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Optimization of Compressive Strength of Concrete Containing Rubber Chips as Coarse Aggregate Based on Scheffe's Model

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Abstract

Rubber tires are produced excessively worldwide every year. It cannot be discharged off easily in the environment as its decomposition takes much time and also produces environmental pollution. In such a case the reuse of rubber would be a better choice. In other to reuse rubber wastes, it was added to the concrete as partial replacement of coarse aggregate, and its different properties like compressive strength were investigated and compared with ordinary concrete. The focus of this research is the development of a function for the optimization of the compressive strength of rubberized cement concrete based on simplex design. The response function was used to optimize the compressive strength of concrete made from water, cement sand, rubber chips, and granites. The results of the response function compared favorably with the corresponding experimental results and the predictions from the response function were tested for adequacy using the statistical student's t-test and found to be adequate at a 95% confidence level. The optimum compressive strength of concrete at 28-days work was found to be 34.45 N/mm^2. This strength corresponds to a mix ratio of 0.565:1:1.6:1.14:2.66 (i.e. water: cement: sand: rubber chips: granites). With the optimization function developed in this research, any desired compressive strength of rubberized/rubber chips cement concrete can be predicted from known mix proportions and vice versa.

Keywords — *Rubber chips, compressive strength, optimization, Scheffe's model.*

I. INTRODUCTION

In Nigeria, every year thousands of used tyres are abandoned along with other used plastic products and all constitute municipal solid wastes. These if not properly disposed of will result in serious environmental pollution leading to health hazards. Even though waste tyres are usually rethreaded and reused or processed into crumbs for making Railway Sleepers, surfaces, and into chips for use as solid fuel, this has not taken care of tyres quantities which are discarded annually.

It is estimated that 259 Million tyres are discarded annually in Nigeria (Federal Environmental Protection Agency, 2015). Recycling of used tyres reduces the volume of disused unsuitable tyres but the volume so utilized is relatively small hence disposal of used tyre waste constitutes an environmental problem due to the large volume of unsuitable used tyres produced annually in the country. This problem was exacerbated due to their durability and the fact that they contain some toxic components that are ecologically problematic (Federal Environmental Protection Agency, 2015). Solid waste management the world over has generated a lot of issues concerning how to manage them to avoid negative environmental impacts on the lives of the people and the ecosystem in general. Accumulated waste tyre rubber has become a source of concern too and such are used in many industries such as thermal power plant, cement kilns, and brick kilns, etc. But this type of waste management is not environmentally friendly and it also requires high technology thereby leading to an increase in cost. However, the use of scrap tyre rubber in the preparation of concrete has been seen as an alternative means of disposing of such waste to protect the environment as well as reduce the cost of reusing them in the manufacturing industries as fuel.

Aggregates are the main constituents of concrete because they constitute about 75 – 80% of the total volume of concrete and they do not only give the body to the concrete, but they also have a significant effect on the properties of fresh and hardened concrete based on their shape, size, texture, grading and crushing value and It is a generally accepted fact that in construction, concrete has a very high demand because of its properties thus leading to the decrease in granite and gravel deposits [1]. Coarse aggregate plays a progressively more important role in concrete behavior as strength increases. It is also true that using rubber chips from scraped or used tyres in the production of concrete will help a great deal in reducing the cost of production since coarse aggregate forms the largest percentage in volume which means that it influences the properties or performance of the concrete.

Most research in concrete is carried out to get a better understanding of its constituents and possibly improve its quality. The task of concrete mix optimization means selecting the suitable concrete aggregates with the right proportion of aggregates, the compressive strength of concrete depends primarily on the age, cement content as well as the water-cement ratio. The compressive strength is the most convenient to measure among other desirable properties of hardened concrete such as the tensile, shear, flexural, bond strength e.t.c and it is used as the criteria for overall quality for the hardened concrete.

Over the past few years, several types of research have focused on the use of different shapes and sizes of waste tires in concrete. A mixture composed of ordinary concrete (Portland cement) and rubber from recycled tires has been presented in technical literature under the names of Rubber Concrete or Rubber Modified Concrete of rubberized concrete. The rubber used in most cases was derived from post-consumption tires of motor vehicles and trucks subjected to mechanical trituration or cryogenic processes. Given the applications and performances required by the final product, the rubber was used as it is or, on some occasions, the textile component was removed and the steel fibers unstrained. In other circumstances, the rubber surface was subjected to particular chemical pretreatments to reinforce adhesion of the rubber with the grout, obtaining a clear improvement of some final properties of the concrete. The latter solution has gained worldwide recognition in the engineering field, directing many researchers in recent years to carry out additional research on the use of waste rubber in concrete. [2] commented from their research on the use of recycled tyres as materials to be used in the concrete as a partial or complete replacement of aggregate that there are four types of scrap tyre particles available which are classified in accordance to their particle size and the texture. These types consist of slit tyre particles in the form of slits which are halved in two halves. Apart from the slit tyre particles, there are shredded tyre particles which are also utilized in concrete as a replacement of aggregate in the concrete. The particle size varies from 300 to 400 millimeters long and 100-200 millimeters wide. There is also the ground type of rubber tyre available for the utility in research work which is cut in the sizes of 0.15mm - 19 mm.

[3] used crumb rubber as a partial and complete replacement of fine aggregate in concrete and reported the various performance levels of concrete subject to the different phenomenon like shrinkage, segregation, workability, flexural bending stresses, shear bending stresses, normal consistency of cement paste, and the initial and final setting times determination. [4] reported that the use of crumb tyre particles as the partial replacement of sand in the concrete has better performance levels as compared to the full or complete replacement of sand in the concrete with the crumb tyre particles. The partial replacement of sand with crumb tyre particles are imparting better performance levels to the concrete at various

Serviceability levels as compared to the complete replacement of crumb aggregate with the sand. The sand in the concrete along with the crumb tyre particles are imparting better shear capacity, fire resistance, and resistance to spalling due to various environmental hazards like fire, rainwater, and collective segregation in concrete. [2] proposed various arrangements and sequences for the preparation of samples for testing in the laboratory for determination of various parameters of structural and material importance. The most common methodology as adopted [2], was to prepare 100x100x100 mm cubes for each mix in the aggregate replacement strategy. However, cylinders of 150mm x 300mm height are also a better option for determining performance levels in concrete. [3] presented the comparison of various ASTM procedures available for the determination of performance levels when the crumb or crushed rubber aggregate is used in concrete as partial replacement of sand. [5] conducted an extensive study on the fire resistance of concrete prepared in crumb tyre aggregates. He had adopted the methodology of specimen preparation in which he used a variable amount of replacement of crushed tyre aggregate in 20%, 40%, 60%, and 80%. [6] noted that by increasing the rubber content in concrete the slump as well as the unit weight decreases. But it still gave a workable mix despite adding rubber to it when compared with ordinary concrete. [7] worked on rubberized concrete and replaced the coarse aggregate in normal concrete with the ground and crushed scrap tyre in various volume ratios. Ground rubber powder and the crushed tyre chips particles range in size from about 4 mm to 15mm were used. The effect of rubber type and rubber content on strength, modulus of elasticity was tested and studied. The stress-strain hysteresis loops were obtained by loading, unloading, and reloading specimens. Brittleness index values were calculated by hysteresis loops. Studies showed that compressive strength and modulus of elasticity of crushed rubberized concrete were lower than the ground rubberized concrete. [8] used chipped tyre rubber and crumb tyre rubber to replace the coarse and fine aggregate respectively in the concrete at replacement levels of 25%, 50%, 75%, and 100% by volume. The tyre rubber was chipped in two groups of size 5 to 10mm and 10 to 20 mm. the crumb tyre rubber of size 1 to5 mm was used. These were mixed with a ratio of 1:1.

[9] determined the hardened properties of concrete using different types of tyre rubber particles as a replacement of aggregate in concrete. The different types of rubber particles used were tyre chips, crumb rubber, and a combination of tyre chips and crumb rubber. These particles were used to replace 12.5%, 25%, 37.5%, and 50% of the total mineral aggregate by volume. The results showed that the fresh rubberized concrete had lower unit weight and workability compared to plain concrete. The result showed a large reduction in strength and modulus of elasticity in concrete when a combination of tyre rubber chips and crumb rubber were used as compared to that when these were used individually. It was found that the brittle behavior of concrete decreased with increased rubber content. The maximum toughness index indicated the post-failure strength of concrete with 25%rubber content.

[10] investigated the performance of concrete mixture incorporating 5%, 7.5%, and 10% tyre rubber by weight as a replacement of aggregate and cement. Two sets of concrete mixes were made. In the first set chipped rubber replaced the coarse aggregate and in the second set scrap tyre powder replaced cement. The durability and mechanical test were performed. The result showed that up to 5%replacement in both sets no major changes occurred in concrete characteristics.

