influence of water/cement ratio on the concrete

It can be clearly seen in the results that water/cement ratio has influence on all the concrete produced (Figure 3), irrespective of the type of admixture added. For all cases, after 28 curing days, the concrete produced with lower water/cement ratio had better compressive strength values when compared with the ones produced with higher water/cement ratio. Improved workability was recorded in the fresh concrete treated with admixtures; this is because at a water/cement ratio of 0.35, it was practically difficult to cast any perfect concrete cube. Although a minimum water/cement ratio of 0.35 to 0.40 was variously given for cement to attain complete hydration (Ramachandran et al., 2002). The result in this study was contrary, as no perfect cube was produced from a water/cement ratio of 0.35, without the addition of admixture to the concrete, as shown in Figure 3. Figure 3 shows that, in all cases, the concrete produced with the MasterRheobuild 1100 admixture had best compressive strength, in all the five water/cement ratios adopted; this was closely followed by the concrete produced with the hydroxycarboxylic acid admixture. These results are in similarity with previous study of Rixom and Mailvaganam (1999), who reported that for any given water/cement ratio, concrete produced with sulfonated naphthalene formaldehyde and sulfonated melamine formaldehyde admixtures gave higher compressive strength to concrete produced with lignosulfonate and hydroxycarboxylic acid admixtures.

Influence of addition of admixtures on the concrete

Taking 28-day concrete as a reference point, it can be observed that compressive strengths of concretes prepared with different admixture types were different

Table 2. Some physical characteristics of the sharp sand.

Aggregate type	Moisture content (%wb)	Specific gravity	Absorption capacity (%)
Sharp sand	8.15±08	2.84±06	3.12±16

Values are means ± standard deviation.

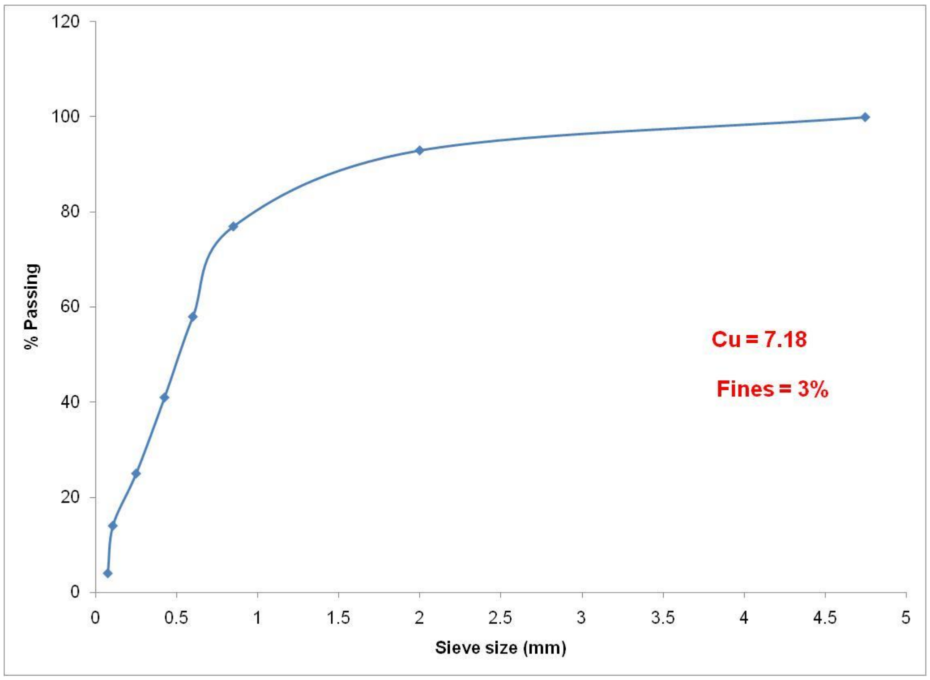

Figure 1. Sieve analysis curve of the sharp sand.

