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# EXPERIMENTAL INVESTIGATION AND INTELLIGENT PREDICTION OF MECHANICAL STRENGTH OF PERVIOUS CONCRETE

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**Abstract** This study determines the mechanical strength characteristics of pervious concrete using fuzzy logic. During construction, the process of determining the quality of concrete produced takes about 28 days before testing, training the fuzzy logic model through the research data gotten from the laboratory experiments in order to intelligently predict the mechanical strength of pervious concrete. Crushed granite was used in this experiment to ensure the pervious concrete has a little degree of fine aggregates and the maximum size of coarse aggregate used was 20 mm. Compressive, flexural and split tensile strength tests were carried out on pervious concrete of mixing ratios 1:4, 1:5 and 1:6 with each of the mixing ratios having varying water to cement ratios of 0.4, 0.5, 0.6 and 0.7. The developed fuzzy logic model was applied to predict the mechanical strengths of the concrete by using data obtained from experimental results, with input parameters of water content, crushing value, weight and density and the mechanical strengths as the output parameters employing the triangular membership function. The model was calibrated using the error measures of the root mean square error (RMSE), mean absolute percentage error (MAPE) and R squared were computed for the model. In this study, it was observed that higher water to cement ratio slightly reduces the mechanical strength of PC but increases the workability compared to increase in cement to granite ratio which notably increases the strength and reduced the workability, alternatively, higher water to cement ratio causes a notable decrease in permeability of the pervious concrete. The correlation between the experimental and predicted values was excellent. This shows that fuzzy logic can be used to predict the mechanical properties of pervious concrete, and fuzzy logic can also be used to appropriately deduce missing values in the mechanical properties of PC subject to further research.

**Keywords:** Compressive Strength, Pervious Concrete, Intelligent Prediction, Mechanical Strength

## I. INTRODUCTION

The word "concrete" originates from the Latin verb "concretes" which literally means to grow together and it has been established that no construction can be done economically without the use of concrete [1]. Concrete is a widely used and very important construction material which comprises of different constituents.

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These constituents include cement, aggregates and water and its quality is hinged on its compressive strength, tensile and flexural. strength. These mechanical strengths depend on mix proportion, consistency of its constituents, as well as its workmanship on site [2]. Concrete is used in the building sector as a result of its reliability, durability and also strength in different climatic conditions. Concrete sets and hardens after mixture and placement and the type and nature of aggregates that make up the concrete strongly affect the concrete's properties at the fresh stage, setting stage and hardened state, and also affects the concrete's mixture proportions and economy [3]. Concrete can be used for making pavements, architectural structures, foundations, bridges, etc.

Pervious concrete (PC) which is also referred to as "no-fines" concrete is a different type of concrete in which little or no fine aggregates are used and gravel has been used to replace coarse aggregates. Therefore, pervious concrete is a mixture of cement, gravel and water [4]. Pervious concrete is an innovative material and it contains a network of hole and voids to allow air or water to be able to pass through the concrete. Kim and Lee [5] investigated the effects of cement paste flow and aggregate type on the acoustical and mechanical properties of pervious concretes. They produced mixtures with maximum sound absorption coefficients of 0.90–1.00, showing that pervious concretes have regular porous structures with potential to work as sound absorbers in urban environments. Some studies suggest that noise generated by cars and trains can be reduced by up to 4 dB from the implementation of pervious concrete pavements in roads or near them [6]. This mixture of cement, gravel and water only allows the pervious concrete to have about 15 to 30% of void space, and these void spaces can range from 0.08 to 0.32 inches in order to allow water to pass through freely without causing damages or danger [1]. Due to the particularity structure of PC, it contains a lot of pores inside. This is both an advantage and a disadvantage of the PC compared to the conventional concrete [7]. Due to the existence of pore structure, the skeleton of PC is not a continuous whole structure, so that the external media, especially water, air, small dust, and so on, can enter freely, which is very unfavourable to the durability [8].

The duration for obtaining or determining concrete's maximum strength is 28 days and it will be innovative to find a way to predict the mechanical strength of concrete faster without having to wait for the 28 days. Artificial intelligence (AI) has been widely applied in different civil engineering fields like geotechnical engineering, project management, transportation engineering and many others. Several studies have shown the efficacy of artificial intelligence (AI) algorithms for predicting the mechanical strength of concrete [9]. Among other AI algorithms, Fuzzy logic is an approach of computing based on degrees of truth and/or false rather than Boolean logic of just true or false. Alagbeyogu and Ozturk [10] predicted the compressive strength of the cement mortars using fuzzy logic and obtained a good correlation between measured and predicted values ($R^2$=0.9993). Charhate et al. [11] also developed fuzzy logic models to predict the slump as well as 7 and 28 days compressive strength of M20 to M70 grades of concrete and they obtained good results with correlation coefficients between 0.90 and 0.96. In this study, fuzzy logic was applied, to investigate and predict the mechanical strength of pervious concrete.

## . II. MATERIALS AND METHODS

### A. Materials

Pervious concrete is made up of three basic materials. These materials are Portland Cement, Water and Coarse Aggregates. Portland cement is used as the binder material in this study and it is composed of chemical elements such as; alumina, silica, iron and gypsum. Dangote brand of Ordinary Portland Cement grade 32.5 class which conforms to BS12 [12] was used. Locally available granite was used as the coarse aggregate. Crushed granite having a little percentage of fine aggregates was used to ensure that the pervious concrete has a little degree of fine aggregates. The maximum size of the aggregate used was 20mm.