[11][12] investigated the effect on freezing and thawing resistance of concrete mixes with rubber. Such research concluded that there is potential for using crumb rubber as a freeze-thaw resistance agent in concrete and that concrete with crumb rubber performed better under freeze-thaw conditions than plain concrete did.

II. OBJECTIVE OF STUDY

This study aimed at optimizing the compressive strength of rubberized concrete using recycled rubber tyre chips as a partial replacement for coarse aggregates in concrete mixes for cost-effectiveness, unit weight reduction, and also to reduce environmental pollution using the Simplex Scheffe's model.

The objectives of this research work among others include;

- To develop a mathematical model of concrete produced with partial replacement of coarse aggregates with Rubber Tyre chips.
- To carry out the experimental test for the compressive strength and workability of concrete for the model and control mixes for the resultant Scheffe's 5,2 mix of rubberized concrete.
- To carry out a cost comparison of rubberized concrete and conventional concrete to achieve an appropriate cost-saving.

To verify the adequacy of the optimized model with the T-test statistical method.

- To develop a computer program for the mathematical model formulated for predicting the compressive strength of concrete with partial replacement of coarse aggregates with Tyre Rubber chips using Matlab.

III. EXPERIMENTAL PROGRAMME

A. Materials

Cement: The cement used for the experiment was the Dangote brand of Portland Limestone cement grade 42.5N Produced at the cement factory located at Obajana in Kogi State, Nigeria. It was obtained in an open market in Mile 3, Port -Harcourt, Rivers State. The cement conforms with the requirements of NIS12 (1996). Table 3. Shows the chemical composition of the cement used for this study as obtained from the cement datasheet.

Table 1: Chemical Composition of Dangote Cement

S/N	CONSTITUENTS	VALUE %
1	Silicon dioxide (SiO_2)	20.54
2	Aluminum Oxide (Al_2O_3)	6.06
3	Ferric Oxide (Fe_2O_3)	2.77
4	Calcium Oxide (CaO)	64.49
5	Magnesium Oxide (MgO)	1.72
6	Sodium Oxide (Na_2O)	0.14
7	Potassium Oxide (K_2O)	0.61
8	Sulphur Oxide (SO_3)	3.03
9	Loss on ignition	0.64

Source: Yahaya, D.M (2009)

Sand: Sharp Sand which serves as the fine Aggregates was obtained from Ogbogoro in Obio/Akpor L.G.A, Port – Harcourt, Rivers State, Nigeria. The sand was collected from a heap of dredged sand from the Ogbogoro Rover, the sand was air-dried and sieved to remove clay and other impurities. The grading of the sand was carried out to [13]. The sand belongs to grading zone C [14].

Granite: Granite Chippings used in the course of this work as coarse Aggregates` with a maximum size of 20mm was sourced from a local quarry site at Akamkpa, Cross- Rivers State of Nigeria. The granite was used following [15].

Water: Water was sourced from the university's laboratory borehole.

Rubber Chips: The rubber Tyre chips were obtained from recycled tyres deposited at Mile 1 Market, Port – Harcourt, Rivers State and cut into sizes of 20mm – 25mm; the pieces were cleaned with soap water and rinsed with clean water. After drying under the sun in an open place, both faces of the tyre chips were rubbed with a hard wire brush to make surfaces as rough as practicable.

Fig. 1: Aggregate Sized Tyre Chips.

The sample preparation and test were performed in the Structural Laboratory of Rivers State University.

B. Determination of Physical Properties of Materials

The physical properties of the materials were carried out by sieve analysis of the fine and coarse aggregate. The bulk density and specific gravity of fine and coarse aggregate were determined as well as the specific gravity of cement and super-plasticizers are also known.

Cement: Grade 42.5 Portland Limestone Cement (PLC), a product of Dangote Cement obtained from Mile 3 Market Port-Harcourt was used. The cement is of uniform color (grey color) and free from any hard lump. The specific gravity of cement determined in the laboratory is 3.10.

Aggregates: The aggregates used in this research work were fine and coarse. The use of aggregate in the concrete mix is to improve both the volume stability and the durability of the resulting concrete.

The following are the types of aggregates we have in the construction industry:

- Normal weight aggregates (having a specific gravity varying from 2.5 to 3.0 and produces concrete density from 2300 to 2500 Kg/m^3). These are mainly crushed stones and gravel.
- Lightweight aggregate produces concrete density from 350 to 850 Kg/m^3 (coarse). Also, 750 to 1100 Kg/m^3 (fine).
- Heavyweight aggregate produces concrete density from 4000 to 5500 Kg/m^3.

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The type of aggregate used in this research is the normal weight aggregate.

Fine Aggregate **(**FA**):** The fine aggregates used was obtained from the natural river sand dredged in Port Harcourt and purchased from the open market as well. The sand was free from clay, debris, and other deleterious materials. The grading of the sand was carried out to [15]. The sand belongs to grading zone C [14]. Sieve analysis was carried out on the fine aggregate following [16] and the particle size distribution curve was plotted using MS Excel 2016. The bulk density test and a specific gravity test was carried out following [15]. The fine aggregate used had a bulk density value of 1936 Kg/m^3 and a specific gravity of 2.50 (2500 Kg/m^3).

Coarse Aggregate **(**CA**):** Granite Chippings used in the course of this work as coarse Aggregates` with a maximum size of 20mm and was sourced from Port Harcourt in Rivers State. The coarse aggregate used had a bulk density value of 1607 Kg/m^3 and a specific gravity of 2.54 (2540 Kg/m^3).

C. Test for Compressive Strength

The Standard Test Method for compressive strength of concrete cubes was used in this work. The method is recommended by the American Concrete Institute (ACI) for the testing of the compressive strength of concrete. A compressive Testing Machine was used to determine the compressive strength of concrete cubes made with rubber chips as coarse aggregate (''Rubber Concrete'' or ''Rubberized Concrete''). The machine automatically evaluates compressive load and display the result from which the compressive strength is calculated.

D. Concrete Mix Design Methods

Mix design consists of selecting the correct proportions of cement, fine aggregate, coarse aggregate, and water to produce concrete having specified properties. It is also the process of producing the most economical and durable concrete to be used with certain prescribed properties. The prescribe-able properties of concrete are workability of fresh concrete, crushing strength of specified concrete, age of concrete, density, thermal characteristics, elastic modulus, flexural strength, durability, etc. There are two methods of mixed design, namely, empirical and statistical methods.

1) *Empirical Methods:*

The empirical methods are of two categories, namely the historical approach and the recommended laid down rules called standards or codes of practice. All the empirical methods are cumbersome, time-wasting, labor-intensive, with high degrees of errors. Some common laid down rules or codes of practice in concrete mix design are Road Note No. 4, ACI standards 211.1-77 and 211.3-75 and 1975 British method, Road Research (1950).

- ***The Historical Method:*** This involves the use of known historical information on concrete mixtures.

  This does not cover materials that have never been used.

- ***Standard Codes of Concrete Practice:*** In this category, we have ACI-211 method, BS 812 methods, BS 5328 part 2 methods, Hughes method, Road note 4 methods, BS1881 (1970) strength method.

All the methods above, involve selecting a trial batch mix proportions. The specimen produced from the trial mix proportion are tested and results evaluated. The mix proportions are evaluated. The mixes are then, adjusted and revised for further trial batches until the specified criteria are met.
The batching method in use is either by weight or by volume. However, weight batching is the most acceptable. A typically specified mix is 1:2:4 which means one-part cement to 2-part fine aggregate to 4-part coarse aggregate. Other prescribed mixes are 1:1.5:3, 1:3:6 and1:4:8.

*2) **Statistical Methods:***

The statistical methods use the theory of statistics and some experimental results, to formulate mathematical models that were used to predict concrete mix ratios for specified properties of concrete. The main advantage is that computer programming can be applied to the models used to predict the mix ratios for specified concrete properties. It can also be used to determine or optimize the properties of concrete products. Some of the known statistical methods are scheffe's simplex methods, axial designs, process variables, orthogonal block designs inverse terms, inert components, log contrast models, mixtures with additive effect, K-models, and Osadebe's regression model [17].

The basic concrete was designed using the ACI Method of Concrete Mix Design. The calculation is summarized in Table 2 while the mix proportion is presented in Table 3.

