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Original Research Article

Experimental Study of the Use of Demolition Wastes in the Production of High-Performance Concrete

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Abstract

This research focuses on the use of concrete demolition wastes to produce High Performance Concrete. The energy discharge during cement production can pose a health risk, and the continuous quarrying of natural aggregates for concrete production from river beds, seashores, and other sources, if not done in accordance with environmental guidelines, can completely devastate our planet. Therefore, scientists, researchers and other related professionals are trying to improve recycled materials to be used as aggregates. Recycled aggregates concrete, with certain adjustments, is one solution for this need. This study aims to evaluate the Experimental investigation of the use of demolition wastes from urbanite concrete samples at Adenuga Building, Bells University of Technology, Ota, Ogun State, Nigeria in the production of high-performance concrete. There were 20 series of mix designs. Recycled coarse aggregate percentage replacements of Natural coarse aggregate was adopted from 0% to 100% at 25% interval, the fiber contents replacements of the concrete volume were integrated at 0% to 1.5 % at 0.5% interval, and the NBRRI Pozzolan (NP) replacements of the cement volume was substituted at 0% to 15% at 5% interval. Various fresh and hardened properties of concrete such as Slump test, Compressive, splitting tensile and Flexural strength tests were determined and tests on cement, aggregates, such as Specific gravity, Sieve analysis were also carried out in accordance with BS standards. It was observed from the results that optimum value of 50.69 MPa, 6.14 MPa, and 2.18MPa were obtained for compressive, flexural and splitting tensile strengths of the concrete at 25% RAC addition, 5% addition of NBRRI pozzolan with 0.5% glass fiber content at 28 days curing age respectively. It is concluded that addition of glass fibre to concrete made by replacing cement with NBRRI pozzolan significantly improved the strength of the concrete. High performance concrete using recycled materials can be adopted in the construction of high-rise structures, bridges, pavements, hydropower structures, tunnels, and other current and future construction projects.

Keywords: Demolition wastes, Aggregates, Pozzolan, Glass Fibre, High-performance Concrete, Strength.

1. INTRODUCTION

Concrete is the most widely used and demanded construction material globally [1], [2] and also one of the most widely consumed products in the world [3]. The emission of concrete is hazardous to the world at large. The quarrying activities for collection of aggregates used for concrete production is making natural resources to be fractionally depleted. In the global emissions budget, the industrial processes, entire energy discharges, and other emissions are always described separately/self-sufficiently [4] and the discharge from the cement production constitute about 5% of global CO_2 emissions [5]. The need to improve the type of concrete being produced in this present age is one of the focuses of Technologists, Engineers, Researchers and other related professionals. One of the replacements to the use of conventional concrete is recycled aggregate (demolition waste) modified with other experimented materials to produce High performance fiber reinforced recycled aggregate concrete.

HPFRRAC was borne out of the need to address the limitations (weaknesses) of RAC. However, there is concurrence among authors regarding the concrete compressive strength of at least 50MPa, despite the fact that there is still no exact description of HPFRRAC (not HPC). The case studies to produce the HPFRRAC are Fiber glass, pozzolans, recycled aggregates and admixtures using the same procedures as a natural aggregate concrete with some modifications required specifically in the mix ratio aspect. It was revealed/proven from [6] findings that there was no discernible impact on the slump, and for both tested levels of concrete's compressive strength, an average 10% decrease in the mechanical properties of the hardened concrete was recorded. The research investigated by [7] showed that utilising well water in concrete produced with NCA causes a 16.0% loss in compressive strength. Implementing well water likewise resulted in a decrease of around 13.2%, 10.0%, and 8.5% for concrete with 25%, 50%, and 100% RCA, respectively. When employing well water, the flexural and splitting tensile strengths also decreased. For good concrete strengths, a 25% recycled coarse aggregate percentage was optimal.

One of the ways to a sustainable progress of each nation is the application/utilization of recycled materials through reuse and recycle of C&DW. Recycled aggregate concrete is a concrete made by using recycled coarse aggregate as the coarse aggregate [8]. In simplicity, recycled coarse aggregates can be derived and extracted from Recycled aggregate concrete. Recycled aggregates are gotten from demolition of existing structures to make room for increased urbanization and/or other considerations. It is either gotten from construction waste or demolition waste. Urbanite (concrete rubble pieces) are useful in the production of high-performance concrete when recycled and enhanced with other materials. The structural performance and applications of Recycled Aggregate Concrete can be limited due to weaknesses (the existence of contaminants, cement mortar, alkali, etc.). According to [9], the addition of RCA may reduce the flexural and splitting tensile strengths of concrete. From [10] findings, it was revealed that Light Weight Concrete and Scoria Light Weight Concrete (SLWC) produced compressive strength of around 30 MPa and 33 MPa (which is about 78 to 86% of control samples), respectively. The findings show that scoria can be used to good effect in the creation of structural lightweight concrete. Furthermore, current renewable aggregate sources will preserve the natural resources for future generation. [11] found out that the 28-day compressive strength of the concrete, which had coconut shell as the coarse aggregate and normal sand as the fine aggregate, ranged from 2 to 36 MPa, and the dried density was between 1865 and 2300 kg/m. Coconut shell concretes demonstrated 28-day modulus of rupture and splitting tensile strength values between 2.59 and 8.45 MPa and 0.8 and 3.70 MPa, respectively. These values fell between 5 and 20% of the compressive strength. Moreover, the flexural property of CSC was found identical to other lightweight concrete types. According to [12], it was found out that the Polypropylene Waste Coarse Aggregate Reinforced Concrete beams coated with sand could withstand the applied loads with a flexural performance deemed reasonable and acceptable. Furthermore, it was noticed that the parameters of the beams under investigation were impacted by changes in the w/c ratio. A detailed study performed by [13] indicated that the mechanical properties of RAC is decreased when RCA are adopted in place of NA. Nevertheless, the concrete's strength remained unaffected even when a minimum of up to 30% RCA substituted NA.

The undesirable effect of RAC on concrete can be lessened by incorporating pozzolanic materials or admixtures [14]. According to [15] research, the findings showed that in addition to the superplasticizer type and dosage having a significant impact on the concrete's fresh properties, these factors including the application of silica fume may also affect the properties of the mixes in their hardened state. For example, the mixes whose superplasticizer were poly-carboxylic-ether exhibited superior compressive and tensile strength compared to other mixes. Additionally, there was a strong correlation between the air contents and the kind of the superplasticizer. Nevertheless, the integration of silica fume reduced the air contents of the mixtures. It was discovered from [16] investigation that Micro Palm Oil Fuel Ash combined with finely graded sand produced a dense and highly strong cement mortar due to the pozzolan reaction and enhanced packing effect. In view of POFA's pozzolanic reaction, the High-Performance Cement Mortar mixtures containing POFA showed higher increases in strength and Ultrasonic Pulse Velocity in addition to a greater decrease in absorption and porosity from 7 to 28 days of curing age compared to the control OPC mortar. [17] studied the results of microstructural and mechanical features of binary and ternary concrete when unveiled to elevated temperature. Compressive strength was found to increase up to 400°C and then decrease above that temperature. As the temperature rises, the Ultrasonic Pulse Velocity value and mass loss reduce, and at a higher temperature, a color shift and crack were noticed.

The strength and durability of RAC can also be increased through the merging of fibres into it. In order to increase the mechanical strength properties of concrete, [18] discussed research on the use of glass fiber in two distinct sizes, 5mm and 8 mm. It was concluded that glass fiber composite concrete with a 5mm length rather than an 8mm length enhances the properties of the concrete. [19] test findings indicated the addition of Polypropylene fibers can greatly increase the concrete materials' flexural and splitting tensile strengths, but their compressive strength is lowered as a result. A 0.5% fiber dosage produced the greatest relative increase in splitting tensile and flexural strength, while a slight decrease was detected in 28-days compressive strength. From [20] investigation, the application of using both types of fiber (recycled polypropylene fiber and commercial polypropylene fiber) outcomes were less compressive strength (10 to 20%), higher flexural strength (up to 27%), and a decreased elastic modulus (by 16%). [21] discovered that the application of uniformly distributed coarse glass particles by integrating/incorporating polypropylene fibers aided in increasing the strength and shrinkage of the investigated concrete mixes. According to [22] research, even though polypropylene hybrid fibers had a detrimental effect on the workability of mortar, nonetheless, the shrinkage risk was decreased and coarser fibers (PF45) were the finest for reducing shrinkage risk. In order to study waste aluminum shavings effect on laterized concrete bond strength, [23] analysis showed that as the percentage of aluminium shavings intensified, compressive strength reduced, while the bond between concrete and steel was strengthened/increased by the aluminium shavings. [24] evaluated the impact of steel fiber's tensile strength on the mechanical characteristics of high-strength concrete reinforced with steel fibres. Tests of the compression, flexure, and direct shear performance of steel fiber-reinforced concrete with high strength samples were conducted using two steel fibre contents (0.38% and 0.75%) and two steel fibre tensile strength levels (1100 MPa and 1600 MPa). The findings revealed that High-strength steel fibre reinforced concrete surpassed normal-strength steel fiber-reinforced concrete in terms of performance.