## B. Methodology

### i. Particle size distribution

Sieve analysis was used in accordance with ASTM C136 standards [13]. A set of sieves was placed and stacked upon one another from the sieve with the largest opening at the top and the sieve with the least opening at the bottom, then a pan placed beneath them to hold the materials that pass through. The sample was poured to the top sieve and thoroughly/mechanically shaken for proper distribution of the materials. The uniformity coefficient ($C_u$) and the Coefficient of Gradation ($C_c$) of the particles was then determined from the sieve analysis using the equations below;

$$\text{Uniformity Coefficient } (C_u) = \frac{D_{60}}{D_{10}} \quad (1)$$

$$\text{Coefficient of curvature } (C_c) = \frac{(D_{30})2}{D_{60}\, X\, D_{10}} \quad (2)$$

Where;

$D_{60}$ is the particle size at 60 % finer,

$D_{30}$ is the particle size at 30 % finer,

$D_{10}$ is the particle size at 10 % finer.

### ii. Specific gravity test

The test was carried out in accordance with BS 882:1992 [14]. The general expression for specific gravity of the sample is given as in the equation below;

$$G_s = \frac{A}{A+C-B} \quad (3)$$

Where; A is the weight of saturated surface dry (SSD) sample

B is the weight of cylinder, SSD, and water

C is the weight of measuring cylinder and water

### iii. Mixing and Casting of Pervious Concrete

After determining the physical properties of all constituents' materials and quantities for the design, the materials were prepared according to the BS 1881-125 [15]. For each concrete mix, batching by weight method was adopted. For the production of all the concrete specimens, that is the cubes, cylinders and beams, wooden mould of 150 x 150 x 150 mm, plastic mould of 100 mm diameter and 200 mm length, and a wooden beam mould of 150 x 150 x 300 mm were used respectively.

The moulds were properly oiled for easy demoulding and then filled with concrete. After casting and finishing, all the specimens were allowed to set. The specimens were demoulded after 24 hours of casting and cured in tank placed at the laboratory until they were brought out for test after 28 days curing period. Compressive strength, split tensile and flexural strength tests were conducted on the concrete cubes, cylinders and beams to study the compressive, split tensile and flexural strengths of the pervious concrete. For each of the tests, mixing ratios of 1:4, 1:5 and 1:6 were used, and for each of these mixing ratios, water to cement ratio of 0.4, 0.5, 0.6 and 0.7 were used to test the variation in the mechanical properties of the pervious concrete.

### iv. Compressive strength test

Different samples were tested at the 28-days curing stages and cubes of side 150 mm were used. The apparatus used were the compressive testing machine, cube moulds, tampering rods, curing tanks. The procedures of performing this experiment are as follows;

1. The cube moulds were cleaned and properly lubricated.
2. The fresh concrete was then poured into these moulds and then tapped with

the tampering rod to remove voids and then, the surface was smoothened.

3. After setting and hardening, the cubes was removed from the moulds and placed in the curing tanks.
4. The cubes were in the tank for 28- days curing stages.
5. After each curing stage, the cubes were removed from the tank and water cleaned off.
6. The samples removed from the tank were weighed, measured and recorded.
7. The cubes were placed in the testing machine in such a way that the load will be applied at opposite sides of the cubes.
8. The load was applied continually without shock until the cubes fell.
9. The compressive strength of the cube was calculated by using;

$$\text{Compressive strength } (N/mm^2) = \frac{\text{Applied load (N)}}{\text{Area of cross-section } (mm^2)} \qquad (4) \qquad 3.5$$

**v. Flexural strength test**

This test was conducted in accordance with BS EN 12390-5:2009 flexural strength of test samples [16]. By applying one concentrated load at the centre of each beam of dimensions 150 mm x 150 mm x 500 mm, samples were then tested at age due ages. The apparatus that was involved in this experiment include; beam mould, tamping rod, testing machine, curing tank. The procedures followed for carrying out this test are as follows;

1. The beam mould was cleaned and lubricated properly.
2. The fresh concrete was poured into these moulds and then tapped with the tampering rod to remove voids and the surface was smoothened.
3. After setting and hardening, the cubes were removed from the moulds and placed in the curing tanks.
4. The cubes were in the tank for 28- days curing stages.
5. The beams at age old curing stages will be placed in the testing machine in such a way that the load will be applied in the direction normal to the direction of compaction.
6. Circular rollers were used to provide support and loading points to the samples.
7. The flexural strength was then calculated using the formula;

$$fb = \frac{pl}{bd^2} \qquad (5)$$

(When a > 20.0 cm for 15.0cm sample or > 13.0 cm for 10cm sample)

Or

$$fb = \frac{3pa}{bd^2} \qquad (6)$$

(When a < 20.0 cm but > 17.0 for 15.0cm sample or 13.3cm but > 11.0 cm for 10.0cm sample).

Where;

a = the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the sample.
b = width of the sample (cm)
d = failure point depth (cm)
*l* = supported length (cm)
p = max load (kN).

