*International Journal of Engineering Inventions*
*e-ISSN: 2278-7461, p-ISSN: 2319-6491*
*Volume 13, Issue 12 [December. 2024] PP: 131-144*

# Predicting the Strength Property of Lightweight Concrete Containing Modified Plastic Aggregate as a Partial Replacement of Coarse Aggregate Using Artificial Neural Network

**Muhammad F.U.[1], Dr. Jamilu Y.[2], Prof. Kunya S.U.[3]**
*Department of Building, Abubakar Tafawa Balewa University Bauchi, Nigeria.*

***Abstract***
*This study investigates the effects of treating Polyethylene terephthalate (PET) waste with calcium hypochlorite solution ($Ca(ClO)_2$) before incorporating it into concrete as a coarse aggregate replacement. Various tests, including density, compressive strength, UPV, split tensile strength and flexural strength were conducted for three replacement percentages: 15%, 30%, and 45% of conventional coarse aggregate with modified plastic aggregates (MPA). The findings show that chemically treated plastic aggregates maintained fresh density while reducing slump value at higher replacement level even with the addition of polycarboxylate acid (super plasticizer) due to surface roughness and it irregular shape. Lightweight concrete with 30% MPA achieved a 28-day density, compressive strength, and UPV of 1996 kg/m³, 23.13 N/mm² and 3643 m/s, respectively, meeting BS EN 206-1 (2013) standards for structural lightweight concrete. While the 30% MPA achieved a 28-day split tensile and flexural strength, of 3.38 N/mm² and 4.10 N/mm$^2$, respectively. The study also employed an Artificial Neural Network (ANN) model to predict MPA concrete compressive strength. The pre-processing, statistical methods, and data visualization techniques were employed for data understanding, achieving high accuracy with $R^2$ value of 0.99 for both the training and testing data. The finding confirms that chemical treatment enhances the bond strength between the cementitious matrix and plastic aggregates, improving compressive strength and utilizing MPA as a partial replacement for conventional coarse aggregate, producing lightweight concrete that meets specifications and is a sustainable construction material.*

***Keywords:*** *Modified Plastic Aggregate Concrete, Artificial Neural Network, Compressive strength, Ultrasonic Pulse Velocity, Split Tensile Strength, Flexural Strength.*

---

Date of Submission: 14-12-2024 Date of acceptance: 28-12-2024

---

## I. Introduction

Concrete, the second most consumed material after water, is favored for its versatility in being moulded into various shapes. Coarse aggregates, constituting 65-75% of concrete by volume, are crucial to its production, contributing significantly to the material's strength, durability, and stability (Babafemi *et al.*, 2018; Smith *et al.*, 2017). The growing need for construction materials and the limited supply of top-quality coarse aggregates have prompted meaningful discussions about sustainability and environmental impact (Smith *et al.*, 2018a). Extracting these aggregates often causes significant environmental disturbances, including habitat destruction and landscape alteration, leading to ecological imbalances and biodiversity loss (Kumar & Sharma, 2018). While coarse aggregates are crucial for concrete structures' strength, durability, and stability (Agboola *et al.*, 2021; Smith *et al.*, 2018b; Smith *et al.*, 2017), they also contribute to several challenges in normal-weight concrete. To address these issues, researchers are exploring using lighter, more environmentally friendly materials as partial replacements for conventional aggregates. This has led to the development of lightweight concrete and the investigation of alternative aggregate sources, such as plastic waste (Kumar *et al.*, 2020; Haque *et al.*, 2019; Poon *et al.*, 2017).

Research has shown that adequately processed plastic waste can partially replace traditional aggregates in concrete mixtures (Babafemi *et al.*, 2022; Mustafa *et al.*, 2021). However, many studies report challenges with using recycled plastic aggregates (RPA) as a partial replacement for conventional aggregates, such as inadequate strength and durability for structural purposes. Some researchers suggest improving the bonds by performing surface modifications using chemical treatments on the RPA (Islam *et al.*, 2016; Bonifazi *et al.*, 2015). A study by Lee *et al.* (2019) demonstrated that treating RPA with an oxidizing agent can strengthen the bond between plastic and cement paste, producing stronger concrete.