This insight was borne out of the need to address the high level of construction waste generated during Students' Works Experience Program (SWEP) annually for adequate landscaping purpose of Bells University of Technology, Ota, Ogun state, Nigeria. The high use of natural resources has caused the environment to be fractionally depleted. This is so due to the demand for infrastructural development as per increasing population growth rate, industrialization, urbanization, and so on. A tremendous quantity of wastes is being produced yearly around the world. According to estimates, United States produces 200–300 million tons of demolition waste each year [25]. The excess waste generated globally during concrete production can be reused/recycled instead of disposing them. The considerable task before Civil engineers, Materials Engineers currently is to look for environmentally friendly, eco-friendly and economic competitiveness/cost-effective replacements to conventional concrete. Consequently, engineers and institutions have developed methods and guidelines for recycling construction and demolition waste into new concrete, such as the RAC [26]. The final form if the properties doesn't reach the standard of a conventional concrete and also to eliminate the weaknesses of this recycled concrete will now be the high-performance concrete. According to [27], concrete's usefulness in structural applications can be roughly estimated from its mechanical properties, such as its tensile strength, compressive strength, and so on. However, the true test of concrete's performance is conducted when it is applied in structural members and examined under simulated loading conditions that closely match real-world stress conditions. These stresses mainly consist of flexural, shear, and tensile stresses, and these tests aid in classifying the concrete's performance requirements.

The importance of conducting this Experimental Study of the use of recycled aggregate for high performance concrete production was that a lot of demolition waste was been generated annually in the production of landscape pavers during SWEP for acquiring of basic training skills in Bells University of Technology. The use of RAC in structural applications is limited due to its inferior strength and performance properties compared with that of natural/standard concrete. There can be an upgrade in the strength and durability of recycled aggregate concrete performances to prevent the risk of attack, and so on with the addition of fibres and pozzolanas into it as established by many researchers.

The purpose of the current research was to explore case studies in the production of HPC and the scientific applications and technical impacts of these replacement materials. It was to demonstrate that not only the conventional concrete composite materials method can be used to produce concrete (thanks to the replacement method). The study was also to indicate that the cement alternative and natural aggregate replacement not only serve as substitute materials, but also assists in other technical solutions such as: The demolition wastes or urbanite concrete samples due to demand for infrastructural development can be readopted in the construction industry now and in the future once modified and integrated with other composite materials instead of disposing them or using as filling materials. A reduction in the effect of the reproduction of cement by curtailing the CO_2 emissions (which causes global warming, greenhouse gas effect, and so on) and decreasing energy consumption in the environment. A minimization in the quarrying activities in order to promote the conservation of natural resources and the environment at large (by encouraging waste management system in which a high-performance concrete using recycled aggregates with other composition materials can be produced while achieving the required attributes).

2. Materials and Methods

Materials

Some of the samples used were procured while others were available. The waste materials were limited locally to the demolition waste around Adenuga building, Bells University of Technology and some of the waste generated on campus during the annual SWEP while the additive materials were procured from Nigerian Building & Road Research Institute NBRRI, Ota and other laboratories. The major laboratory Centre for the experimental works was the Structures and Materials laboratory in Civil and Environmental Engineering Department, Bells University of Technology, Ota, Ogun State.

2.1.1. Natural Aggregates description, properties and preparations

The natural fine and natural coarse aggregates adopted were procured from NBRRI. The natural coarse aggregates not greater than a nominal maximum size of 10mm was adopted. The aggregates (river sharp sand and granite) were maintained in a designated area outside the laboratory. They were ensured to be free from organic matters and also Air-dried before the particle size distribution, specific gravity, and water absorption were carried out in conformance to [28].

2.1.2. Recycled Coarse Aggregates

The Recycled aggregates used in this research were obtained by the collection of at least 350kg (estimated total weight of a phase consisting of 16 series) of the quantity of demolition wastes surrounding the uncompleted Adenuga Building, Bells University of Technology and demolition wastes recovered during the production of the interlocking paving stones at Bells University of Technology 2019 Students' Works Experience Programme (SWEP I) and they both fall under Type Il i.e. Concrete waste originated aggregates. Fig. 1 displays the Google map showing the construction site of recycled aggregate concrete source. The NA replacement percentages by the RAC was 0%, 25%, 50%, 75% and 100%. The Recycled aggregate concrete (RAC) materials were first collected in a bag as shown in Fig. 2 before the Recycled Coarse Aggregate (RCA) were broken from it. Then, the recycled coarse aggregates were crushed into the required 10mm nominal maximum aggregate size by 10mm aggregates crusher. The RCA were cleaned from impurities and other deleterious substances which are capable of lowering the quality of the material before the particle size distribution, specific gravity, and water absorption were carried out, and the NDT analysis including SEM and XRD of the aggregates were conducted according to the acceptable standards.

Fig. 1. Google Map showing the construction site of RAC source [29]

Fig. 2. The Recycled Coarse Aggregates collected in a bag

2.1.3. Cement description and properties

The cement adopted in this research was the Dangote Ordinary Portland cement (CEM Il/B-V 42,5R) whose description is shown in fig. 3 and cement lumps were removed before conducting the experimental works in conformance with [30].

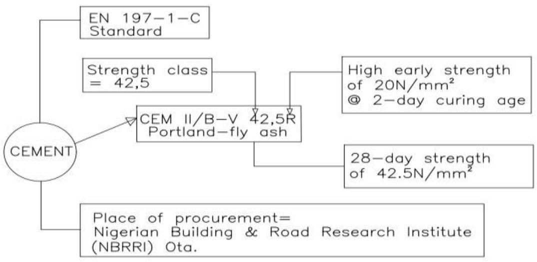

Fig. 3. Dangote OPC material chart

2.1.4. Pozzolan

The pozzolan used in this study was NBRRI pozzolan. The replacement percentages of cement by NBRRI pozzolan throughout this experiment was 0%, 5%, 10% and 15% of the cement volume in the concrete. Its mineral and chemical compositions are shown in Tables 1 and 2.

Table 1
Mineral/material composition of NBRRI pozzolan [31]

Sample	Kaolinite	Mica/Illite	Smectite	Calcite	Palygorskite	Quartz	Dolomite
Ifenitedo	40.88	9.08	0.84	0.00	0.00	49.20	0.00
Calcined clay	2.53	6.89	0.11	0.00	0.99	89.44	0.04
Imoto yewa	20.38	0.32	0.39	0.30	0.00	78.62	0.00
Raw clay	30.13	9.73	0.06	0.00	0.00	60.08	0.00

Table 2
Chemical/Oxide composition of NBRRI pozzolan [32]

Sample	Na_2O%	CaO%	LOI%	SiO_2%	SO_3%	Al_2O_3%	MgO%	K_2O%	Fe_2O_3%
Ifenitedo	0.04	0.5	15.29	55.03	0.03	24.51	0.24	0.18	2.17
Calcined clay	0.85	2.57	2.2	65.45	0.13	19.07	0.6	0.19	6.38
Imoto yewa	0.58	0.48	9.78	63.36	0.04	16.36	0.4	0.1	5.44
Raw clay	0.92	0.53	12.48	56.28	0.08	18.84	0.58	0.15	6.08

2.1.5. Fiberglass

The alkali resistant glass fiber used throughout this experiment was procured locally. The fibers were integrated into the concrete in the range of 0%, 0.5%, 1.0% and 1.5% of concrete volume. The alkali-resistant glass fibers types were wet chopped strands exhibiting various properties: Strands consisting of density of 2.70 g/cm3, diameter of 0.5mm, length of 24 mm, aspect ratio of 100, elastic modulus of 80.0GPa, tensile strength 2480 MPa, ZrO_2 content of 16.7%, and breaking elongation of 3.6% as shown in Fig. 4.

Fig. 4. Alkali resistant glass fiber matrix (chopped strands)

2.1.6. Chemical admixture

The chemical admixture used for the concrete throughout the experiment was the Superplasticizer (SP 430) and was procured from NBRRI, Ota. The properties of Superplasticizer SP430 adopted is displayed in Table 3. Conplast superplasticizer SP430 was first stored in a cool dry place and later integrated into concrete mixes during experiments so as to sustain same level of constancy throughout the laboratory work as suggested from the concrete mix designs.

Table 3
Properties of Superplasticizer SP430 [33]

S/N	PROPERTY	VALUE
1.	Appearance	Brown liquid
2.	Specific gravity	1.18 @ 20^0c
3.	Chloride content	Nil
4.	Alkali content	Max 6% by mass (less than 1g Na_2O equivalent/litre of admixture)

2.1.7. Water
Water prepared and used throughout this experimental work for mixing and curing of samples was a portable water free from impurities and contaminations sourced from the departmental laboratory.