### vi. Split tensile test

Tensile strength test was carried out on cured samples of 150 mm x 300 mm as provided in BS 1881: Part 117:1983 [15]. The apparatus involved in this experiment include; testing machine, cylinder moulds, tamping rods. The procedures followed for this experiment are as follows;

1. Freshly mixed pervious concrete was placed in a clean and moisturized cylindrical mould of 150 mm diameter and 300 mm height.
2. After setting and hardening, the concrete was placed in the curing tank at an average temperature for curing.
3. After the curing age has been reached, the cylinders were removed from the curing tank and dried.
4. Weight and dimension of the specimens were measured and recorded.
5. The load was applied at a constant rate to the specimen up to the point of failure and the point of failure was recorded.
6. The split tensile strength was calculated by using the following equation;

$$\text{Split Tensile Strength } (\text{N/mm}^2) = \frac{(2P)}{\pi \times d \times l} \quad (7)$$

Where;
P = Maximum Load at failure
*l* = Length of the Cylindrical Sample in mm,
d = Diameter of Cylindrical sample in mm.

### vii. Fuzzy logic

Fuzzy logic model was created using fuzzy logic toolbox built on the MATLAB numeric computing environment. The model was trained to predict the strength properties of concrete. Triangular membership functions were used for the input and output variables, and the defuzzification method employed was centroid method.

The limit values of input and output variables used in the Mamdani-type fuzzy inference model are listed in Table 1 to 3 for the flexural, split tensile and compressive strengths. The developed fuzzy logic model was applied to predict the mechanical strengths of the concrete by using data obtained from experimental results. The fuzzy logic model has input parameters of water content, crushing value, weight and density of concrete and output parameters are the compressive, split tensile and flexural strengths as shown in Figure 1. Triangular membership function was employed for the input and output parameters used for fuzzy modeling as shown in Figure 2. To have an objective comparison of the performance of the model, the error measures of the root mean square error (RMSE), mean absolute percentage error (MAPE) and R squared were computed for the model.

## III. RESULTS AND DISCUSSION

### i. Sieve analysis

Figure 3 shows the particle size distribution curve of the coarse aggregate used in this experiment. The coefficient of gradation ($C_c$) and the coefficient of uniformity ($C_u$) of the sample are 1.31 and 1.96 respectively. The coefficient of uniformity of granite falls between the range of 1 to 5 and it can therefore be classified as a uniformly graded and makes it suitable for use as an aggregate in the production of pervious concrete [12].

**Table 1: The input and output variables of the compressive strength models**

| | Data used for Training and Testing Models | |
|---|---|---|
| Variables | Minimum | Maximum |
| Water content | 0.4 | 0.7 |
| Weight | 7.8 | 8.8 |
| CV | 75.5 | 198.5 |
| Density | 2338 | 2590 |
| Compressive Strength | 3.2 | 8.9 |

**Table 2: The input and output variables of the split tensile strength models**

| | Data used for Training and Testing Models | |
|---|---|---|
| Variables | Minimum | Maximum |
| Water content | 0.4 | 0.7 |
| Weight | 2.9 | 3.9 |
| CV | 38 | 125.5 |
| Density | 1900 | 2420 |
| Split Tensile Strength | 1 | 4 |

**Table 3: The input and output variables of the flexural strength models**

| | Data used for Training and Testing Models | |
|---|---|---|
| Variables | Minimum | Maximum |
| Water content | 0.4 | 0.7 |
| Weight | 21 | 31 |
| CV | 91 | 188 |
| Density | 3280 | 4550 |
| Flexural Strength | 8 | 16.8 |