Table 2: ACI Method of Mix Design

A.	**Calculation of volume of concrete material for three molds:**	**Output**
	$Dimension\ of\ mould\ = 0.15x0.15x0.15m^3\ =$	$0.003375m^3$
	$Density\ of\ concrete\ = 24KN/m^3$	$24000N/m^3$
	Converting Density from N/m^3 to kg/m^3	
	$Density\ of\ concrete\ = \frac{24000}{9.81} =$	2446.48kg/m^3
	$Mass\ of\ mould\ for\ one\ mould\ = 1x0.003375x2446.48 =$	8.26kg
	$Mass\ of\ materials\ for\ three\ moulds\ = 8.26x3 =$	24.78kg
B.	**The calculation for concrete cubes**	
1.	Mix proportion (1:1.68:2.60) at w/c 0.55	
	$Mass\ of\ cement\ 1 + 1.68 + 2.60 + 0.55 =$	5.83
	$Mass\ of\ cement\ = \frac{1x24.78}{5.83} =$	4.25kg
	$Mass\ of\ fine\ aggregate\ = \frac{1.68x24.78}{5.83} =$	7.14kg
	$Mass\ of\ water\ = \frac{0.55x24.78}{5.83} =$	2.34kg
	$Mass\ of\ coarse\ aggregate\ = \frac{2.60x24.78}{5.83} =$	11.05kg
	Rubber chips 5% of 11.05kg =	0.55kg
	Mass of coarse aggregate used	10.50kg

E. Experimental Procedure

1) **Sieve Analysis (Particle Size Distribution (BS 812 Part 103.1 (1985), BS 1377: (1975) Standards):** The sieve sizes are given in terms of the number of openings per millimeter. The number of openings per square millimeter is equal to the square of the sieve. The sieve analysis is a basic test, which consists of sieving a measured quantity of aggregate through a series of successively smaller sieves. The weight retained on each sieve is then expressed as a percentage of the total sample. Following BS 812 specification the sieve used are designated as 20.0mm, 19.0mm, 13.2mm, 9.50, 6.70mm, 4.75mm, 2.36mm, 1.18mm, 600mm, 300mm, 150mm, 75mm, and pan. The result of sieve analysis for the different aggregates is presented in Appendix 1 to Appendix 3 while the particle size distribution is shown in the curve in Figures 4.1 to 4.2.

The particle-size distribution can be used to determine the following four parameters for a given aggregate:

- **Effective Size (D_{10}):** This parameter is the diameter in the particle-size distribution curve corresponding to 10% finer. The effective size of a granular aggregate is a good measure to estimate the hydraulic conductivity and drainage through soil/aggregate.
- **Uniformity Coefficient (C_u):** This parameter is defined as:
  $C_u = \frac{D_{60}}{D_{10}}$
  Where D_{60} = diameter corresponding to 60% finer.

If Cu < 4.0 then the soil is uniformly graded. If the Cu > 4.0 then the soil is well-graded or gap graded.
The fineness modulus is calculated thus:

$$FM = \frac{sum\ of\ total\ \%\ retained}{100}$$

2) **Bulk Density:** Bulk density is the density of a volume of aggregate as it exists naturally, it is defined as the total mass of aggregate per unit total aggregate volume. Following BS 812, the bulk density of aggregate was measured by taking an undisturbed specimen from the field, determining its volume, and weighing it. The aggregate specimen was dipped into water to measure water displacement, and hence to calculate the volume. When the aggregate cores cutter is taken by a metal cylinder, the exact volume was determined by measuring the cylinder volume.

Table 3: Concrete Mixture Proportion

Mix ID	W/C	Mix Proportion	% Replacement for Coarse Aggregate (Rubber Chips) (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Rubber Chips (Kg/m^3)	Fine Aggregate (Kg/m^3)	Cement (Kg/m^3)	Water (Kg/m^3)	Total (Kg/m^3)
M1C	0.55	1:1.68:2.60	0	1091.36	0.00	705.19	419.75	231.11	2447.41
M1			5	1037.04	54.32	705.19	419.75	231.11	2447.41
M2C	0.60	1:1.50:2.20	0	960.00	0.00	720.00	480.00	288.40	2448.40
M2			10	864.20	95.80	720.00	480.00	288.40	2448.40
M3C	0.50	1:1.2:2.40	0	1151.61	0.00	575.80	480.00	240.00	2447.41
M3			20	921.48	230.12	575.80	480.00	240.00	2447.40
M4C	0.52	1:1.3:3.10	0	1281.98	0.00	537.28	413.83	215.31	2448.40
M4			30	897.78	384.20	537.28	413.83	215.31	2448.40
M5C	0.56	1:1.4:3.50	0	1326.42	0.00	530.37	379.26	212.35	2448.40
M5			5	1260.25	66.17	530.37	379.26	212.35	2448.40
M6C	0.50	1:1.4:3.32	0	1306.67	0.00	551.11	393.09	193.54	2444.41
M6			10	1176.30	130.37	551.11	393.09	193.54	2444.41
M7C	0.58	1:1.6:3.60	0	1299.75	0.00	577.78	360.49	209.38	2447.40
M7			20	1040.00	259.75	577.78	360.49	209.38	2447.40
M8C	0.60	1:1.5:2.70	0	1139.75	0	633.09	421.73	252.84	2447.41
M8			30	798.04	341.73	633.09	421.73	252.84	2447.43
M9C	0.55	1:1.1:3.40	0	1375.80	0.00	445.43	404.94	222.22	2448.39
M9			5	1312.59	63.21	445.43	404.94	222.22	2448.39
M10C	0.59	1:1.6:3.75	0	1322.47	0	563.95	355.56	208.40	2450.38
M10			10	1190.12	132.35	563.95	355.56	208.40	2450.38
M11C	0.575	1:1.7:4.0	0	1345.19	0	571.85	335.8	193.58	2446.42
M11			20	1076.54	268.64	571.85	335.8	193.58	2446.41
M12C	0.565	1:1.6:3.80	0	1335.31	0	537.28	360.49	198.52	2431.60
M12			30	934.32	400.99	537.28	360.49	198.52	2431.60

3) **Specific Gravity Test: BS 812: Part 2: 1995 – 1999, BS 1377:1975:** Specific gravity is the ratio of the mass of the aggregate particles to the mass of the same (absolute) volume of water. 100ml Pycnometer bottle and 100kg weighing balance were used in the experiment. The samples were oven-dried at 115°C for 24 hours. The test required that a series of weighing be carried out after the soil has been placed in a special density bottle called a pycnometer. Water was added to the sample and the weight determined, also the weight of empty bottle plus sample were determined and it is calculated by the formula:

For fine aggregate and cement using 100ml pycnometer;

$$G_s = \frac{W_2 - W_1}{100 - (W_3 - W_2)}$$

Where:
W_1 = weight of density bottle, W_2 = weight of the bottle and dry sample, W_3 = weight of the bottle, sample, and water.
For coarse aggregate using core cutter;

$$G_s = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_1)}$$

Where:
W_1 = weight of core cutter cylinder
W_2 = weight of core cutter cylinder + sample
W_3 = weight of core cutter cylinder + sample + water and
W_4 = weight of core cutter cylinder when filled with water only.

4) **Workability of Concrete**
According to the American Concrete Institute (ACI), Workability is defined as the ease with which concrete can be mixed, placed, consolidated, and finished. A mix that is difficult to place and consolidate will increase the cost of handling and ultimately lead to poor strength, durability, and appearance. Because it is practically impossible to devise test methods that can simultaneously check all these characteristics and properties, the measure of workability of a concrete mixture is obtained indirectly through its consistency. Consistency is the relative mobility, and or the ability of freshly mixed concrete to flow. It is indicative of the wetness of the mix. Wetter mixes are more workable.
Water requirement for a given consistency depends mostly on aggregate characteristics, hence to increase cohesiveness and finish ability of concrete for mixes with high consistency, use of water reducing and the mixture should be considered rather than adding more water. For high strength concrete, a low w/c ratio should be maintained. While workability should be achieved by the use of admixtures, such as water reducers and air-entertainer.

- **Slump Flow Test:** The slump flow test is done to access the horizontal flow of concrete in the absence of obstructions. It is the most commonly used test and gives a good assessment of filling ability. The test also indicates the resistance to segregation [18].

This was carried out following BS 1881: Part 102: 1983.