2.2. Methods
Various experiments were carried out on cement, aggregates, and concrete in accordance with BS standards. Control concrete mix, 1:1.3:2.67 was designed for all specimens with w/c of 0.36 to produce a High-performance concrete of grade C50/M50. There were 20 series of mix designs. The percentage of recycled coarse aggregates replacing the natural coarse aggregates by weight were 0%, 25%, 50%, 75%, and 100% respectively at 25% interval with 0% selected as the reference concrete. Replacement percentage of cement with pozzolanic material (NP) by volume was integrated from 0%, 5%, and 15% at 5% interval. 24mm chopped strands of alkali-resistant Fiberglass substituting the concrete by volume were integrated at 0%, 0.5%, 1% and 1.5% at 0.5% interval for several concrete batches. Few of the factors affecting the properties (fresh or hardened) of concrete are the water cement W/C ratio, chemical admixtures content, the mix design proportion and curing days. The constant W/C ratio used for high performance concrete production was 0.36 because the higher the water cement content, the lower the strength and vice versa. The fixed quantity of Superplasticizers (SP430) content used/incorporated was 1.2kg/m^3 or 0.28kg. The introduction of superplasticizers 430 reduces the water percentage to be added and makes the concrete more workable. The factors were implemented respectively in all the mixes all through the experimental techniques.

2.2.1. Concrete mix design and categorization
The concrete mix design considerations followed the Building Research Establishment (BRE) procedures for conventional concrete designs. Modifications are required in the use of the BRE provisions so as to balance the normal condition of aggregates used for the laboratory tests and the conditions specified. The adjustments made were based on [34]. Aggregates were assumed to be saturated surface dry (SSD), condition (not oven dry or air dry) while preparing design mix. There were five phases of mix designs in the study each represented percentage replacement of NA by RCA and each consisted of 4 series thereby resulting in a total of 20 series. The concrete mixes design was made for the characteristic compressive cube strength of 50MPa at 28 days. A sum of three hundred (300) concrete samples were produced and cured in all consisting of 9 standard cubes of 150 x 150 x 150 mm each, 3 cylinders of 100 mm diameter and height of 200 mm each and 3 standard rectangular prisms each measuring 100 x 100 x 500 mm and was tested (crushed) on 7-day, 14-day and 28day curing ages for the cubes and likewise 7-day, 14-day and 28-day curing ages for both the prismatic and the cylindrical samples respectively. The Material characterization and concrete mix design chart adopted is shown in fig. 5.

The Outputs of Compressive Strength, Splitting Tensile Strength and the Flexural Strength of the control concrete and the variation concretes were also reflected in the Chapter of Results and Discussion.

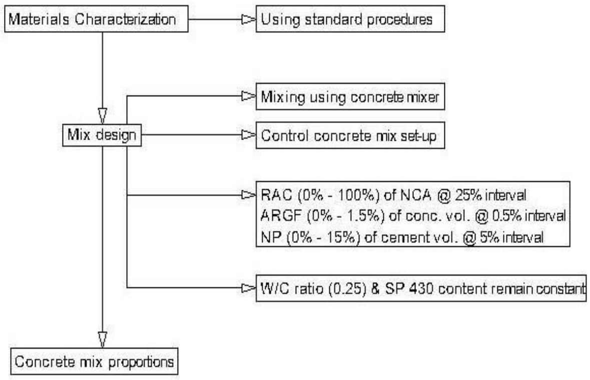

Fig. 5. Materials characterization and concrete mix design chart adopted

2.2.2. Testing of cement and pozzolan
2.2.2.1. Consistency test
Consistency test was carried out in accordance with [35].
2.2.3. Testing of Aggregates
Tests were completed on all aggregates i.e., natural fine, natural coarse and recycled concrete so as to establish their particle size distribution, specific gravity and water absorption respectively.
2.2.3.1. Material characterization methods of RAC
2.2.3.1.1. Characterization of solid material using Electron microscopy and energy dispersion
A. Scanning Electron Microscopy (SEM): This is a microscope that implements electrons instead of light to understand the microstructure of specimens and produce an image. X-rays and electrons are released from the sample as soon as the beam strikes it. Since the sample's volume is not lost as a result of the x-rays produced by electron interactions, it is

believed to be nondestructive and allows for repeated analysis of the same materials. This test was carried out according to [36].

B. Energy-Dispersive X-ray Spectroscopy/analysis/microanalysis (EDS/ EDX/ EDXS/XEDS): This is an analytical method adopted for the elemental investigation (by displaying how a structure's components are distributed) or chemical characterization of a specimen. It depends on a sample and some X-ray emission source colliding. Due to the non-destructive nature of this method, little to no sample preparation is required in order to analyze specimens of interest in situ. This test was in accordance with the specifications of [37].

2.2.3.1.2. Characterization of solid and liquid materials

It is divided into Xray fluorescent (XRF) and Xray diffraction (XRD). XRF is a NDT which evaluates for chemistry (Chemical or elemental analysis/composition) without signifying the phases and it is also used to measure the elemental configuration of solid, liquid, and powder specimens while XRD determines and measures the existence and quantity of minerals classes in a sample, including signifying phases and it is also used to determine the category of material as crystalline or amorphous. XRD was adopted.

A. X-ray Diffraction (XRD): This is a non-destructive test technique adopted to examine the structure of crystalline materials. This test was carried out in accordance with [38].

2.2.3.2. Particle size distribution (sieve analysis/ size and grading)

This test was in accordance with the specifications of [39].

2.2.3.3. Particle density and Water absorption/natural moisture content

These tests were carried out according to [34].

2.2.4. Testing of concrete

2.2.4.1. Slump test

This test was performed in accordance with [40].

2.2.4.2. Compressive strength testing

Compressive strength test was carried out according to [41].

2.2.4.3. Flexural strength testing

This was performed according to [42].

2.2.4.4. Splitting tensile strength testing

The splitting tensile strength test was conducted in accordance with [43].

3. Results and Discussion

3.1. Consistency test

The results of consistency test of cement are presented in table 4 while that of pozzolan are presented in table 5. It can be seen from the tables that the 4^{th} experiment of cement conformed and satisfied the standard range and that the 2^{nd} experiment of pozzolan conformed and satisfied the standard range of penetration required.

Table 4
Consistency test of cement

S/N	Weight of Cement (g)	Percentage by water of dry cement (%)	Amount of water added (g)	Penetration (mm)
1	300	26	78	6.7
2	300	28	84	10
3	300	30	90	20
4	300	32	96	34

Table 5
Consistency test of pozzolana (NP)

S/N	**Weight of pozzolana (g)**	**Percentage by water of dry pozzolans (%)**	**Amount of water added (g)**	**Penetration (mm)**
1	300	26	78	10
2	300	28	84	35

3.2. Characterization of RAC

Figs. 6 and 7 show the SEM and EDS of RAC while Fig. 8 displays the XRD analysis of RAC

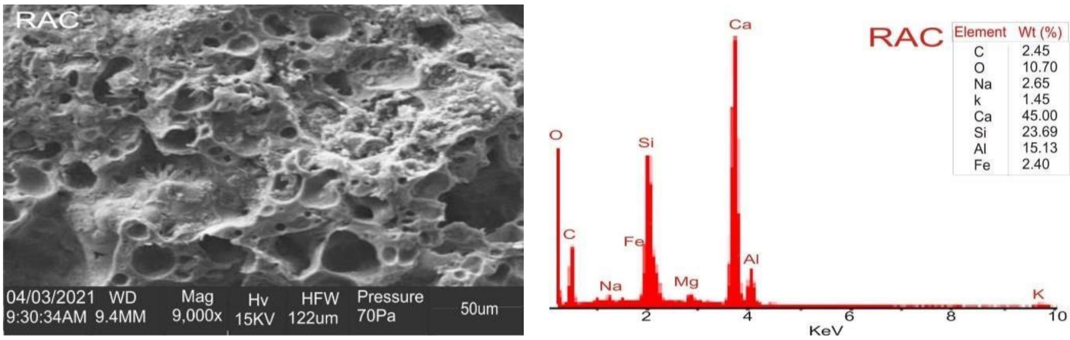

Fig. 6. SEM/EDS of the RAC adopted

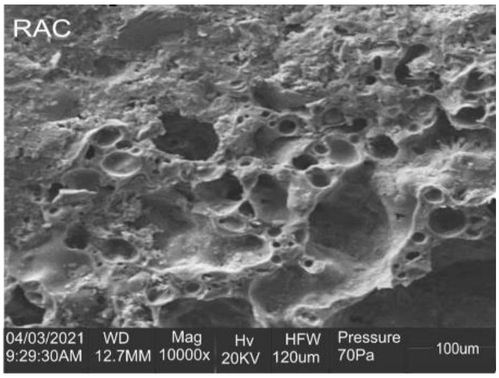

Fig. 7. SEM of the RAC implemented

The covering/superstrata/platform surface, at two different time intervals NDT, presented a course pattern/fragment/ particle structure with mortar, pores, aggregates, and interfacial transition zone (ITZ) which is the interface between bulk cement matrix/paste and aggregate particles.