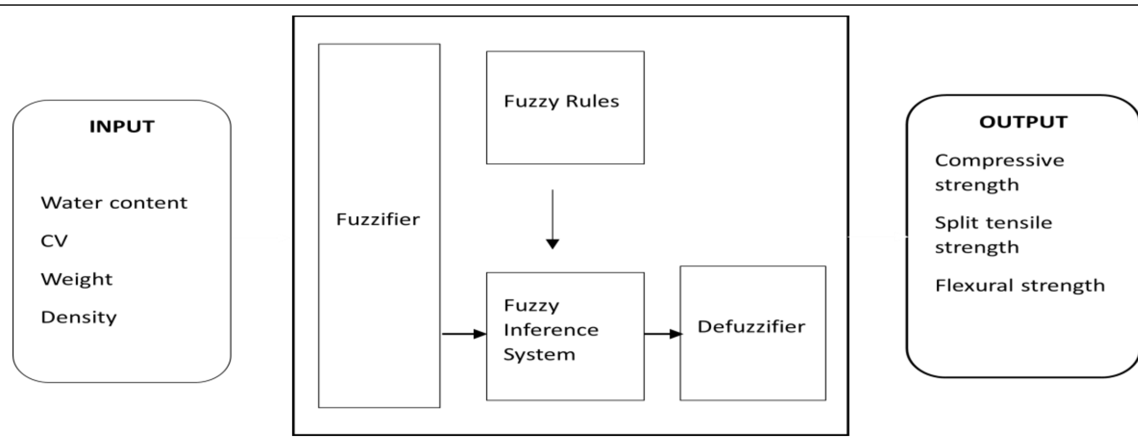
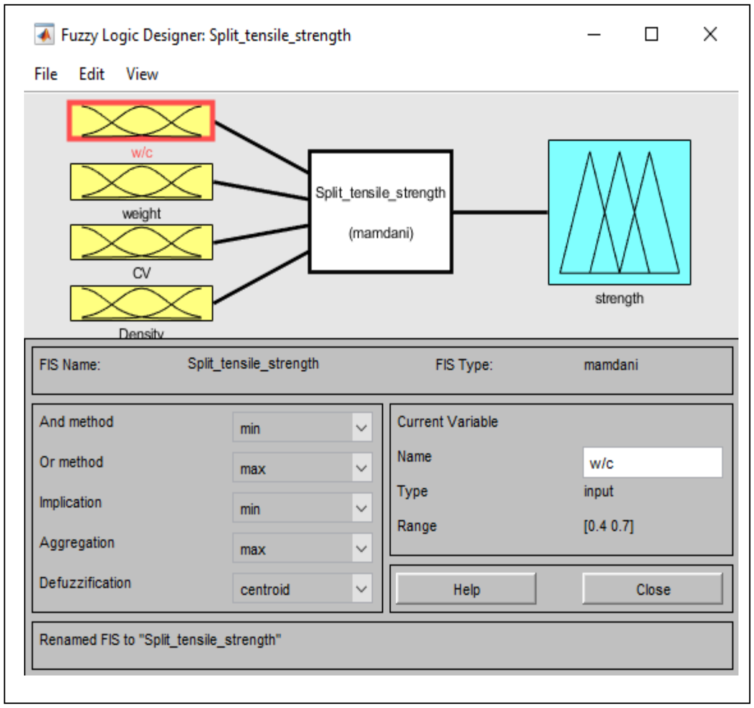
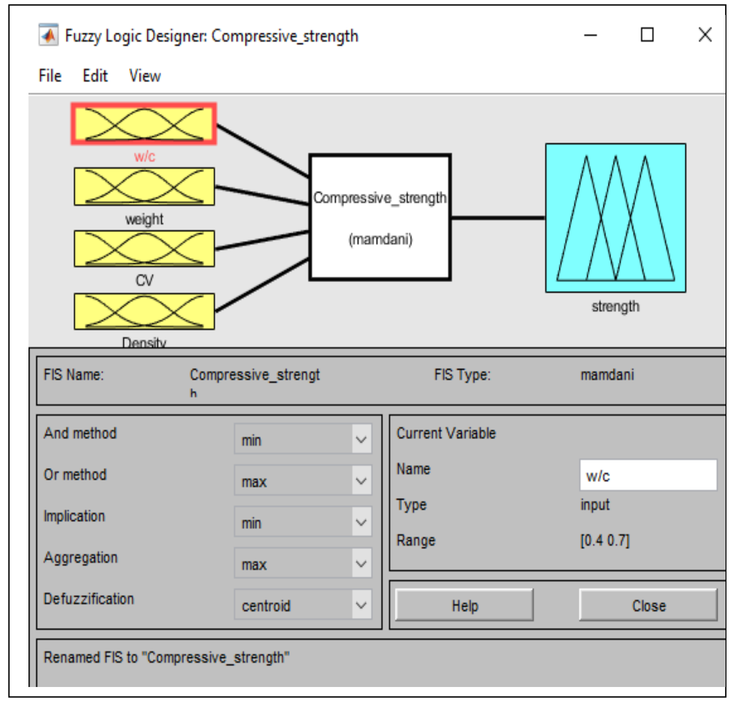