Equipment:

- The usual slump cone having a base diameter of 200mm, to the diameter of 100mm, and a height of 300mm is used.
- A stiff base plate square in shape having at least 700mm side. Concentric circles are marked around the center point where the slum cone is to be placed. A firm circle is drawn at 500mm in diameter.
- A trowel
- Scoop
- Measuring tape
- Stopwatch

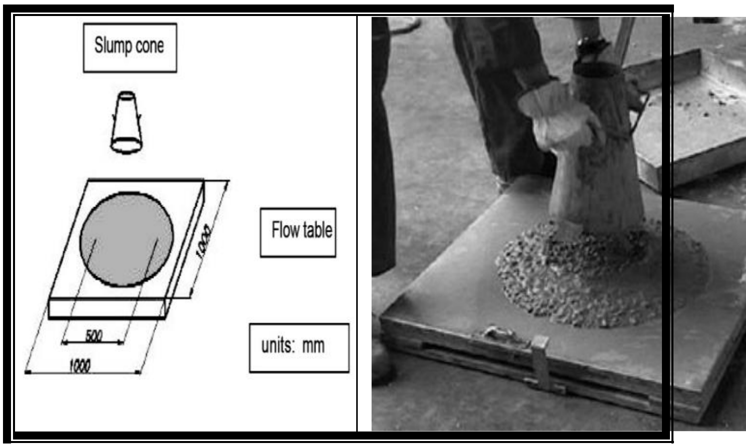

Fig 2: Slump Flow Test Method

Procedure:
About 6 liters of concrete is needed for this test. Place the baseplate on level ground. Keep the slump cone centrally on the base plate. Fill the cone with the scoop and tamp it. Simply strike off the concrete level with the trowel. Remove the surplus concrete lying on the base place. Raise the cone vertically and allow the concrete to flow freely. Measure the final diameter of the concrete in two perpendicular directions and calculate the average of the two diameters. This is the slump flow in mm. Note that there is no water or cement paste or mortar without coarse aggregate is seen at the edge of the spread concrete.

5) **Compressive Strength of Concrete:** Concrete mixtures can be designed to provide a wide range of mechanical and durability properties to meet the design requirement of a structure. The compressive strength of concrete is the most common performance standard used by engineers in designing buildings and other structures. The compressive strength is measured by breaking cylindrical/cube concrete specimens in a compressive testing machine.

The compressive strength is calculated by dividing the failure load read from the Compressive machine after crushing and it is divided by the cross-sectional area resisting the load.

$$Compressive\ Strength = \frac{Crushed\ Load\ (N)}{Effective\ Area\ (mm^2)}$$

Compressive strength tests are primarily used to determine if the concrete mixture as delivered meets the requirements of the specified strength (f_c) in the job specifications. Strength test results are used for Quality Control and Quality Assurance as well as in the design of the target.

Strength test results from cast cylindrical/cubes concrete may be used for quality control, acceptance of concrete, or for estimating the concrete strength in a structure for planning and scheduling construction operations such as fixing/removal of formwork as well as for evaluating the adequacy of curing.

A test result is the average of at least two standard strength specimens and tested at the same age. In most cases, strength requirements for concrete are at the age of 28 days. Design engineers use specific strength f_{cx}, higher than the specified strength such as the risk of not complying with the strength specification is minimized.

It is also very important that an individual test falling below f_{cx} does not necessarily constitute a failure to meet specification requirements. When the average of the strength tests on a job is at the required average strength, $f_{cx,}$ the probability that individual strength tests will be less than the specified strength is about 10% and this is accounted for in the acceptance criteria.

When strength test results indicate that the concrete delivered fails to meet the requirements of the specification, it is important to recognize that the failure may be in the testing, not in the concrete.

This is specifically true if the fabrication; handling, carrying, and testing of cylinders are not conducted following standard procedures. Historical strength test records are used by the concrete producer to establish the target strength of concrete mixtures for future work.

- **Compressive Strength Test:** The Cube tests were carried out following BSEN206 2001: Part 3.

Apparatus

- 150 x 150 x150mm mould
- Tamping rod
- Hand Trowel
- Curing Tank
- Weighing Balance
- Compressive Testing Machine

Procedure:

The freshly batched concrete mixes were filled into the 150x150x150mm mold in three layers with each layer given 35 strokes of the tamping rod. The concrete was stored under damp sacking for 24 hours. The cubes were later demoulded after 24 hours and thereafter cured in the water tank at room temperature. After 7, 14, and 28days the cubes were brought out of water dried, and weigh. The compressive strength was conducted on 7, 14, and 28days using the compressive machine. The compressive strength is calculated from the equation below;

$$f_c = \frac{failure\ load}{cross\ sectional\ area}$$

For cubes,

$$f_c = \frac{P}{A}$$

Where f_c = compressive strength, P = failure load, A = cross sectional area of cube

F. Steps in Scheffe's Modeling Technique for 5, 2 Mix:

Step1: Generate a designed mix using the ACI Method of concrete mix design to determine mix ratios of basic without the replacement of coarse aggregate with Rubber Chips.

Step 2: Optimization of deigned mix

(i) Generate variations of the designed mix by varying the contents of Rubber Chips at the imaginary boundaries of the factor space. These are the actual mixes, comprising five (5) pure blends at vertices: (a, 0, 0, 0, 0, 0), (0, a, 0, 0, 0, 0), (0, 0, a, 0, 0, 0), (0, 0, 0, a, 0, 0), (0, 0, 0, 0, a, 0), (0, 0, 0, 0, 0, a); ten (10) binary blends at mid points: (a/2, a/2, 0, 0, 0) , (a/2, 0, a/2, 0, 0), (a/2, 0, 0, a/2, 0) , (a/2, 0, 0, 0, a/2), (0, a/2, a/2, 0, 0), (0, a/2, 0, a/2, 0) , (a/2, a/2, 0, 0, 0), (a/2, a/2, 0, 0, 0), (a/2, a/2, 0, 0, 0); and fifteen (15) combinations of ternary and complete blends (a/3, a/3, a/3, 0, 0), (a/3, a/3, a/3, 0, 0), (a/4, a/4, a/4, 1/4, 0) and (a/5, a/5, a/5, a/5, a/5,) which make up the controls systems, where a=1.

(ii) Interact the mixes with the pseudo values at the corresponding points in the factor space as follows S = AX, where S= actual component of the mix, A=Matrix of all the component mixtures at vertices, while X is the pseudo values.

Step 3: The ratios resulting from the above mathematical operations are converted to real values of combination by multiplying the ratios with the total weights/volumes of the already known resultant mixture.

Step 4. The results of the laboratory test are used to fit the models, while the result of the mathematical operations on the control segment is used for validation of the model.

Step 5: The model is validated by stating the hypothesis for which the result between model prediction and laboratory varies or close.

IV. DISCUSSION OF RESULT

A. Sieve Analysis (Particle Size Distribution): The particle size distribution for the coarse aggregate and fine aggregate were determined from the sieve analysis test. The results from the sieves analysis test (PSD) for the coarse aggregate (20mm max.) and fine aggregate are shown in figures 3 & 4 below.

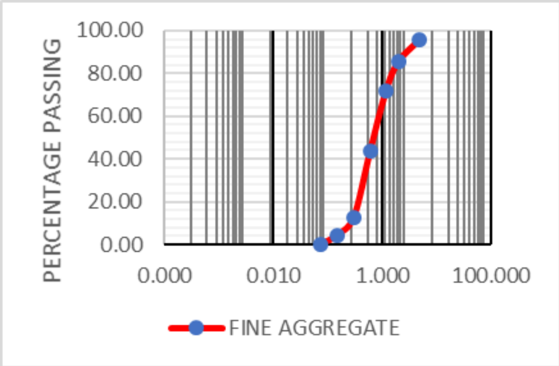

Fig 3: Particle Size Distribution for the Fine Aggregate

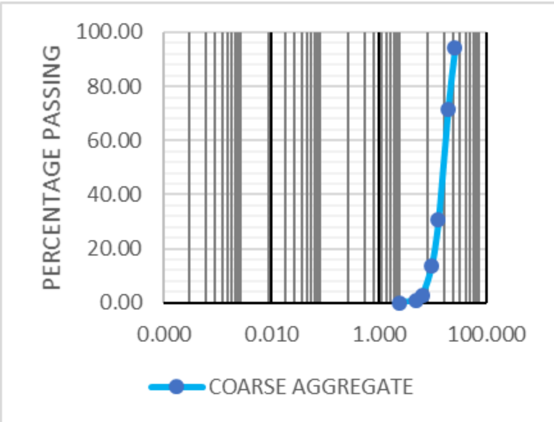

Fig. 4: Particle Size Distribution for the Coarse Aggregate (20mm max. size)

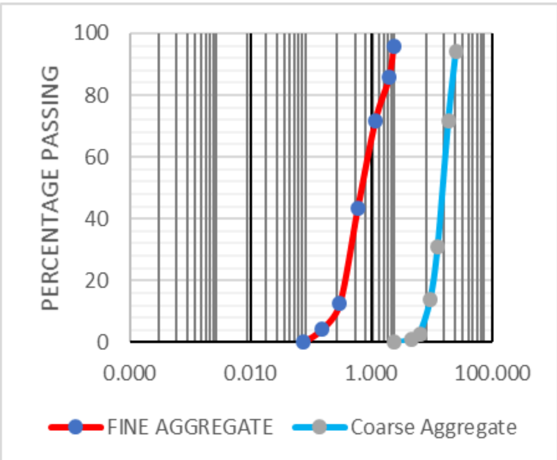

Fig 5: Particle Size Distribution for All Aggregates

Table 4: Summary of Particle Size Distribution Calculation Results (for Aggregates)

Particle Size Distribution	Fine Aggregate	Coarse Aggregate
Fineness Modulus (FM)	3.00	18.00
Uniformity Coefficient (Cu)	2.80	2.00

B. Workability: The replacement of coarse aggregate by tyre rubber affects the workability of the concrete. The workability of rubberized concrete shows an increase in a slump with an increase of waste tyre rubber content of the total aggregate volume. The result of the normal concrete mix showed an increase in workability, but it can be summarized that the workability is adversely affected by the incorporation of chipped tyre rubber. The result of the slump test is shown in table 5 and Figure 6.