EDS analyses shown in Fig. 6 was used to determine the RAC elemental deposits. The RAC was composed of: C (2.45%), O (10.7%), Na (2.65%), K (1.45%), Ca (45%), Si (23.69%), Al (15.13%), and Fe (2.4%). The EDS superstrata NDT revealed Ca, Si, Al, and O peaks.

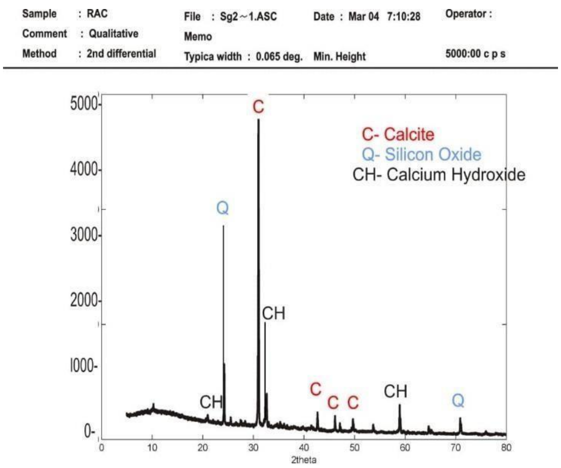

Fig. 8. XRAY diffraction of the RAC material

The attained result was derived at 5 degrees. C showed the highest diffracted peak, at a location of about 31 degrees, with an intensity up to 5000. The foremost diffracted peaks for the RAC emerged from 10 to 71 degrees.

3.3. Sieve Analysis

The particle-size distribution curves in figs. 9, 10, and 11 were used to derive the effective sizes (D10, D30, and D60), coefficient of gradation (Cc), and uniformity coefficient (Cu) for fine aggregates, coarse aggregates, and recycled coarse aggregates respectively. It can be understood from the figures and data that the fine, coarse, and recycled coarse aggregates employed for concrete work were uniformly graded and satisfied the speculations of [44].

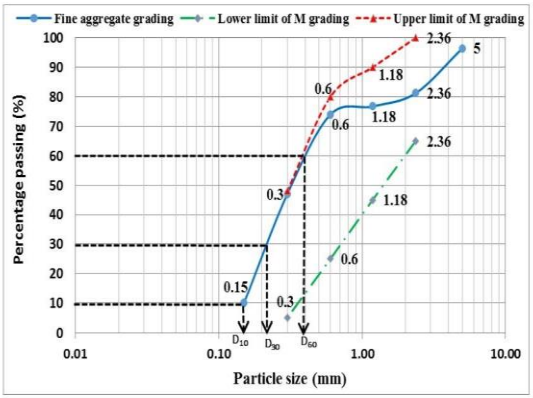

Fig. 9. Particle size distribution curve of fine aggregate

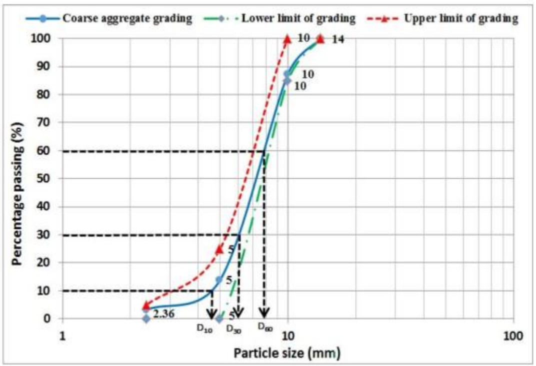

Fig. 10. Gradation curve of natural coarse aggregate

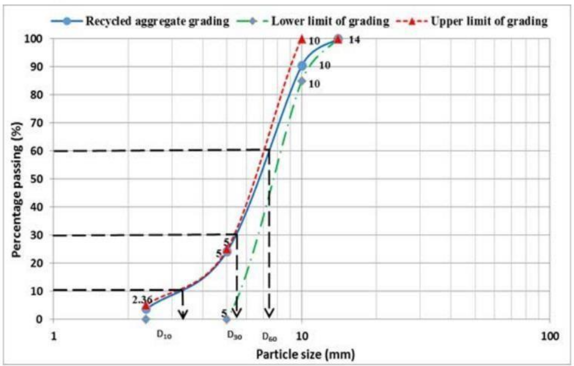

Fig. 11. Grading curve of recycled coarse aggregate

3.4. Particle density and water absorption

Particle density and water absorption measurements for fine, natural, and recycled coarse aggregates are shown in Table 6.

Table 6
Particle density and water absorption results for aggregates

Aggregate	Fine Aggregates (FA)	Natural Coarse Aggregates (NCA)	Recycled Coarse Aggregates (RCA)
Particle density (Oven dry) (kg/m³)	2209	2471	2159
Particle density (SSD) (kg/m³)	2446	2750	2324
Water absorption (%)	1.68	1.45	7.66

The particle density of the fine aggregate was 2446kg/m³ and 2209kg/m³ under saturated surface dry (ssd) and oven dry conditions respectively while the water absorption was 1.68. The particle density can also be expressed as a unit of apparent and bulk specific gravity. At saturated surface dry (ssd) and oven dried conditions, the particle density of recycled coarse aggregate was 2324kg/m^3 and 2159kg/m^3, respectively. Under the same conditions, the particle density for natural coarse aggregate was 2750kg/m^3 and 2471kg/m^3, respectively. The differences were caused, among other things, by the adhering paste's low density and high porosity on recycled aggregate from the source concrete components. Water absorption was 1.45% for natural coarse aggregate and 7.66% for recycled coarse aggregate, respectively. This means that the water absorption of natural aggregates was approximately five times lower than that of recycled aggregates. The presence of bigger pores in the recycled coarse aggregates contributed to the reduction in the Particle density and increase in the Water absorption.

3.5. Slump test

The average workability result of each concrete phase is presented on Fig. 12

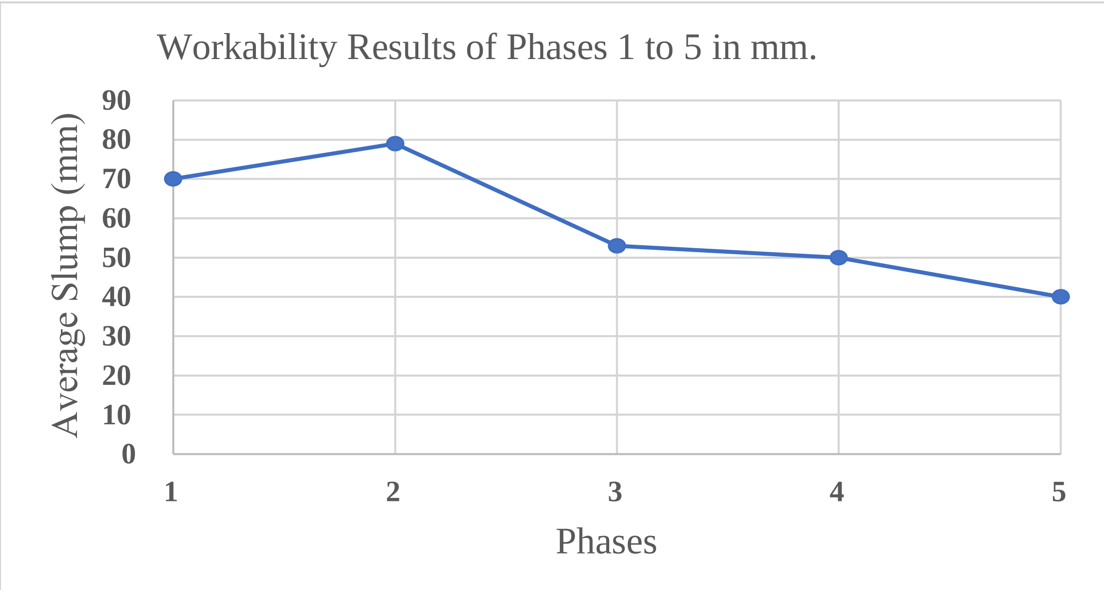

Fig. 12. Workability showing the slump results in mm of phase 1 to 5

The workability/consistency of the Control Concrete and Variation Concretes using Slump test reduced as the percentage of Recycled Aggregate Concrete, NBRRI pozzolan and glass fiber increased respectively in each phase. The numerical value of the average slump of 25% RAC Replacement was higher than other Phases average Slump due to Phase 2 being the optimal phase. The result which was optimal was shown at Phase 2 as 79mm Average Slump value.