**Figure 1: Structure of fuzzy logic approach for the strength prediction**




**(b)**

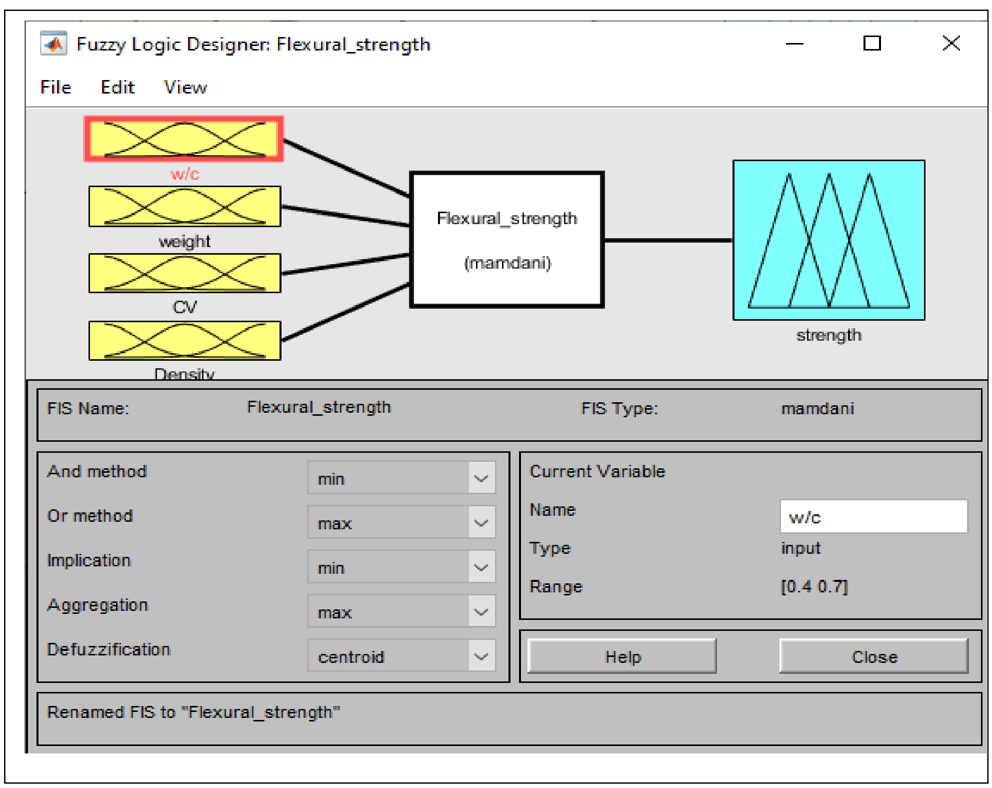



**Figure 2: Fuzzy logic designer for (a) split tensile strength (b) compressive strength (c) flexural strength**

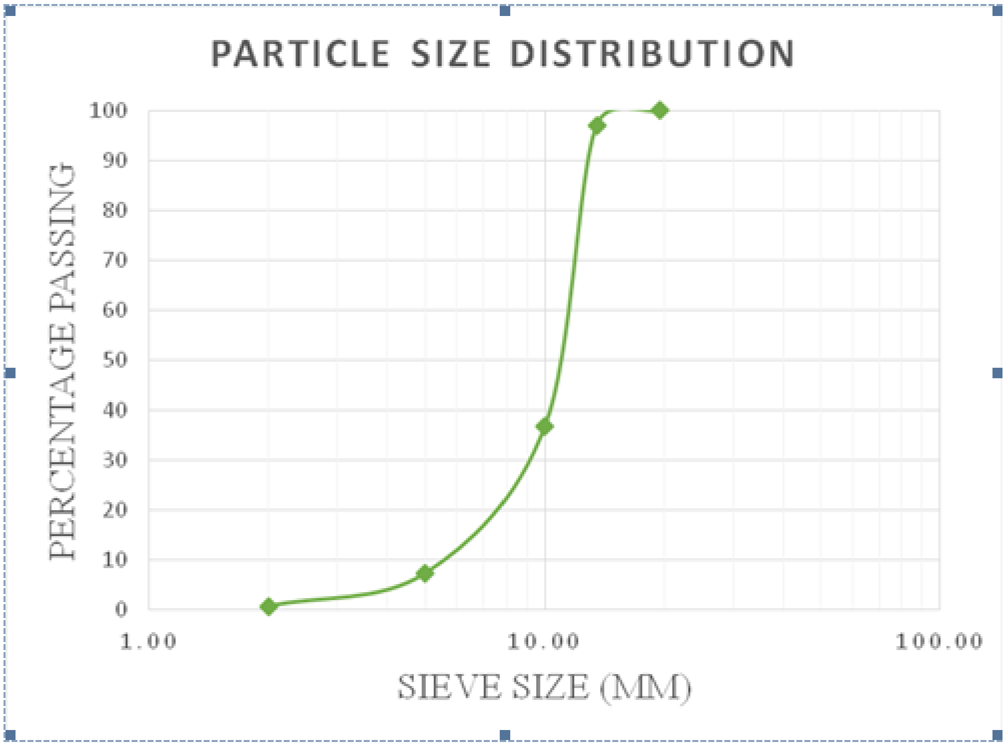



**Figure 3: Particle size distribution curve for Coarse Aggregate**

### ii. Specific gravity

Specific gravity of concrete is a factor that determines the density of concrete. The specific gravity of cement is 3.10 and that of granite is 2.87. The specific gravity of granite falls within the acceptable range of 2.4 to 3.0 according to [13]. Khankhaje *et al.* [17] reported a slightly higher value for the specific gravity of cement (3.15) while Raj and Chockalingam [18] recorded a lower value for the specific gravity of granite (2.70). A higher specific gravity of concrete indicates that the density of concrete will be high.

### iii. Compressive strength

The results of compressive strength of pervious concrete with varying mixing ratios and water to cement ratio are shown in Figure 4. It was notably observed that the compressive strength of the PC decreased with the increase in the mixing ratio and also decreases if the water to cement ratio increases.

At water to cement ratio of 0.4, and at mixing ratio of 1:4, the compressive strength of PC was 8.69 MPa and it decreased at about 2 MPa as the mixing ratio increased at constant water to cement ratio that is the amount of cement reduced and the amount of granite increased slightly at same 0.4 water to cement ratio. At 0.5 water to cement ratio and mixing ratio of 1:4, the compressive strength dropped slightly (8.19 MPa) compared to that of the water cement ratio of 0.4 and the compressive strength decreases markedly as the mixing ratio was increased at constant water to cement ratio.

Similar declination was seen at the water to cement ratios of 0.6 and 0.7. The compressive strengths reduced markedly compared to the preceding water to cement ratio with similar mixing ratios, and the compressive strength dropped as the mixing ratio of cement to granite increased. It was discovered that the maximum compressive strength after 28 days curing period was gotten at 1:4 concrete mixing