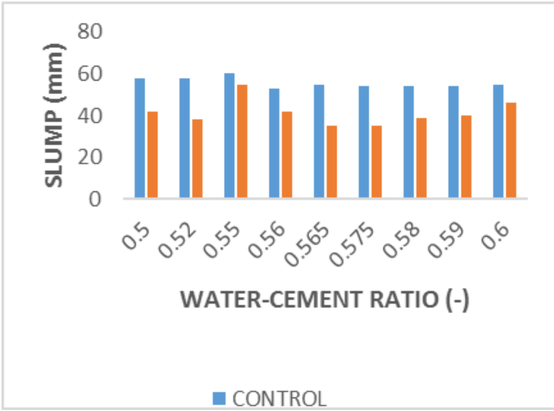

Fig 6: Plot of Slump Flow (mm) against W/Cement Ratio

C. Compressive Strength: The results of the compressive strength of concretes tested after 7, 14 ad 28 days of wet curing are presented in Table 6 and figures 7, 8, and 9.

D. Density: Table 7 shows the results of the laboratory tests on 28 days density of rubberized concrete from hardened concrete. It can be observed from Table 7 that a water/cement ratio of 0.55, mix M9 with mix proportion of 1:1.1:3.40 achieved a density of normal concrete of 2415kg/m^3.

E. Scheffe's Method: Scheffe's method of optimization is applicable to mixtures in which the desired response depends on the proportion of component mixture consisting of water, cement, river sand, rubber chips, and crushed granite rock. This was analyzed using a four-dimensional simplex lattice. The four-dimensional simplex lattice factor space is shown in figure 11 below:

Table 6: Compressive Strength of Rubberized Concrete from Hardened Concrete

Mix ID	Compressive Strength						Average Compressive Strength		
	7 Days Compressive Strength (N/mm^2)		14 Days Compressive Strength (N/mm^2)		28 Days Compressive Strength (N/mm^2)		7 Days Strength (N/mm^2)	14 Days Strength (N/mm^2)	28 Days Strength (N/mm^2)
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2			
M1C	27.92	25.25	27.03	28.81	28.00	26.20	26.59	27.92	27.10
M1	26.67	24.00	25.78	27.56	27.56	31.11	25.34	26.67	29.34
M2C	26.98	27.87	27.42	27.87	27.00	23.40	27.43	27.65	25.20
M2	25.78	26.67	26.22	26.67	30.22	28.44	26.23	26.45	29.33
M3C	20.71	22.48	22.93	22.04	26.04	26.93	21.60	22.49	26.49
M3	19.56	21.33	21.78	20.89	24.89	25.78	20.45	21.34	25.34
M4C	18.88	21.54	21.54	22.43	26.88	25.99	20.21	21.99	26.44
M4	17.78	20.44	20.44	21.33	25.78	24.89	19.11	20.89	25.34
M5C	19.92	25.25	24.36	23.47	27.92	27.03	22.59	23.92	27.48
M5	18.67	24.00	23.11	22.22	26.67	25.78	21.34	22.67	26.23
M6C	23.42	21.64	26.09	27.87	28.76	31.87	22.53	26.98	30.32
M6	22.22	20.44	24.89	26.67	27.56	30.67	21.33	25.78	29.12
M7C	22.48	23.37	26.04	23.37	26.93	28.71	22.93	24.71	27.82
M7	21.33	22.22	24.89	22.22	25.78	27.56	21.78	23.56	26.67
M8C	22.43	21.54	21.99	22.43	25.10	27.32	21.99	22.21	26.21
M8	21.33	20.44	20.89	21.33	24.00	26.22	20.89	21.11	25.11
M9C	22.58	25.25	22.58	27.92	26.00	27.60	23.92	25.25	26.80
M9	21.33	24.00	21.33	26.67	27.56	28.44	22.67	24.00	28.00
M10C	20.76	19.87	18.98	22.98	28.76	28.76	20.32	20.98	28.76
M10	19.56	18.67	17.78	21.78	27.56	27.56	19.12	19.78	27.56
M11C	24.26	23.37	25.15	26.04	28.71	29.59	23.82	25.60	29.15
M11	23.11	22.22	24.00	24.89	27.56	28.44	22.67	24.45	28.00
M12C	26.88	25.99	31.32	31.77	33.99	33.10	26.44	31.55	33.55
M12	25.78	24.89	30.22	30.67	32.89	32.00	25.34	30.45	32.45
M13C	20.71	22.48	22.93	22.04	26.04	26.93	21.60	22.49	26.49
M13	19.56	21.33	21.78	20.89	24.89	25.78	20.45	21.34	25.34
M14C	26.98	27.87	27.42	27.87	31.42	29.64	27.43	27.65	30.53
M14	25.78	26.67	26.22	26.67	30.22	28.44	26.23	26.45	29.33
M15C	27.92	25.25	27.03	28.81	28.81	32.36	26.59	27.92	30.59
M15	26.67	24.00	25.78	27.56	27.56	31.11	25.34	26.67	29.34

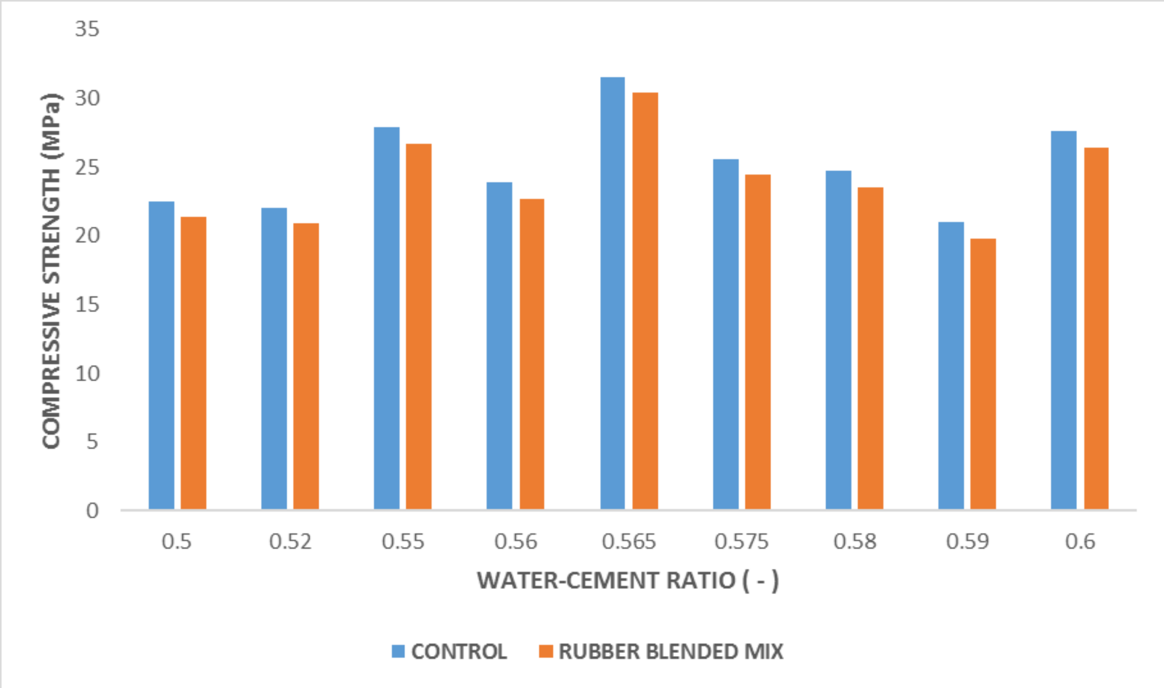

Fig. 8: Plot of the 14 days Compressive Strength (MPa) against Control Mix and % of Rubber Chips for Concrete