3.6. Compressive strength, Flexural strength, and Splitting Tensile Strength of Phase 1 to 5

The mix designs input following Building Research Establishment (BRE) and Design of Experiments (DOE) procedures by extensive calculations of BRE standards of materials and of the results gotten from the properties of the materials tested for M5O (HPC) – (Control) – 0% RAC, 0% ARFG and 0% PZ indicated that the control concrete mix proportions be inputted in the ratio 1:1.3:2.67 to give the results presented as outputs (concrete curing/crushing ages) in the tables and figures of results after Concrete mixing, pouring, placing, curing and testing. A total of 5 phases each consisting of 4 series making a sum of 20 series outputs are presented as results. The results of the Compressive, flexural and splitting tensile strengths in phase 1 design mix for ages 7, 14 and 28 days are presented in Table 7 and Figs. 13, 14, and 15 respectively. The results of phase 2 design mix for same strengths and similar curing ages are presented in Table 8 and Figs. 16, 17, and 18 respectively. The results of phase 3 design mix for same strengths and similar curing ages are presented in Table 9 and Figs. 19, 20, and 21 respectively. The results of phase 4 design mix for same strengths and similar curing ages are presented in Table 10 and Figs. 22, 23, and 24 respectively. The results of phase 5 design mix for same strengths and similar curing ages are presented in Table 11 and Figs. 25, 26, and 27 respectively.

Table 7
Compressive, flexural and splitting tensile strengths in N/mm^2 for the control concrete and variation concretes in phase 1 design mix for ages 7, 14 and 28 days per cum. of concrete.

CONCRETE MIX PROPORTIONS - PHASE ONE 0% RECYCLED AGGREGATE CONCRETE REPLACEMENT										
S/N	Mix Description	Compressive strength (N/mm^2)			Flexural strength (N/mm^2)			Splitting tensile strength (N/mm^2)		
		7d	14d	28d	7d	14d	28d	7d	14d	28d
1	Control (0% RAC + 0% ARGF + 0% NP)	33.49	42.40	48.23	4.66	5.45	5.94	1.44	1.82	2.07
2	(0% RAC + 0.5% ARGF + 5% NP)	32.50	41.15	46.80	4.57	5.35	5.83	1.40	1.77	2.01
3	(0% RAC + 1% ARGF + 15% NP)	31.32	39.65	45.10	4.46	5.21	5.68	1.35	1.70	1.94
4	(0% RAC + 1.5% ARGF + 15% NP)	30.53	38.65	43.96	4.38	5.13	5.59	1.31	1.66	1.89

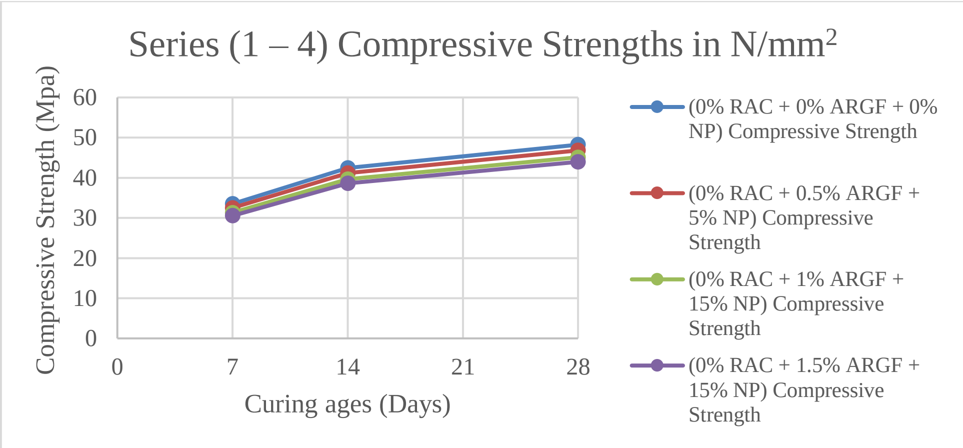

Fig. 13. Phase 1 design mix (Series 1 – 4) Compressive Strengths in N/mm^2

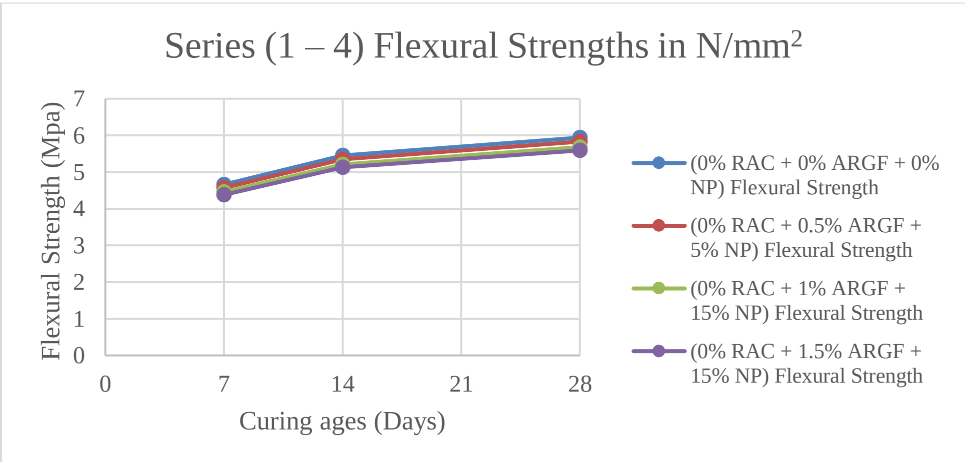

Fig. 14. Phase 1 design mix (Series 1 – 4) Flexural Strengths in N/mm^2

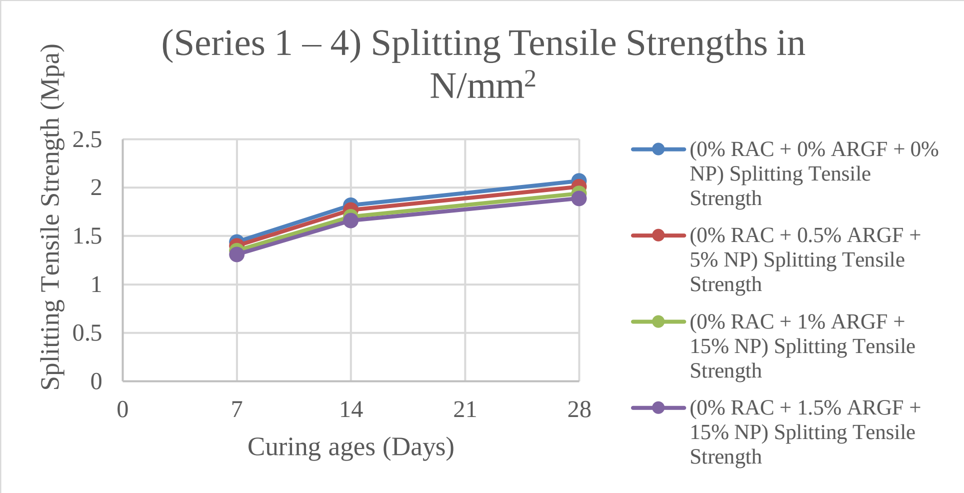

Fig. 15. Phase 1 design mix (Series 1 – 4) Splitting Tensile Strengths in N/mm^2

Table 8
Compressive, flexural and splitting tensile strengths in N/mm^2 for the variation concretes in phase 2 design mix for ages 7, 14 and 28 days per cum. of concrete.