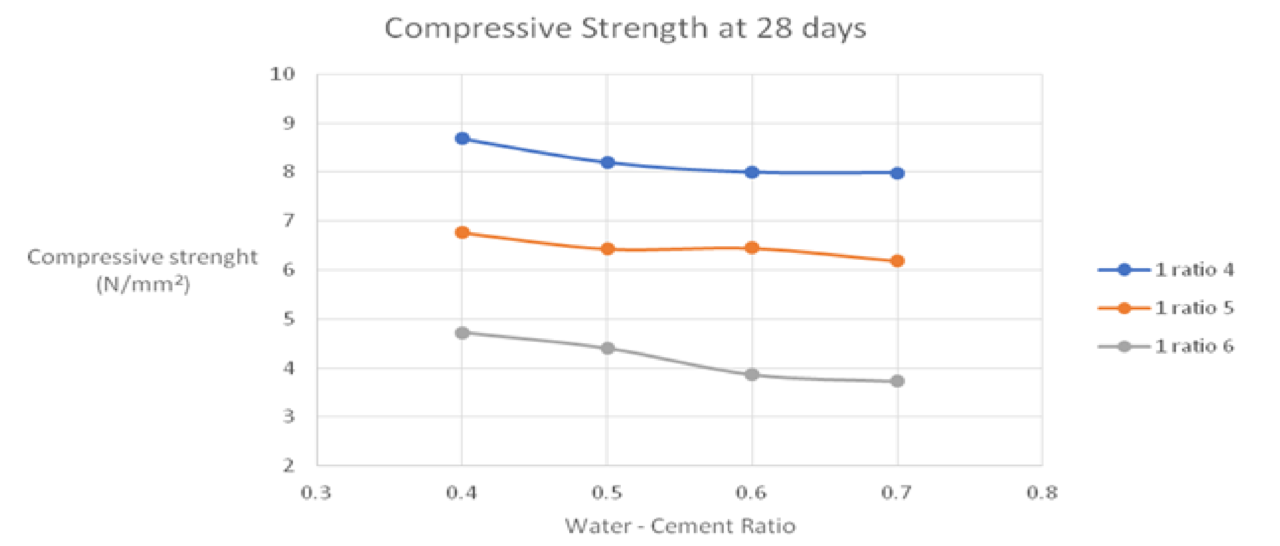



**Figure 4: Compressive strength of pervious concrete at 28 days**

### iv. Split tensile strength

The split tensile strengths shown in Figure 5 cover all mixing ratios and water to cement ratios. It is evident from the plot that the optimal tensile strength is observed at 1:4 mixing ratio and 0.4 water to cement ratio. All samples were tested after 28 days curing age and it can be observed from the curve that the split tensile strength of the PC decreases with increase in water to cement ratio and further decreases with higher coarse aggregate content.

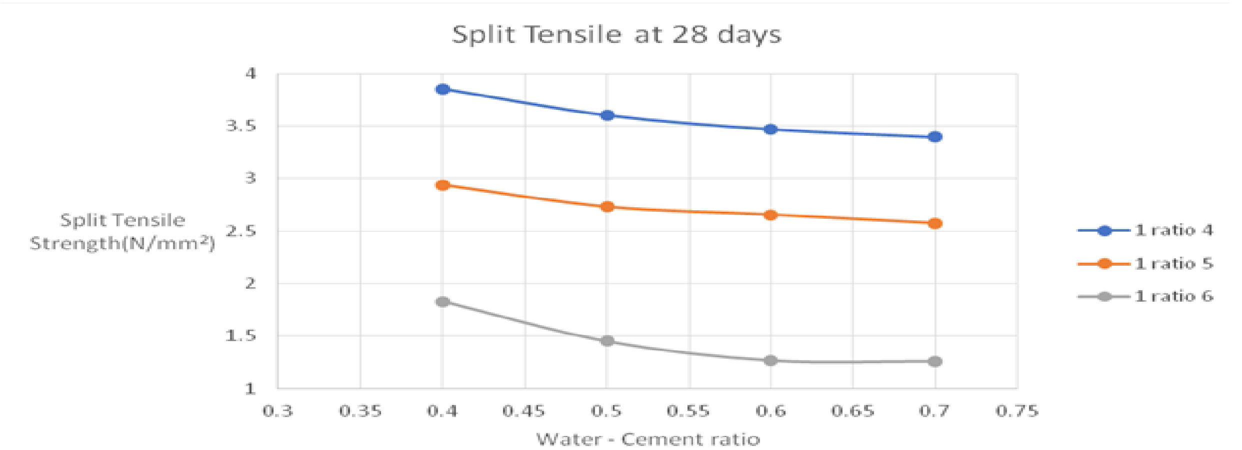



**Figure 5: Split tensile strength of pervious concrete at 28 days**

**v. Flexural strength**

The flexural strengths of the pervious concrete produced are represented in Figure 6. The study revealed that flexural strength of concrete reduces with increase in water to cement ratio and further decreases with increase in coarse aggregates. The flexural strengths of the pervious concrete at 0.4, 0.5, 0.6 and 0.7 water to cement ratios produced at 28 days of curing