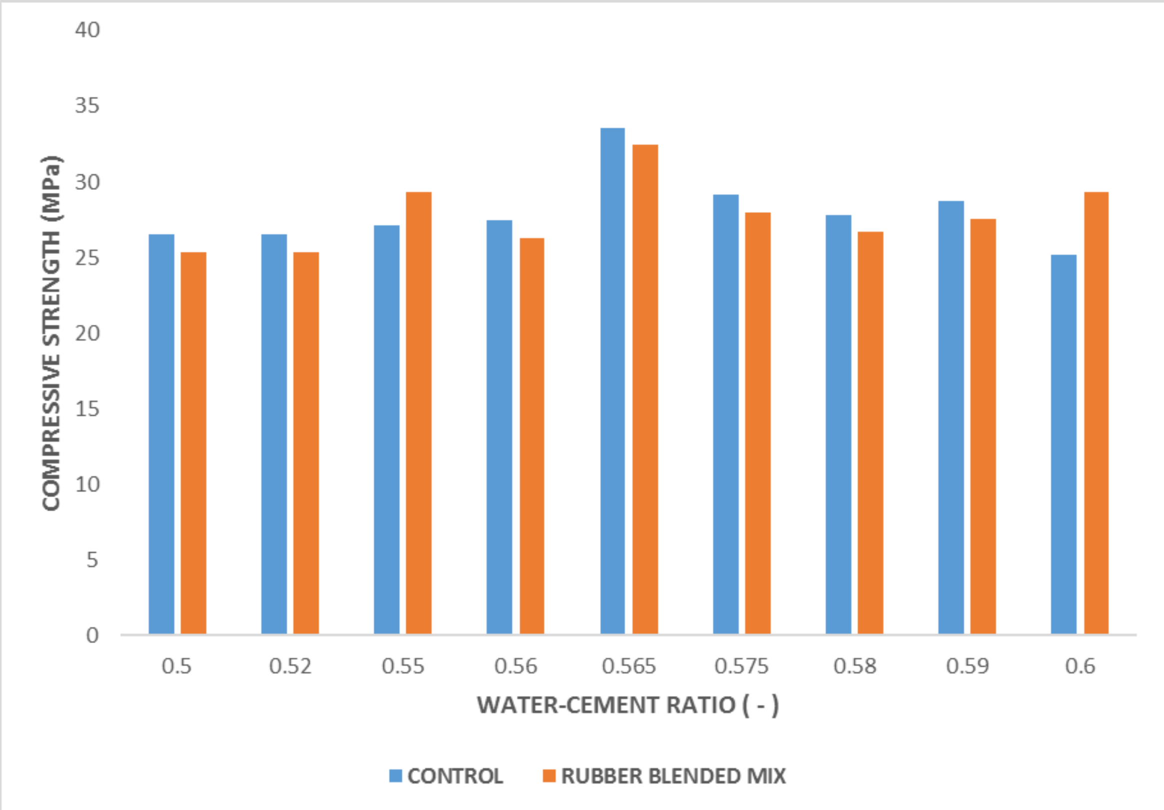

Fig. 9: Plot of the 28 days Compressive Strength (MPa) against Control Mix and % of Rubber Chips for Concrete

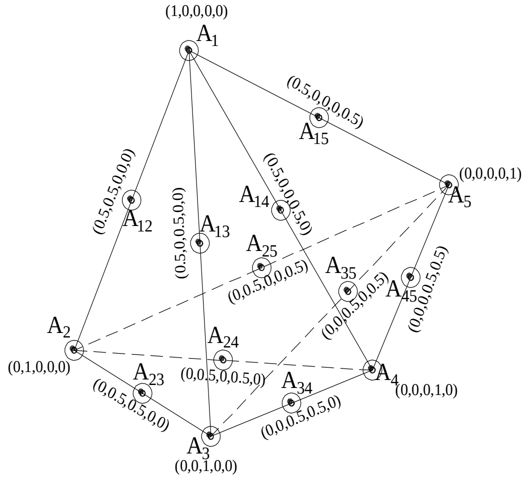

Fig 11: A Four-dimensional for a (5, 2) Factor Space

According to[19], a five-component mixture like rubber chips-cement concrete, the X_i of the i^{th} component of the mixture must satisfy the following constraint:

$$X_i \geq 0 \ (i = 1,2,3,4,5) \qquad (1)$$

And the sum of all proportions of the constituents of the five-component of rubber chips-cement concrete must be equal to unity, i.e.

$$\sum_{i=1}^{q} X_i = 1 \qquad (2)$$

For the five-component rubber chips-cement concrete,

$$X_1 + X_2 + X_3 + X_4 + X_5 = 1 \qquad (3)$$

The response sought for the performance criterion of interest (i.e. compressive strength of the rubber chips-cement concrete) is presented using a polynomial function of pseudo components. According to [19], the equation of response represented by a polynomial function is given by Equation (4):

$$Y = b_0 + \sum b_i X_i + \sum b_{ij} X_i X_j + \sum b_{ijk} X_i X_j X_k + \cdots + e$$

Where;

b_i, b_{ij}, b_{ijk} are constants; X_i, X_j, X_k are pseudo components and e is the random error term represents the combined effect of all variables not included in the model.

The number of coefficients, k, of the polynomial, is determined using Equation (5).

$$k = \frac{(q + m - 1)!}{(q - 1)! * m!} \qquad (5)$$

Where q is the number of components of the mixture, and, m is the degree of the polynomial.

For the five-pseudo component mixture with two degrees, the number of coefficients is fifteen. The equation of the response, Y, for the five-pseudo component mixture is given as:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{15}X_1X_5 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{25}X_2X_5 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{45}X_4X_5 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 + b_{55}X_5^2 \qquad (6)$$

Multiplying Equation (3) by b_0 yields Equation (7)

$$b_0X_1 + b_0X_2 + b_0X_3 + b_0X_4 + b_0X_5 = b_0 \qquad (7)$$

Multiplying Equation. (3) Successively by X_1, X_2, X_3, X_4 and X_5 rearranging the products, gives Equation.

$$X_1^2 = X_1 - X_1X_2 - X_1X_3 - X_1X_4 - X_1X_5$$
$$X_2^2 = X_2 - X_1X_2 - X_2X_3 - X_2X_4 - X_2X_5$$
$$X_3^2 X_3 - X_1X_3 - X_2X_3 - X_3X_4 - X_3X_5 \qquad (8)$$
$$X_4^2 = X_4 - X_1X_4 - X_2X_4 - X_3X_4 - X_4X_5$$
$$X_5^2 = X_5 - X_1X_5 - X_2X_5$$

Substituting Equation. (7) & (8) into Equation (6) and simplifying the results, gives Equation (9)

$$Y = \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{14}X_1X_4 + \beta_{15}X_1X_5 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{25}X_2X_5 + \beta_{34}X_3X_4 + \beta_{35}X_3X_5 + \beta_{45}X_4X_5 \qquad (9)$$

Where β_i and X_i are the coefficient of response equation and pseudo components of the mix respectively.

The coefficients β_i and X_i are defined as follows:

$$\left.\begin{aligned} \beta_i &= b_0 + b_i + b_{ii} \\ \beta_{ij} &= b_{ij} - b_{ii} - b_{jj} \end{aligned}\right\} \qquad (10)$$

And Equation (5) can be represented in the form:

$$Y = \sum_{i=1}^{5} \beta_i X_i + \sum_{i \leq j \leq 5}^{5} \beta_{ij} X_i X_j \qquad (11)$$

1) **Determination of the Coefficients of the Polynomial Function:** If the response function is represented by Y, the response function for the pure component, 'i' and that of binary mixture components, 'ij' are Y_i and Y_{ij} respectively.

$$Y_i = \sum_{i=5}^{5} \beta_i X_i \qquad (12)$$

And

$$Y_{ij} = \sum_{i=5}^{5} \beta_i X_i + \sum_{i \leq j \leq 5}^{5} \beta_{ij} X_i X_j \quad (4) \qquad (13)$$

The substituting of the values of the pseudo components X_1, X_2, X_3, X_4 and X_5 at the i^{th} on the lattice into Equation. (12), yields Equation. (14)

$$Y_i = \beta_i \qquad (14)$$

And substituting the pseudo components X_1, X_2, X_3, X_4 and X_5 at the point ij, into Equation (13), yields Equation. (15)

$$Y_{ij} = \frac{1}{2}\beta_i + \frac{1}{2}\beta_j + \frac{1}{4}\beta_{ij} \qquad (15)$$

Rearrangement of Eqn. (14) and (15) gives:

$$\beta_i = Y_i \qquad (16)$$
$$\beta_{ij} = 4Y_{ij} - 2Y_i - 2Y_j \qquad (17)$$

Let $n_i = Y_i$ & $n_{ij} = Y_{ij}$, hence, Equations (16) and (17) will be:

$$\beta_i = n_i \quad (18)$$

$$\beta_{ij} = 4n_{ij} - 2n_i - 2n_j \quad (19)$$

Substituting Equation. (18) & (19) into Equation. (9), simplifying further gives:

$$Y = n_1X_1(2X_1 - 1) + n_2X_2(2X_2 - 1) + n_3X_3(2X_3 - 1) + n_4X_4(2X_4 - 1) + n_5X_5(2X_5 - 1) + 4n_{12}X_1X_2 + 4n_{13}X_1X_3 + 4n_{14}X_1X_4 + 4n_{15}X_1X_5 + 4n_{23}X_2X_3 + 4n_{24}X_2X_4 + 4n_{25}X_2X_5 + 4n_{34}X_3X_4 + 4n_{35}X_3X_5 + 4n_{45}X_4X_5 \quad (20)$$

Equation (20) is the response function for the optimization of rubber chip cement concrete consisting of five components. The terms n_i and n_{ij} are the responses (i.e. compressive strengths) at the points i and ij. The values of these responses are determined by carrying out compression tests on cubes obtained using rubber chips as one of the components of concrete.