Given the variability in the quality and properties of plastic aggregates, it is essential to develop a model that can predict its strength properties to design solid and durable concrete. With advancements in artificial intelligence, predicting concrete properties has become more accessible. Machine learning algorithms, such as Artificial Neural Networks (ANN) is being employed to forecast these properties accurately.

Artificial Neural Networks (ANNs) have significant applications in concrete technology, improving the development, optimization, and quality control of concrete materials and processes. ANNs are particularly useful for predicting the properties and performance of concrete mixtures by analyzing various input variables, such as component proportions, curing conditions, and environmental factors. This allows for accurate predictions of critical properties like compressive strength and workability (Yeh, 2018).

This study aims to evaluate the effects of modified plastic aggregate (MPA) as a coarse aggregate supplement in producing lightweight concrete (LWC). The objectives were to investigate how calcium hypochlorite surface-treated plastic aggregates impact concrete strength.

## II. Materials and Methods

### 2.1 Materials

Materials that were used in this work include; cement, fine aggregate, coarse aggregate, PET bottle, polycarboxylic acid (superplasticizer) and water.

### 2.2 Methods

### 2.2.1 Experimental design

Figure 1 explained the step procedures that were used to conduct the research analysis.

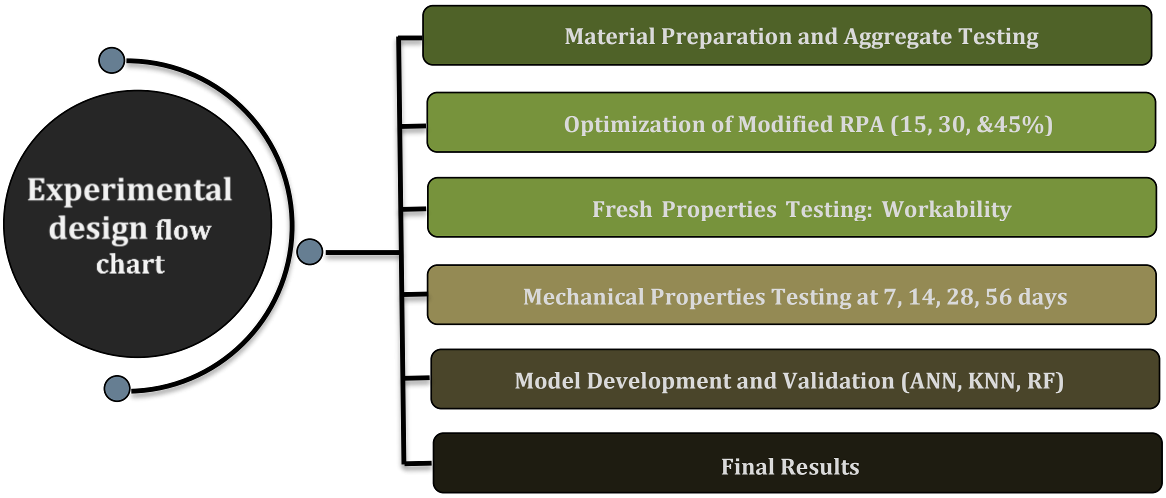

*Figure 1: Flowchart describing the research design*

This study investigates the durability properties of MPA as a partial coarse aggregate replacement in concrete. First, the MPA were produced by crushing the MPA into sizes ranging from 10 to 20 mm. Before mixing with concrete, the MPA were treated by soaking in an oxidizing agent for 24 hours. 500 grams of calcium hypochlorite ($Ca(ClO)_2$) was diluted in five litres of water for this treatment. This chemical etching treatment provided the plastic aggregates with a rough surface texture to improve the bond between the cement paste and the plastic. The treated MPA was then air-dried to ensure no residual chemicals remained on the surface. A superplasticizer at 1% of the weight of cement was added to the mix as a chemical admixture to slow the hydration process and improve the hydrophobicity of the MPA with water. Cube sizes of 100 x 100 x 100 mm were produced to study the physical, mechanical and durability properties of the samples. All samples were cured for the period of (7, 14, 28, and 56 days). Four mixes were prepared: the control (0%), then coarse aggregate at different ratios of 15% MPA, 30% MPA, and 45% MPA. The concrete curing process was conducted according to BS 8110-1:1997.