CONCRETE MIX PROPORTIONS - PHASE TWO 25% RECYCLED AGGREGATE CONCRETE REPLACEMENT										
S/N	Mix Description	Compressive strength (N/mm^2)			Flexural strength (N/mm^2)			Splitting tensile strength (N/mm^2)		
		7d	14d	28d	7d	14d	28d	7d	14d	28d
1	(25% RAC + 0% ARGF + 0% NP)	35.01	44.32	50.41	4.80	5.62	6.12	1.51	1.91	2.17
2	(25% RAC + 0.5% ARGF + 5% NP)	35.21	44.50	50.69	4.82	5.64	6.14	1.52	1.92	2.18
3	(25% RAC + 1% ARGF + 15% NP)	32.84	41.57	47.29	4.60	5.38	5.87	1.41	1.79	2.03
4	(25% RAC + 1.5% ARGF + 15% NP)	32.05	40.57	46.15	4.52	5.30	5.77	1.38	1.74	1.98

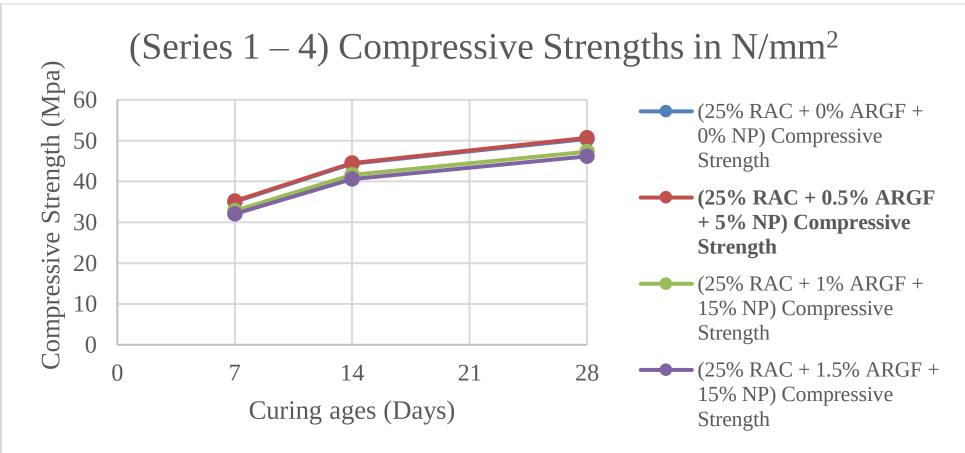

Fig. 16. Phase 2 design mix (Series 1 – 4) Compressive Strengths in N/mm^2

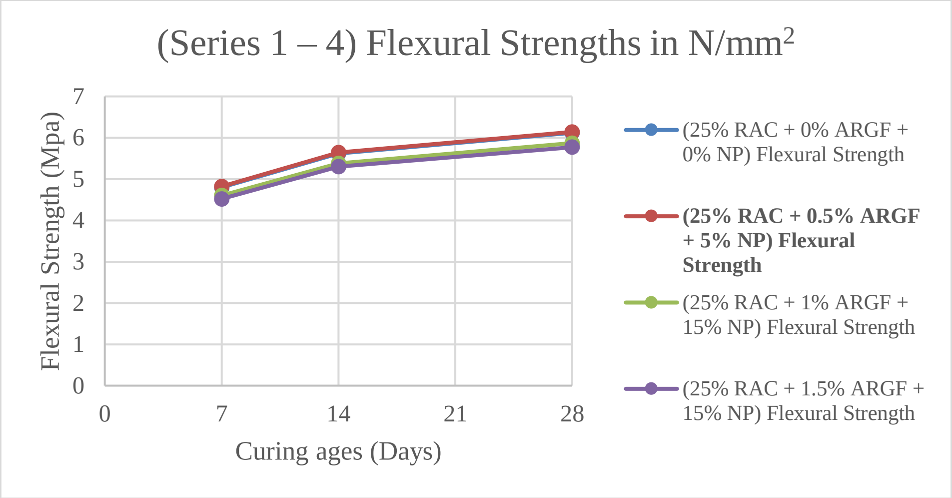

Fig. 17. Phase 2 design mix (Series 1 – 4) Flexural Strengths in N/mm^2

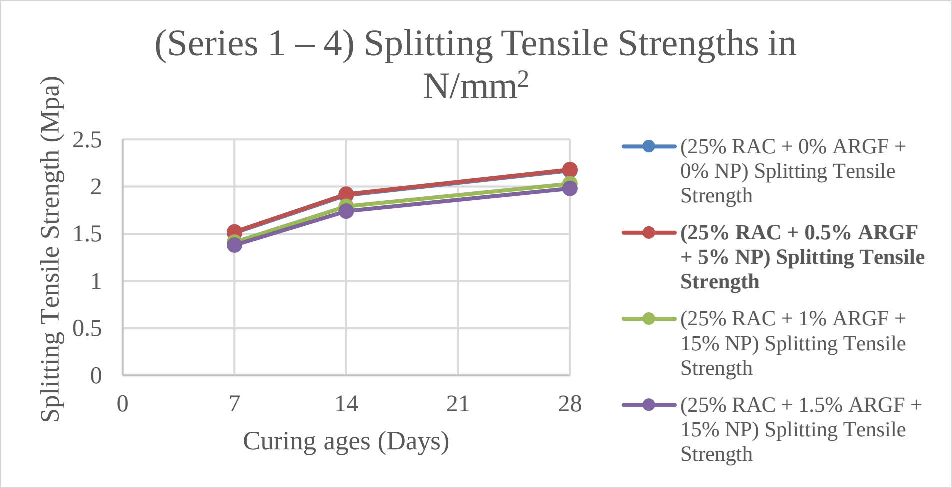

Fig. 18. Phase 2 design mix (Series 1 – 4) Splitting Tensile Strengths in N/mm^2

Table 9
Compressive, flexural and splitting tensile strengths in N/mm^2 for the variation concretes in phase 3 design mix for ages 7, 14 and 28 days per cum. of concrete.

CONCRETE MIX PROPORTIONS - PHASE THREE 50% RECYCLED AGGREGATE CONCRETE REPLACEMENT										
S/N	Mix Description	Compressive strength (N/mm^2)			Flexural strength (N/mm^2)			Splitting tensile strength (N/mm^2)		
		7d	14d	28d	7d	14d	28d	7d	14d	28d
1	(50% RAC + 0% ARGF + 0% NP)	27.85	35.26	40.10	4.12	4.82	5.25	1.20	1.52	1.72
2	(50% RAC + 0.5% ARGF + 5% NP)	26.86	34.01	38.68	4.02	4.71	5.13	1.16	1.46	1.66
3	(50% RAC + 1% ARGF + 15% NP)	25.68	32.51	36.98	3.90	4.57	4.98	1.10	1.40	1.59
4	(50% RAC + 1.5% ARGF + 15% NP)	24.89	31.51	35.84	3.82	4.47	4.88	1.07	1.35	1.54