2) **Concrete Mix Ratios:** Five mixed ratios (real and pseudo) that defined the vertices of the four-dimensional simplex lattice used in this study are shown in Table 8.

According to [17] the actual mix ratios relate to pseudo mix ratios is defined by the following equation:

$$\{S\} = [A]\{X\} \quad (21)$$

where'S.A and X represent the real mix ratio, coefficient of relation matrix, and pseudo mix ratio respectively. According to [17], matrix A can be taken to be the transpose of the first five real mix ratios shown in Table 8, and this resulted in matrix A:

$$A = \begin{matrix} 0.55 & 0.60 & 0.50 & 0.52 & 0.56 \\ 1 & 1 & 1 & 1 & 1 \\ 1.68 & 1.5 & 1.2 & 1.3 & 1.4 \\ 2.47 & 1.8 & 1.92 & 2.17 & 3.32 \\ 0.13 & 0.2 & 0.48 & 0.93 & 0.17 \end{matrix} \quad (22)$$

(5, 2) simplex design, ten other observations are needed to add up to the first five to get a total of fifteen observations needed for the development of the response function. The remaining ten points are located at the midpoints of the lines joining the five vertices. On successive substitution of these ten pseudo mix ratios into Equation (22), the real mix ratios corresponding to the pseudo ones were obtained. Their values are shown in Table 9.

To validate the optimization function, extra fifteen points (C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}, C_{11}, C_{12}, C_{13}, C_{14}, and C_{15}) of observations were used. These observations provided control mix ratios needed to test the validity of the response function. The mix ratios (actual and Pseudo) for the entire work are shown in Table 10

3) **Optimization Function for Predicting the Compressive Strength of the Concrete:** The final optimization function is obtained by substituting the compressive strength of concrete cubes from the first fifteen points of observations (N_1, N_2, N_3, N_4, N_5, N_{12}, N_{13}, N_{14}, N_{15}, N_{23}, N_{24}, N_{25}, N_{34}, N_{35}, and N_{45}) into Equation (20) to obtain Equation (23):

$N_1 = 29.$

$N_2 = 29.33$

$N_3 = 25.34$

$N_4 = 25.34$

$N_5 = 26.23$

$N_{12} = 4(29.12) = 116.48$

$N_{13} = 4(26.67) = 106.68$

$N_{14} = 4(25.11) = 100.44$

$N_{15} = 4(28.00) = 112$

$N_{23} = 4(27.57) = 110.28$

$N_{24} = 4(28.00) = 112$

$N_{25} = 4(32.45) = 129.8$

$N_{34} = 4(25.34) = 101.36$

$N_{35} = 4(29.33) = 117.32$

$N_{45} = 4(29.34) = 117.36$

$$Y = 29.34(2X_1 - 1)X_1 + 29.33(2X_2 - 1)X_2 + 25.34(2X_3 - 1)X_3 + 25.34(2X_4 - 1)X_4 + 26.23(2X_5 - 1)X_5 + 116.48X_1X_2 + 106.68X_1X_3 + 100.44X_1X_4 + 112X_1X_5 + 110.28X_2X_3 + 112X_2X_4 + 129.8X_2X_5 + 101.36X_3X_4 + 117.32X_3X_5 + 117.32X_4X_5 \quad (23)$$

The Equation (23) is the final function for the optimization of compressive strength of rubber chips cement concrete.

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Table 8: Five Mix Ratios (Actual and Pseudo) Obtained from Scheffe's (5, 2) Factor Space

Points	Real Mix Ratios: Water S_1	Cement S_2	Sand S_3	Granite S_4	RCP S_5	Pseudo Mix Ratios: Water X_1	Cement X_2	Sand X_3	Granite X_4	RCP X_5
N_1	0.550	1.0	1.68	2.47	0.13	1.0	0.0	0.0	0.0	0.0
N_2	0.600	1.0	1.50	1.80	0.20	0.0	1.0	0.0	0.0	0.0
N_3	0.500	1.0	1.20	1.92	0.48	0.0	0.0	1.0	0.0	0.0
N_4	0.520	1.0	1.30	2.17	0.93	0.0	0.0	0.0	1.0	0.0
N_5	0.560	1.0	1.40	3.32	0.17	0.0	0.0	0.0	0.0	1.0

Legend: RCP = Rubber Chips

Table 9: Ratios for Thirty Points Observations (Actual and Pseudo) Obtained from Scheffe's Factor

	Real Mix Ratios					Pseudo Mix Ratios				
Points	Water S_1	Cement S_2	Sand S_3	Granite S_4	RCP S_5	Water X_1	Cement X_2	Sand X_3	Granite X_4	RCP X_5
N_1	0.550	1.0	1.68	2.47	0.13	1.0	0.0	0.0	0.0	0.0
N_2	0.600	1.0	1.50	1.80	0.20	0.0	1.0	0.0	0.0	0.0
N_3	0.500	1.0	1.20	1.92	0.48	0.0	0.0	1.0	0.0	0.0
N_4	0.520	1.0	1.30	2.17	0.93	0.0	0.0	0.0	1.0	0.0
N_5	0.560	1.0	1.40	3.32	0.17	0.0	0.0	0.0	0.0	1.0
N_{12}	0.500	1.0	1.40	2.99	0.33	0.50	0.50	0.00	0.00	0.00
N_{13}	0.580	1.0	1.60	2.88	0.72	0.50	0.00	0.50	0.00	0.00
N_{14}	0.600	1.0	1.50	1.89	0.81	0.50	0.00	0.00	0.50	0.00
N_{15}	0.550	1.0	1.10	3.24	0.16	0.50	0.00	0.00	0.00	0.50
N_{23}	0.590	1.0	1.59	3.35	0.37	0.00	0.50	0.50	0.00	0.00
N_{24}	0.575	1.0	1.70	3.21	0.8	0.00	0.50	0.00	0.50	0.00
N_{25}	0.565	1.0	1.49	2.59	1.11	0.00	0.50	0.00	0.00	0.50
N_{34}	0.500	1.0	1.20	1.92	0.48	0.00	0.00	0.50	0.50	0.00
N_{35}	0.600	1.0	1.50	1.80	0.20	0.00	0.00	0.50	0.00	0.50
N_{45}	0.550	1.0	1.68	2.47	0.13	0.00	0.00	0.00	0.50	0.50
CONTROL										
C_1	0.550	1.0	1.68	2.60	0.0	0.333	0.333	0.333	0.00	0.00
C_2	0.600	1.0	1.50	2.00	0.0	0.333	0.00	0.333	0.333	0.00
C_3	0.500	1.0	1.20	2.40	0.0	0.333	0.00	0.00	0.33	0.333
C_4	0.520	1.0	1.30	3.10	0.0	0.25	0.25	0.25	0.25	0.00
C_5	0.560	1.0	1.40	3.50	0.0	0.25	0.00	0.25	0.25	0.25
C_6	0.500	1.0	1.40	3.32	0.0	0.25	0.25	0.25	0.00	0.25
C_7	0.580	1.0	1.60	3.61	0.0	0.50	0.25	0.25	0.00	0.00
C_8	0.600	1.0	1.50	2.70	0.0	0.25	0.00	0.25	0.00	0.50
C_9	0.550	1.0	1.10	3.40	0.0	0.40	0.20	0.20	0.20	0.00
C_{10}	0.590	1.0	1.59	3.72	0.0	0.20	0.20	0.20	0.20	0.20
C_{11}	0.575	1.0	1.70	4.01	0.0	0.30	0.10	0.20	0.20	0.20
C_{12}	0.565	1.0	1.49	3.70	0.0	0.10	0.20	0.20	0.30	0.20
C_{13}	0.500	1.0	1.20	1.92	0.0	0.35	0.15	0.25	0.00	0.25
C_{14}	0.600	1.0	1.50	1.80	0.0	0.25	0.20	0.15	0.20	0.20
C_{15}	0.550	1.0	1.68	2.47	0.0	0.45	0.05	0.00	0.20	0.30