### 2.2.2 Mixing procedure and sample preparation

The mixing procedure involved manually mixing cement and sand for three minutes, followed by the addition of crushed stones and MPA for another three-minutes. After dry mixing, water and superplasticizer were added, and the mixture was further mixed for three minutes before casting the fresh MPA concrete into 100 × 100 × 1000mm plastic moulds in three layers, with each layer vibrated for 30 seconds. Similarly, concrete cylinders of size 300 × 100 mm were used for split tensile strength test, while concrete beams of size 100× 100 × 500 mm were used for flexural strength test. The samples were covered with plastic bags and set in the laboratory for 24 hours before remoulding. Post-remoulding, specimens were cured in a curing tank according to BS 8110-1:1997 before subjected to physical, and mechanical test.

**Table 1: Mix Proportion of MPA Concrete**

| Parameters | 0% MPA | 15% MPA | 30% MPA | 45% MPA |
|---|---|---|---|---|
| W/C ratio | 0.52 | 0.40 | 0.40 | 0.40 |
| Water content (kg/m$^3$) | 181 | 139 | 139 | 139 |
| Cement content (kg/m$^3$) | 348 | 348 | 348 | 348 |
| Sand content (kg/m$^3$) | 627 | 627 | 627 | 627 |
| Coarse agg. (kg/m$^3$) | 1226 | 1042 | 858 | 674 |
| MPA (kg/m$^3$) | 0 | 36 | 72 | 108 |
| SP at 1% of cement (kg/m$^3$) | 0 | 3.48 | 3.48 | 3.48 |
| Target Density (kg/m$^3$) | 2382 | 2195 | 2047 | 1899 |

### 2.3 Experimental Work

#### 2.3.1 Density Test

Density plays an important role in determining the properties and performance of lightweight concrete. As the density of lightweight concrete decreases, several key characteristics are affected, influencing its mechanical, thermal, and durability properties. The test was carried out according to BS EN 12390-7:2019. The concrete density test was carried out at 7, 14, 28 and 56 days. The densities of the concretes are expected to reduce over time because the specimens were subjected to air drying at room temperature after curing until day of testing.

#### 2.3.2 Mechanical Properties

Mechanical property tests are usually conducted to find out the hardened properties of the concrete specimens. The tests include both destructive and nondestructive test such as compressive strength, Ultrasonic Pulse Velocity (UPV), tensile strength and flexural strength test respectively.

##### *2.3.2.1 Compressive Strength*

The compressive strength test was carried out using the universal crushing machines conform to BS EN 12390-3 (2009). The compressive strength test was carried out at 7, 14, and 28 days respectively. The average of three samples was presented as the compressive strength results.

##### *2.3.2.2 Ultrasonic Pulse Velocity (UPV)*

The UPV test is a non-destructive test conducted on concrete cubes 100 x100 x100mm before the compressive strength tests at 7, 14, and 28 days respectively. The test was conducted according to BS 1881-203:2011 using PUNDIT (ultrasonic pulse velocity machine). The Average of three results was taking as the UPV result for each mixture.

##### *2.3.2.3 Tensile Strength*

Concrete cylinders of size 100Ø × 300mm height were used to conduct the tensile strength test according to BS EN ISO 6892-1. Standard test method for splitting tensile strength of cylindrical concrete specimens using universal compressive strength testing machine with capacity of 3000kN and conform to BS EN 12390-3 (2009). The tensile strength test was conducted at 7, 14, and 28 days, respectively.

##### *2.3.2.4 Flexural Strength*

The flexural strength test for concrete beams of size 100 x 100 x 500mm was conducted according to BS EN 12390-5:2000 Standard test method for flexural strength of concrete using ELE universal testing machine. The concrete specimen, the flexural strength test was conducted at 7, 14 and 28 days, respectively.

#### 2.3.3 Development and Validation of Artificial Neural Networks (ANN) Model

An Artificial Neural Network (ANN) is a computational model inspired by how biological neural networks in the human brain process information. It comprises interconnected processing units called neurons, which work collectively to solve specific problems. An artificial neural network (ANN) architecture consists of an input layer, one or more hidden layers, and an output layer. Each layer is composed of multiple neurons connected by weights. During the learning process, these weights are adjusted based on the output error compared to the desired outcome, typically using algorithms like backpropagation (Goodfellow *et al.*, 2016). ANNs are highly effective in dealing with complex, non-linear relationships, which makes them a valuable tool in various fields, including image and speech recognition, natural language processing, and predictive analytics. Recent advancements have further enhanced ANN capabilities by incorporating techniques like deep learning, which involve deeper networks with many layers, allowing for more sophisticated data representations and improved performance in tasks such as object detection and language translation (Krizhevsky *et al.*, 2017).