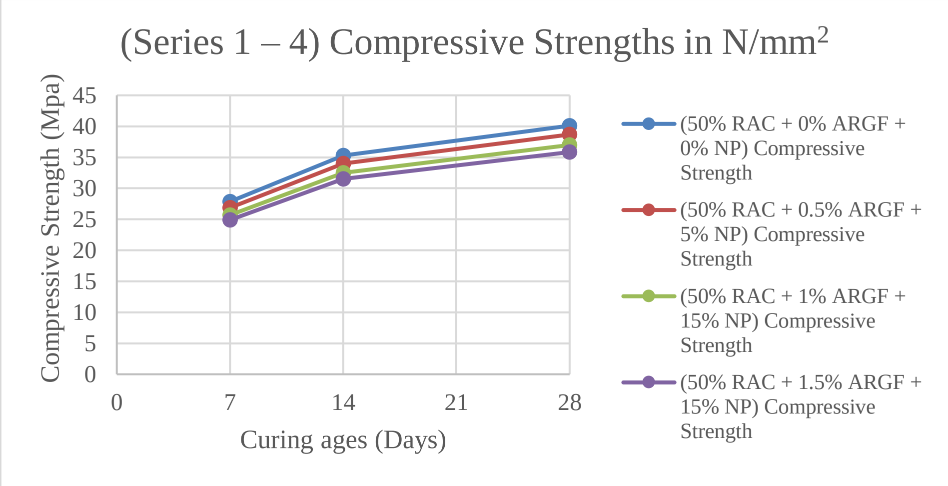

Fig. 19. Phase 3 design mix (Series 1 – 4) Compressive Strengths in N/mm^2

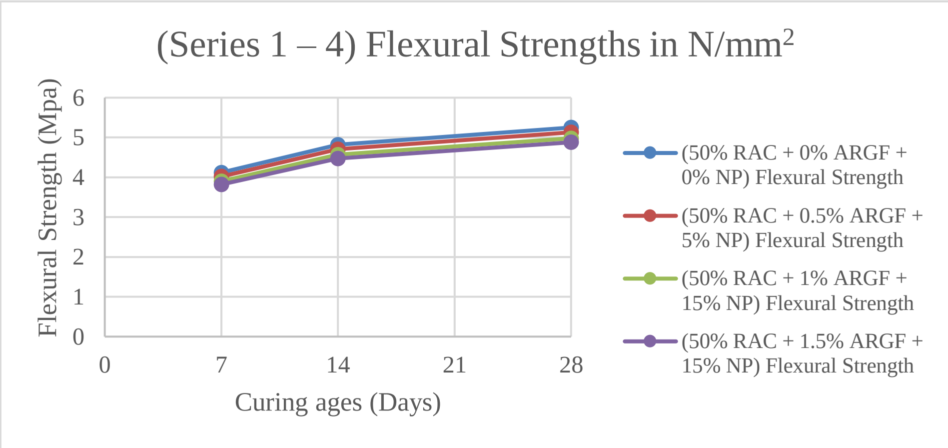

Fig. 20. Phase 3 design mix (Series 1 – 4) Flexural Strengths in N/mm^2

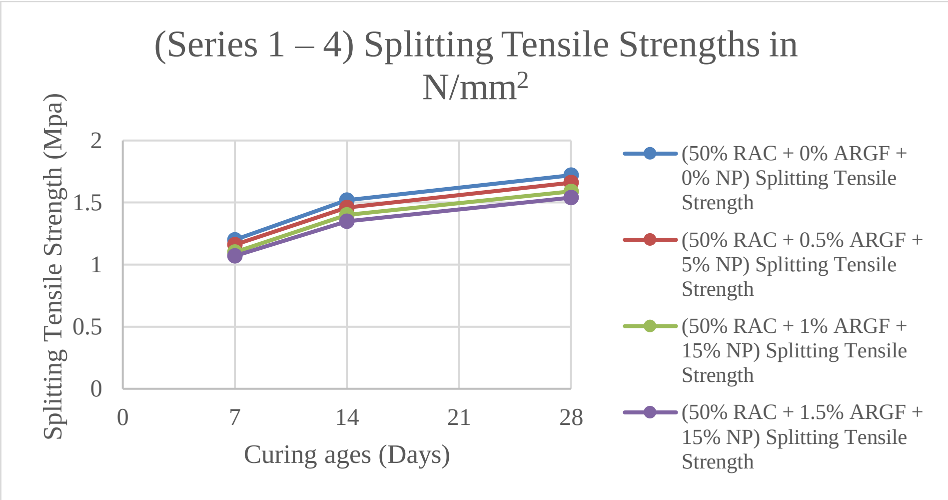

Fig. 21. Phase 3 design mix (Series 1 – 4) Splitting Tensile Strengths in N/mm^2

Table 10
Compressive, flexural and splitting tensile strengths in N/mm^2 for the variation concretes in phase 4 design mix for ages 7, 14 and 28 days per cum. of concrete.

CONCRETE MIX PROPORTIONS - PHASE FOUR 75% RECYCLED AGGREGATE CONCRETE REPLACEMENT										
S/N	Mix Description	Compressive strength (N/mm^2)			Flexural strength (N/mm^2)			Splitting tensile strength (N/mm^2)		
		7d	14d	28d	7d	14d	28d	7d	14d	28d
1	(75% RAC + 0% ARGF + 0% NP)	24.53	31.05	35.32	3.79	4.43	4.83	1.05	1.34	1.52
2	(75% RAC + 0.5% ARGF + 5% NP)	23.54	29.80	33.90	3.68	4.31	4.70	1.01	1.28	1.46
3	(75% RAC + 1% ARGF + 15% NP)	22.36	28.30	32.19	3.56	4.17	4.54	0.96	1.22	1.38
4	(75% RAC + 1.5% ARGF + 15% NP)	21.57	27.30	31.06	3.47	4.07	4.43	0.93	1.17	1.34

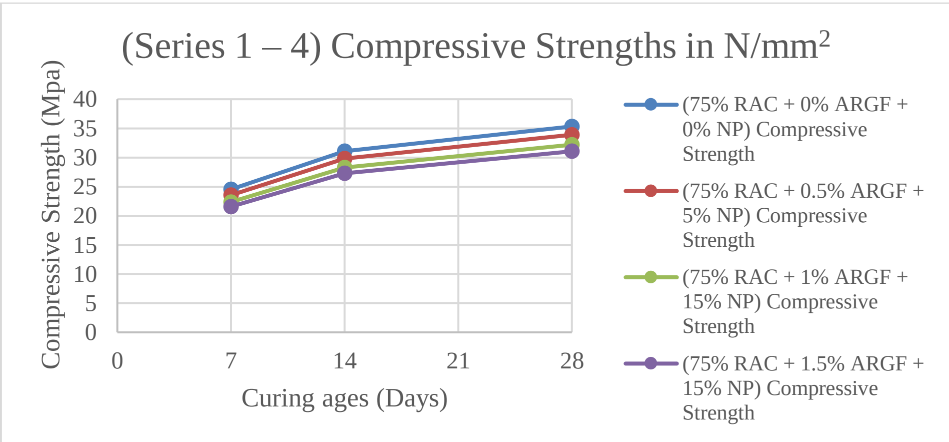

Fig. 22. Phase 4 design mix (Series 1 – 4) Compressive Strengths in N/mm^2

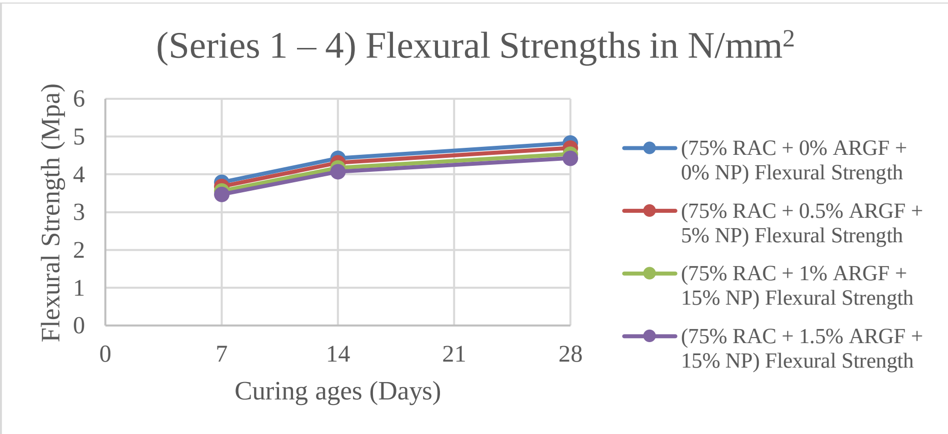

Fig. 23. Phase 4 design mix (Series 1 – 4) Flexural Strengths in N/mm^2

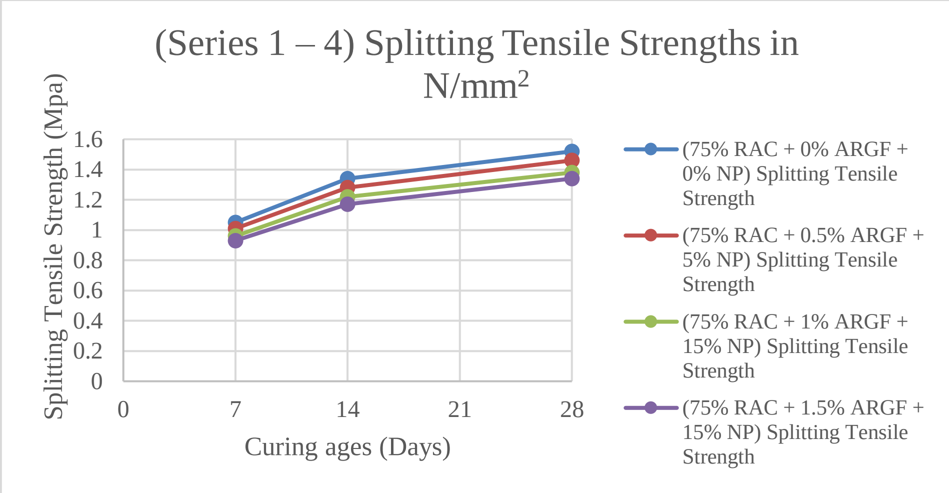

Fig. 24. Phase 4 design mix (Series 1 – 4) Splitting Tensile Strengths in N/mm^2

Table 11
Compressive, flexural and splitting tensile strengths in N/mm^2 for the variation concretes in phase 5 design mix for ages 7, 14 and 28 days per cum. of concrete.

CONCRETE MIX PROPORTIONS - PHASE FIVE 100% RECYCLED AGGREGATE CONCRETE REPLACEMENT										
S/N	Mix Description	Compressive strength (N/mm^2)			Flexural strength (N/mm^2)			Splitting tensile strength (N/mm^2)		
		7d	14d	28d	7d	14d	28d	7d	14d	28d
1	(100% RAC + 0% ARGF + 0% NP)	23.91	30.27	34.43	3.72	4.36	4.75	1.03	1.30	1.48
2	(100% RAC + 0.5% ARGF + 5% NP)	22.92	29.02	33.01	3.62	4.24	4.61	0.99	1.25	1.42
3	(100% RAC + 1% ARGF + 15% NP)	21.74	27.52	31.30	3.49	4.09	4.45	0.93	1.18	1.35
4	(100% RAC + 1.5% ARGF + 15%NP)	20.95	26.52	30.16	3.41	3.99	4.35	0.90	1.14	1.30