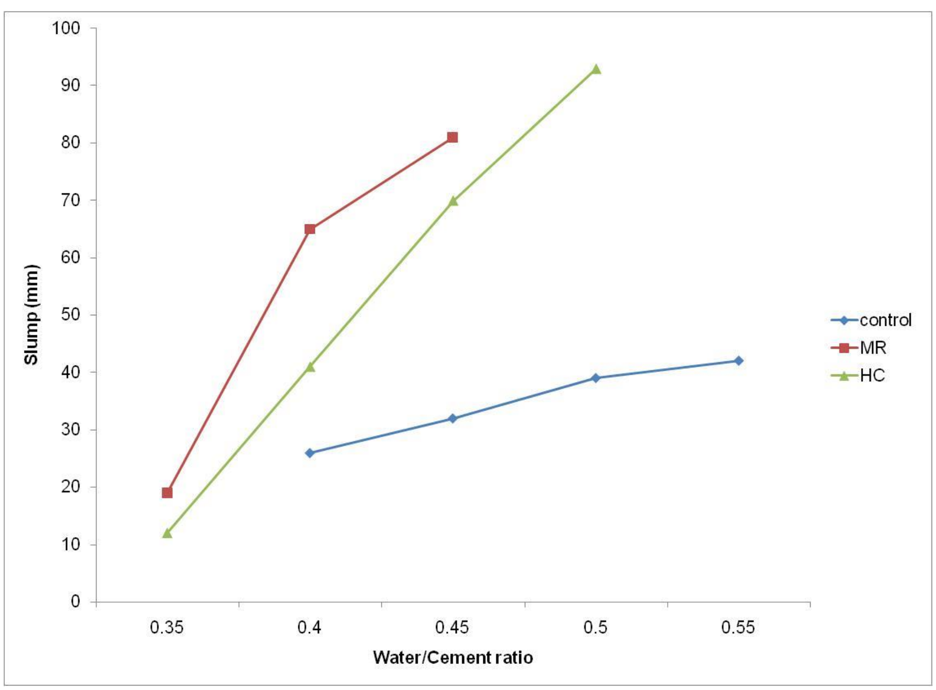

Figure 2. Slump tests curve of the fresh concrete.

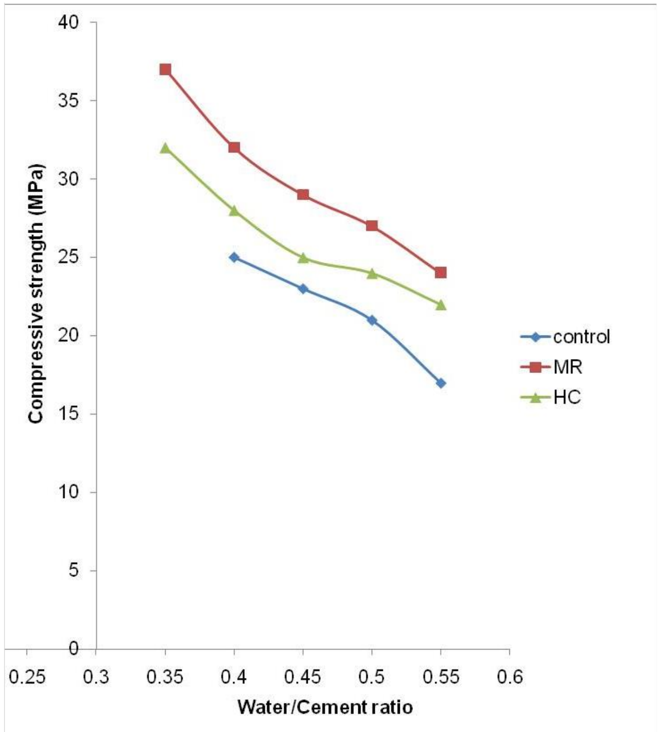

Figure 3. Curve showing the effect of water/cement ratio on the concrete.