Legend: RCP = Rubber Chips

Table 10: Compressive Strength (N/mm^2) of the 28 Day Old Concrete Cubes

Points	Compressive Strength (N/mm^2)		Mean Experiment Compressive Strength (N/mm^2)	Predictive Compressive Strength of Concrete Cubes (N/mm^2)
	Replicate 1	Replicate 2		
N_1	27.56	31.11	29.34	29.34
N_2	30.22	28.44	29.33	29.33
N_3	24.89	25.78	25.34	25.34
N_4	25.78	24.89	25.34	25.34
N_5	26.67	25.78	26.23	26.23
N_{12}	27.56	30.67	29.12	29.12
N_{13}	25.78	27.56	26.67	26.67
N_{14}	24.00	26.22	25.11	25.11
N_{15}	27.56	28.44	28.00	28.00
N_{23}	27.56	27.56	27.56	27.57
N_{24}	27.56	28.44	28.00	28.00
N_{25}	32.89	32.00	32.45	32.45
N_{34}	24.89	25.78	25.34	25.34
N_{35}	30.22	28.44	29.33	29.33
N_{45}	27.56	31.11	29.34	29.33
C_1	27.00	27.20	27.10	27.63
C_2	25.30	25.10	25.20	25.31
C_3	26.04	26.93	26.49	27.33
C_4	26.88	25.99	26.44	26.78
C_5	27.92	27.03	27.48	27.66
C_6	28.76	31.87	30.32	29.51
C_7	26.93	28.71	27.82	27.95
C_8	25.10	27.32	26.21	28.50
C_9	27.40	26.20	26.80	26.89
C_{10}	28.76	28.76	28.76	28.68
C_{11}	28.71	29.59	29.15	28.03
C_{12}	33.99	33.10	33.55	28.76
C_{13}	26.04	26.93	26.49	28.98
C_{14}	31.42	29.64	30.53	28.64
C_{15}	28.81	32.36	30.59	28.06

4) Test of Adequacy of the Model

The test for adequacy of the optimization function, obtained from the (5, 2) simplex design, was done using statistical student's t-test at 95% accuracy level. The compressive strength at the control points C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}, C_{11}, C_{12}, C_{13}, C_{14}, and C_{15}). Two hypotheses were considered in the test namely:

- **Null Hypothesis**: At 95% accuracy level, that there is no significant difference between the laboratory concrete cube strength and the cube strength results obtained from the optimization function.
- **Alternative Hypothesis:** At a 95% accuracy level, there is a significant difference between the laboratory concrete cube strength and concrete cube strength obtained from the optimization model.

The test is carried out as shown in Table 11.

D_i = The difference of compressive strength obtained from Experiment, Y_E and the one optimization function, Y_m.

D_A = The mean of $D_i = \frac{\sum D_i}{N}$

The variance of the square of the difference between D_A and D_i,

$$S^2 = \frac{\sum (D_A - D_i)^2}{N-1}$$

N = Number of observation points

The standard deviation of the difference between D_A and D_i, $S = \sqrt{S}$

Therefore,

$$D_i = \frac{\sum D_i}{N} = \frac{4.19}{15} = 0.2793$$

$$S^2 = \frac{\sum (D_A - D_i)^2}{N-1} = \frac{46.2396}{14} = 3.3028$$

$$S = \sqrt{S} = \sqrt{5.1959} = 1.8174$$

- **Actual value of total variation in t-test**

For the two-tailed test, the actual value of t is:

$$t_{calculated} = \frac{D_A N^{0.5}}{S} = \frac{0.2793\,(15)^{0.5}}{1.8174} = 0.5952$$

- **Allowable value of total variation in t-test:**

Degree of freedom = N-1 = 15 – 1 = 14

At 5% significance level, for the two-tailed test = 2.5%

100 – 2.5% = 97.5% = 0.975

Allowable total variation in t-test, i.e. $t_{table} = t_{(0.97514)}$ = 2.14 (obtained from standard statistical table).

From the t-table, the calculated t = 0.5952 which is less than the t-value of 2.14 from the standard statistical table.

Thus, $t_{table} > t_{calculated}$

This implied that the difference between the set of cube's compressive strength is insignificant. Hence the null hypothesis is accepted and the alternative hypothesis rejected. Therefore, the optimization function for the prediction of compressive strength of rubber chip cement concrete is adequate.

Table 11: Statistical Student's t-test for (5, 2) Simplex Design

TWO-TAILED t-TEST					
Point	**Y_E**	**Y_M**	**$D_i = Y_E - Y_M$**	**$D_A - D_i$**	**$(D_A - D_i)^2$**
C_1	27.10	27.63	-0.53	0.8090	0.6545
C_2	25.20	25.31	-0.11	0.3890	0.1513
C_3	26.49	27.33	-0.84	1.1240	1.2634
C_4	26.44	26.78	-0.35	0.6240	0.3894
C_5	27.48	27.66	-0.18	0.4640	0.2153
C_6	30.32	29.51	0.81	-0.5260	0.2767
C_7	27.82	27.95	-0.13	0.4090	0.1673
C_8	26.21	28.50	-2.29	2.5690	6.5998
C_9	26.80	26.89	-0.09	0.3690	0.1362
C_{10}	28.76	28.68	0.08	0.1990	0.0396
C_{11}	29.15	28.03	1.12	-0.8410	0.7073
C_{12}	33.55	28.76	4.79	-4.5060	20.3040
C_{13}	26.49	28.98	-2.50	2.7740	7.6951
C_{14}	30.53	28.64	1.89	-1.6110	2.5953
C_{15}	30.59	28.06	2.53	-2.2460	5.0445
			$\sum D_i = \mathbf{4.19}$		$\sum (D_A - D_i)^2 = \mathbf{46.2396}$

Legend: Y_E is the experiment compressive strength and Y_M is the model compressive stren

V. CONCLUSION

Using simplex design polynomial equation, mix design function for a five-component rubber chips cement concrete cube was developed. This optimizing function could predict the compressive strength of the concrete cube when the mix ratios are known and vice versa. The predictions from this model were tested at a 95% accuracy level using statistical student's t-test and found to be adequate. The maximum strength predicted by this model is 32.45 N/mm^2. This strength is from a mix ratio of 0.565:1:1.6:1.14:2.66 (corresponding to the water: cement: sand: rubber chips: granite).

The model for the design of rubberized concrete using the scheffe's simplex theory is given as:

$$Y = 29.34(2X_1 - 1)X_1 + 29.33(2X_2 - 1)X_2 + 25.34(2X_3 - 1)X_3 + 25.34(2X_4 - 1)X_4 + 26.23(2X_5 - 1)X_5 + 116.48X_1X_2 + 106.68X_1X_3 + 100.44X_1X_4 + 112X_1X_5 + 110.28X_2X_3 + 112X_2X_4 + 129.8X_2X_5 + 101.36X_3X_4 + 117.32X_3X_5 + 117.32X_4X_5$$

From the study, the following recommendations are made;

1. The use of waste tyres for various applications by traditional recyclers is not a common practice in Nigeria so far. With the increase in urbanization and the change in the living conditions of the society, the conventional way cannot continue with time. Hence, there will be a potential accumulation of waste tyres, especially in the larger cities of the country. The Government so far has attempted by declaring the solid waste management proclamation on the import of waste tyres. Moreover, the country should also enforce laws regarding the management of waste tyres before the problem expands and reaches an uncontrollable level.

2. It is observed most times that designers and contractors go the extra mile to achieve high strength and expensive concrete to get few improved properties such as impact resistance in parking areas and lightweight structures for particular applications. Nevertheless, these properties can be achieved through the application of rubberized concrete by first conducting a laboratory test regarding the desired properties. Therefore, the use of rubberized concrete is an alternative concrete making material that needs attention.
3. Since the long-term performance of these mixes was not investigated in the present study, the use of such mixes is recommended in places where the high strength of concrete is not as important as the other properties.
4. Future studies should be continued in the following areas as part of the extension of this research work.
5. In this research, a constant dosage of admixture was used for a particular mix category. It will be more helpful if the effects of the various dosages of admixtures are investigated.
6. This research was done by preparing a single grader's rubber aggregate of size 20mm. The effect of different sizes should be studied in the future. Besides this, the effects in different percentage replacements other than those made in this research need to be investigated.

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