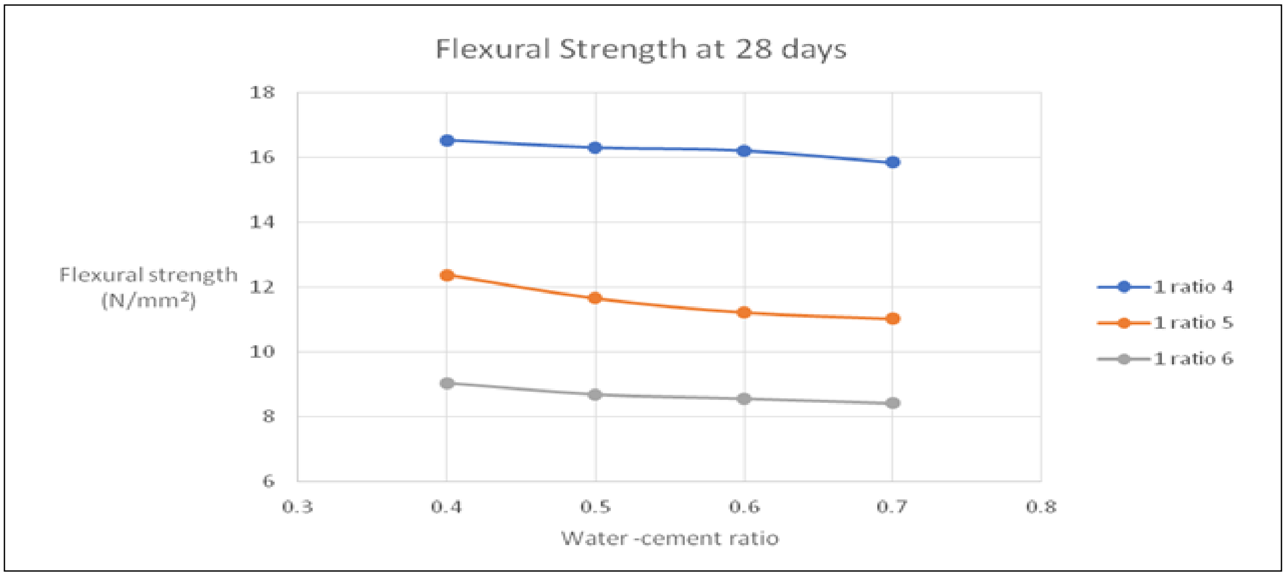



**Figure 6: Flexural strength of pervious concrete at 28 days**

**i. Fuzzy logic prediction of the characteristic strengths**

Fuzzy logic implementation requires the definition of membership functions that can be triangular, trapezoidal or even Gaussian depending on the distribution training data inputs. Eight triangular membership functions were defined for the input and output data respectively except the water cement ratio which has four. After determining the membership functions, 351 fuzzy rules were defined for compressive strength, 280 for flexural strength and 151 rules for split tensile strength predictions so that they can predict more accurately. The RMSE and MAPE values for the compressive strength, flexural strength and split tensile strength are shown in Table 4.

RMSE of 0.25 and MAPE of 9.56% for the Split tensile strength are satisfactory since values closer to zero shows that the prediction is satisfactory according to Alaneme et al. [20]. RMSE of 0.84 and MAPE of 4.08 % for the flexural strength are satisfactory. Also, RMSE of 0.31 and MAPE of 4.15 % for compressive strength are also satisfactory.

The slope of the regression line of experimental and predicted result of the fuzzy logic models are presented in Figure 6 to Figure 8. The results show the correlation between the experimental and predicted result. According to Alaneme et al. [20], Alaybeyoglu and Ozturk,

**Table 4: Error measure of the models**

| Model | MAPE (%) | RMSE | R-S |
|---|---|---|---|
| Split Tensile Strength | 9.55 | 0.25 | 0.987 |
| Flexural Strength | 4.08 | 0.84 | 0.95 |
| Compressive Strength | 4.14 | 0.313 | 0.977 |