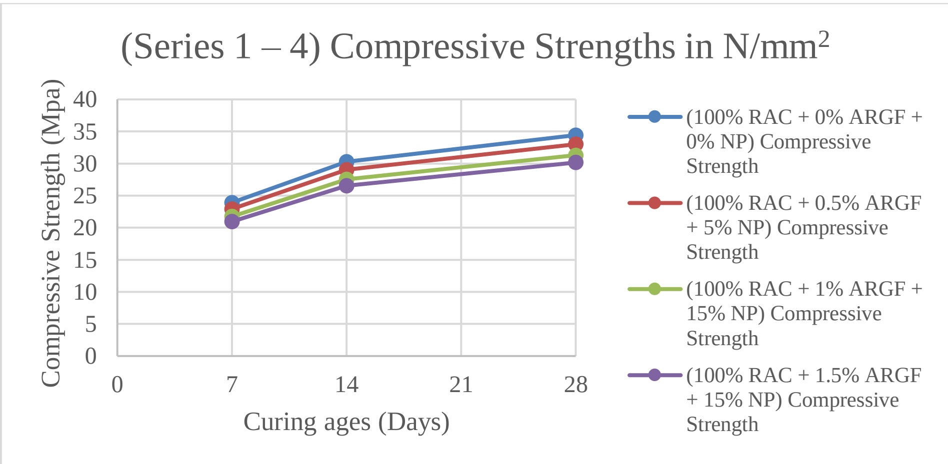

Fig. 25. Phase 5 design mix (Series 1 – 4) Compressive Strengths in N/mm^2

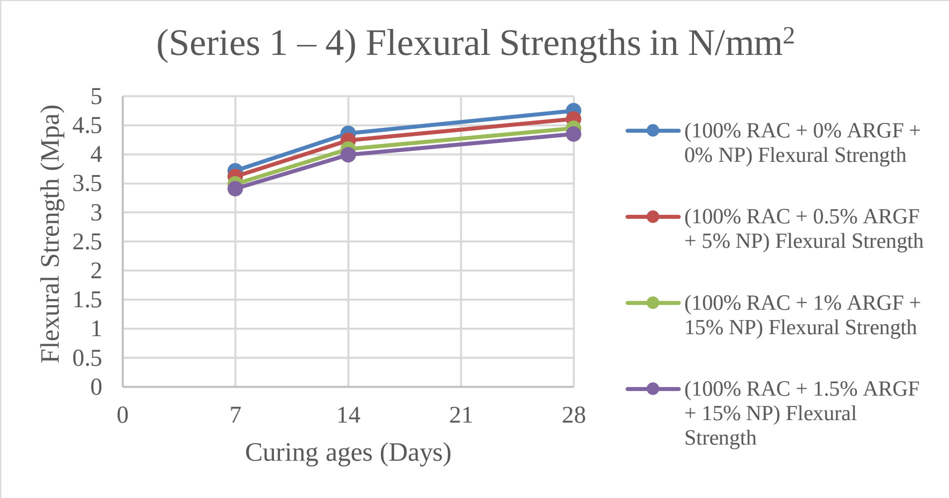

Fig. 26. Phase 5 design mix (Series 1 – 4) Flexural Strengths in N/mm^2

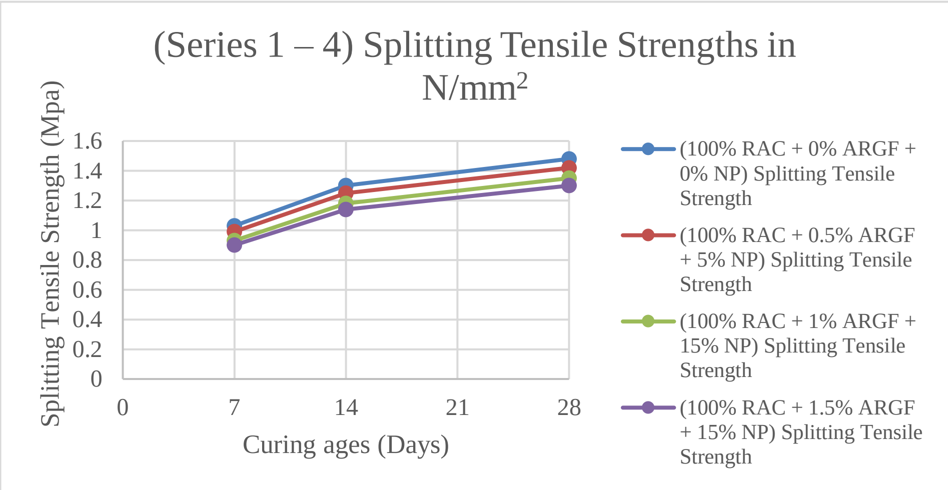

Fig. 27. Phase 5 design mix (Series 1 – 4) Splitting Tensile Strengths in N/mm^2

In the concrete mix design summary table, the RAC of 0% RAC were replacing natural coarse aggregate by weight directly while 25% RAC, 50% RAC, 75% RAC, and 100% RAC considered replacement of RAC using total weight of aggregates. The optimal Compressive strength result presented at 7 days was 35.21N/mm^2. At 14 days, it was 44.5MPa. At 28 days, 50.69N/mm^2 was the result. The optimal Compressive strength values were all arrived at Phase 2 series 2. The optimal Flexural strength result presented at 7 days was 4.82 N/mm^2. At 14 days, it was 5.64MPa. At 28 days, 6.14MPa was the result. The optimal Flexural strength values were all arrived at Phase 2 series 2. The optimal Splitting Tensile strength result presented at 7 days was 1.52N/mm^2. At 14 days, it was 1.92MPa. At 28 days, 2.18N/mm^2 was the result. The optimal Splitting Tensile strength values were all arrived at Phase 2 series 2. The optimal Compressive, Flexural and Splitting Tensile Strengths were 50.69MPa, 6.14MPa and 2.18MPa respectively. Compressive, Flexural and Splitting tensile strengths of the entire concrete were tested and established to be Optimal at Phase 2 (25% RAC Replacement).

As the percentage of Recycled Coarse Agggregate, NBRRI pozzolan and glass fiber were added to the mix in a SSD condition, the hardened strengths clearly decreased as the RCA content and other major constituents increased respectively in each Phase (except in Phase 2 where the Strengths increased at series 2 and was higher than other series then continually dropped at other series due to Phase 2 Series 2 being the Optimal Series). Phase 2 was the optimal Phase which gave the highest Compressive, Flexural and Splitting Tensile Strengths. The use of Demolition waste (as a recycled aggregate concrete) as the full replacement of Conventional Concrete in the production of High-performance Concrete was found to have the required strengths at least 28 curing days.

CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

Based on the study, the following conclusions can be drawn:

1. The physical properties of material aggregates, demolition wastes, Ordinary Portland Cement and pozzolanic materials were all determined in the laboratory.
2. The natural aggregates weight, volumes of natural concrete and that of cement using various percentages of recycled aggregates, fiberglass and pozzolana respectively were all replaced. It was realized that concrete demolition waste (instead of adopting the common route of discarding them or being used as filling materials) which is a significant member in this High-Performance Concrete Production and a recycled material to conserve natural resources reduces the conventional concrete process risky CO_2 discharge during cement production and decreases the continuous quarrying of natural aggregates.
3. The strength properties (Compressive, Splitting Tensile Strength and Flexural Strength at 28 days, workability and so on) of wet and hardened High performance concrete were determined in the laboratory by using various construction composite materials, and not depending on only the conventional concrete method.
4. The high-performance concrete using recycled aggregates, pozzolanic materials, alkali resistant fiberglass and superplasticizers were compared with the control concrete in terms of timeframe and the performance matrix of durability, strength, and essential consistency.

4.2. Recommendations

Based on the investigations of the study, the following suggestions are proffered:

1. Further studies could be made on the production of concrete using other alternatives/substitutes/case studies and should be experimented on.
2. Engineers and technologists should exercise caution and health, safety, and environment during the production of conventional concrete because of concrete's environmental impact.
3. Further investigations regarding the design mix could be done and extended on the Strength of High-Performance Concrete beyond 28 days of curing (i.e., to 56 days, 91 days).
4. Further research into this work should study the Experimental investigation of Recycled aggregate concrete in the production of high-performance concrete using artificial intelligence prediction due to the huge and tedious experiment.

ABBREVIATIONS

ARGF: Alkali Resistant Glass Fibre.
BRE: Building Research Establishment.
C&DW: Construction and Demolition waste.
CO_2: Carbondioxide.
CSC: Coconut Shell Concrete
EDS: Energy-Dispersive X-ray spectrometer.
HPC: High Performance Concrete.
HPFRRAC: High-performance fibre-reinforced recycled aggregate concrete.
NBRRI: Nigerian Building and Road Research Institute.
NDT: Non-destructive technique.
NP: NBRRI Pozzolan.
POFA: Palm Oil Fuel Ash
RAC: Recycled Aggregate Concrete.
RCA: Recycled Coarse Aggregates.
SEM: Scanning Electron Microscopy.
SLWC: Scoria Light Weight Concrete
SP: Superplasticizer.
SWEP: Students' Works Experience Program.
XRD: Xray diffraction.
XRF: Xray Fluorescent.

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