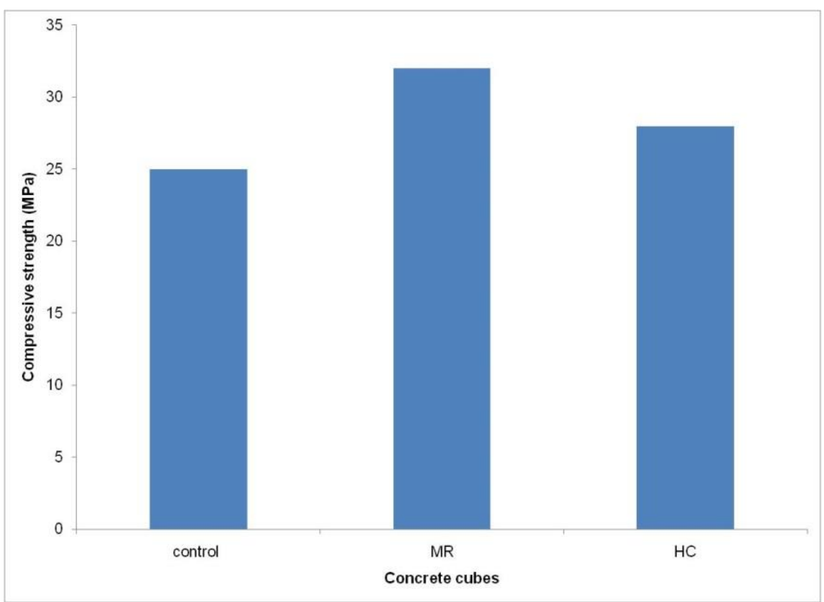

Figure 4. Effect of chemical admixture on the compressive strength of the concrete.

(Figure 4). This shows that chemical admixtures strongly influenced the compressive strength of concrete produced. In all cases, the concrete produced with MasterRheobuild 1100 admixture had the highest compressive strength (32 MPa); when compared with the compressive strength of the concrete produced with the hydroxycarboxylic acid admixture (28 MPa), and the control concrete samples (25 MPa). This study showed that when the compressive strength of a concrete becomes a vital factor during construction, addition of admixture becomes the lifeline; even though, it adds additional cost to concrete production. Results obtained from this study are in conformity with previous researches reports. Ramachandran et al., (2002) reported that lignosulfonate admixture at the concentration of 0.26%, increased the compressive strength of the concrete produced by 15% after 28 curing days.

According to Mohammed et al. (2017), concretes produced with chemical admixture (sulfonated naphthalene polymerbased superplasticizer) were stronger (higher compressive strength and splitting tensile strength), when compared with concrete produced without chemical admixture. Ramachandran et al. (2002) stated that the effect of carboxylic acids on OPC hydration and setting is very similar to that of lignosulfonate, although different percentages of admixtures are required to obtain similar effects. Nevertheless, on a caution note, Gagn´e et al. (1996) suggested that addition of chemical admixture overdose to concrete can lead to the deterioration of its physical characteristics. This is because it (the overdosage) will lead to internal bleeding of the concrete, which may reduce the quality of paste-aggregate interface (Mohammed et al., 2017). The results obtained from this study further showed that the addition of chemical admixtures to concrete will reduce the pressure on cement production globally; therefore, helping to curtail climate change, a prevailing problem in the world today. But more researches are needed to evaluate the production and utilization of these chemical admixtures on the ecosystem, since most chemicals (including their by-products) are not environmentally friendly.

Conclusion

This study was done to evaluate the effect of chemical admixtures (hydroxycarboxylic acid and MasterRheobuild 1100) on compressive strength of concrete. All the concretes were produced and tested in accordance to ASTM and NIS standard recommendations. From the results obtained from this study, the following conclusions can be drawn:

1. The utilization of chemical admixtures can increase the workability of fresh concrete without increasing the water/cement ratio.
2. Fresh concretes with hydroxycarboxylic acid admixture have better workability than fresh concrete produced with MasterRheobuild 1100 admixture.
3. Chemical admixtures greatly influenced the compressive strength of concretes, as about 31% concrete strength increment was recorded.
4. Concretes produced with MasterRheobuild 1100 had better compressive strength when compared with concretes produced with hydroxycarboxylic acid.
5. When high compressive strength becomes a vital factor during structural construction, it is more economical to utilize chemical admixtures.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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