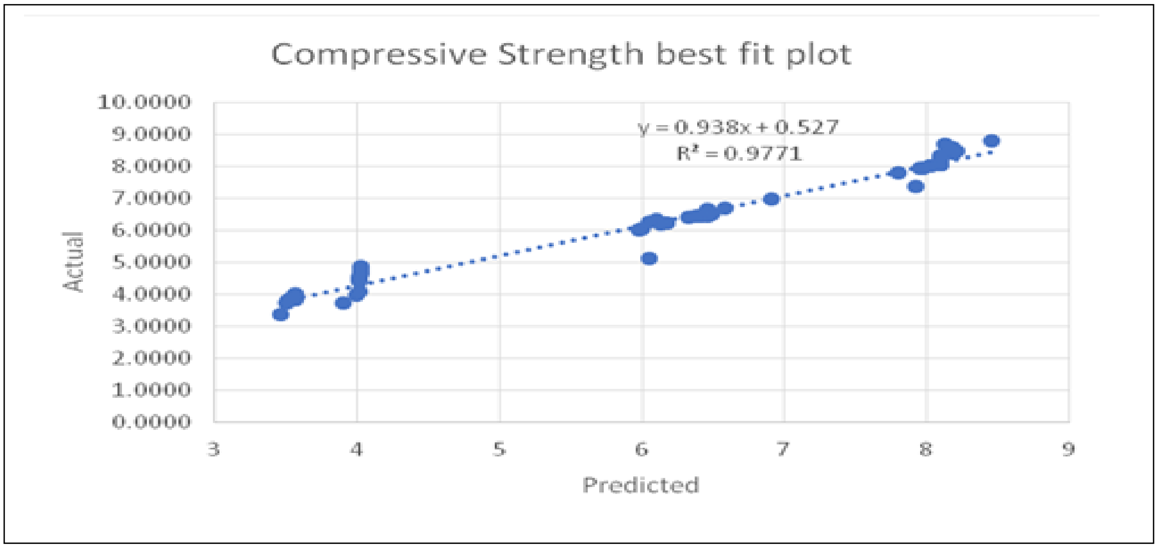



**Figure 6: Compressive strength line of fitness plot**

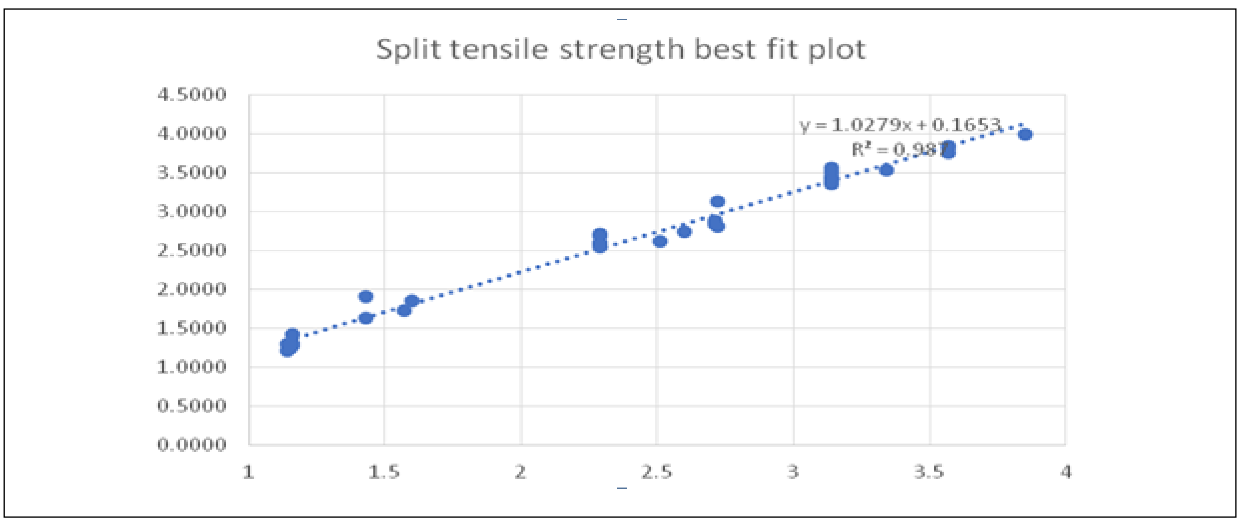



**Figure 7: Split tensile strength line of fitness plot**

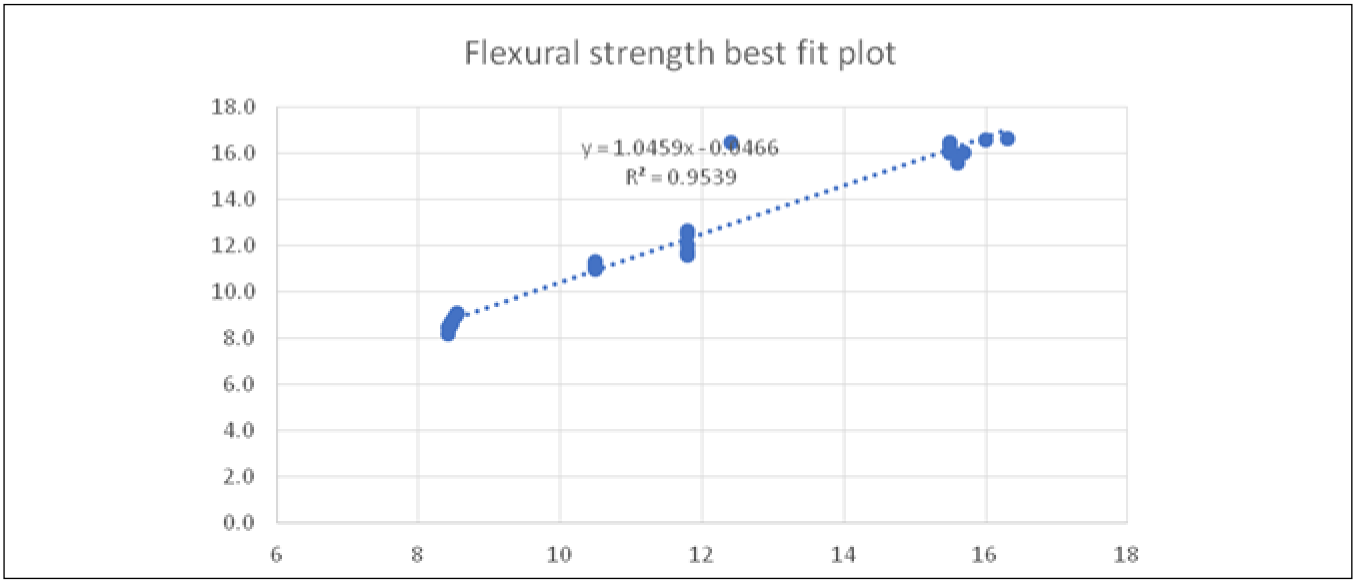



**Figure 8: Flexural strength line of fitness plot**

[10], and Charhate et al., [11] R-squared greater than 0.8 shows a good correlation between the actual and predicted values. The results reveal that the predicted and actual values are a good fit. This indicates that the fuzzy logic model is a good fit for split tensile and compressive strength tests.

## IV. Conclusion

The following conclusions were drawn from the results gotten from this research work;

1. The compressive strength of pervious concrete reduces slightly with increase in water to cement ratio and a higher amount of cement to granite ratio causes a stronger pervious concrete in terms of compression but low workability. In order to get a higher compressive strength and better workability, the water to cement ratio can be increased slightly while maintaining the mix ratio of cement to granite, preferably 1:4.
2. Higher water to cement ratio slightly reduces the mechanical strength of PC compared to increase in cement to granite ratio which notably reduces the strength, alternatively, higher water to cement ratio causes a notable decrease in permeability of the pervious concrete. Preference of either mechanical strength or workability should be considered when choosing water to cement ratio or cement to granite ratio for pervious concrete.
3. The fuzzy logic model developed in this study showed an excellent correlation between the experimental and predicted values. This shows that fuzzy logic can be used to predict the mechanical properties of pervious concrete, and fuzzy logic can also be used to appropriately deduce missing values in the mechanical properties of PC.

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