### 2.4 Performance Evaluation of Predictive Models

To evaluate the performance of predictive models, three indicators are used: the coefficient of determination ($R^2$), Mean Absolute Error (MAE), and Mean Squared Error (MSE).

### 2.4.1 Coefficient of Determination ($R^2$)

$R^2$ measures the proportion of variance in the dependent variable predictable from the independent variables, ranging from 0 to 1, where 1 indicates perfect prediction as shown in the equation.

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \quad \text{-----------------------------------------------------------------}(1)$$

### 2.5.2 Mean Absolute Error (MAE)

MAE assesses the average magnitude of errors in predictions without considering their direction, providing insight into how far predictions are from actual outcomes on average as shown in the equation.

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n} |y_i - \hat{y}_i| \quad \text{----------------------------------------------------------------}(2)$$

### 2.4.3 Mean Squared Error (MSE)

MSE, which is sensitive to outliers, calculates the average of the squares of the errors, giving more weight to larger errors and measuring error magnitude. Each of these metrics provides a unique perspective on the accuracy and reliability of the models as shown in the equation.

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n} (yi - \hat{y}_i)^2 \quad \text{-----------------------------------------------------------------}(3)$$

Where; $SS_{res}$ is the sum of squares of the residuals, $\sum(yi - \hat{y}i)^2$
SStot is the total sum of squares, $\sum(yi - \bar{y})^2$
$y_i$ are the actual values
$\hat{y}_i$ are the predicted values
$\bar{y}$ is the mean of the actual values.
n is the number of observations

## III. Results and Discussions

### 3.1 Properties of Materials

Table 2 summarizes the material properties used in this study. The specific gravity of fine aggregate was 2.59, which falls within BS 882 standards. Crushed stones had a specific gravity of 2.71, while MPA had a specific gravity of 0.53, confirming its lightweight nature for reducing structural loads in lightweight concrete applications. The compacted and uncompacted bulk densities of fine aggregate were 1525 kg/m$^3$ and 1340 kg/m$^3$, respectively. The compacted and uncompacted bulk densities for crushed stone were 1727 kg/m$^3$ and 1398 kg/m$^3$, respectively. MPA's compacted and uncompacted bulk densities were 337 kg/m$^3$ and 212 kg/m$^3$, respectively.

Water absorption for crushed stone was 2.21%, and for MPA, it was 0.50%, indicating minimal porosity, which enhances concrete performance and durability. The aggregate impact values for crushed stone and MPA were 5.2% and 2.0%, respectively, and fall within the BS EN 1097-2 standard limits. Aggregate crushing values were 6.6% for crushed stone and 3.20% for MPA, within the British standard BS 812: Part 110:1990 limits.

**Table 2: Properties of Materials**

| Materials | FA-Bulk Density (Kg/m$^3$) | | Specific gravity (g) | Water Absorption (%) | Impact Value (%) | Crushing Value (%) |
|---|---|---|---|---|---|---|
| | Compacted | Uncompacted | | | | |
| Sand | 1525 | 1340 | 2.59 | - | - | - |
| Crushed Stone | 1727 | 1398 | 2.71 | 2.21 | 5.20 | 6.60 |
| MPA | 337 | 212 | 0.53 | 0.50 | 2.00 | 3.20 |

### 3.2 Effect of MPA as Partial Replacement of Coarse Aggregate in LWC

MPA was introduced to replace conventional coarse aggregate at varying percentages: 0%, 15%, 30%, and 45%. The properties of the produced specimens were evaluated for up to 56 days to understand the effects of MPA inclusion on concrete performance.

### 3.2.1 Workability

The workability of the concrete reduces at higher MPA replacements due to its irregular shape and surface texture as shown Table 3 and Figure 2 shows respectively.

**Table 3: Workability of MPA concrete**

| Replacement level | Slump (mm) | Degree of workability |
|---|---|---|
| Control (0%) | 20 | Low workability |
| 15% MPA | 30 | Low workability |
| 30% MPA | 20 | Low workability |
| 45% MPA | 10 | Low workability |

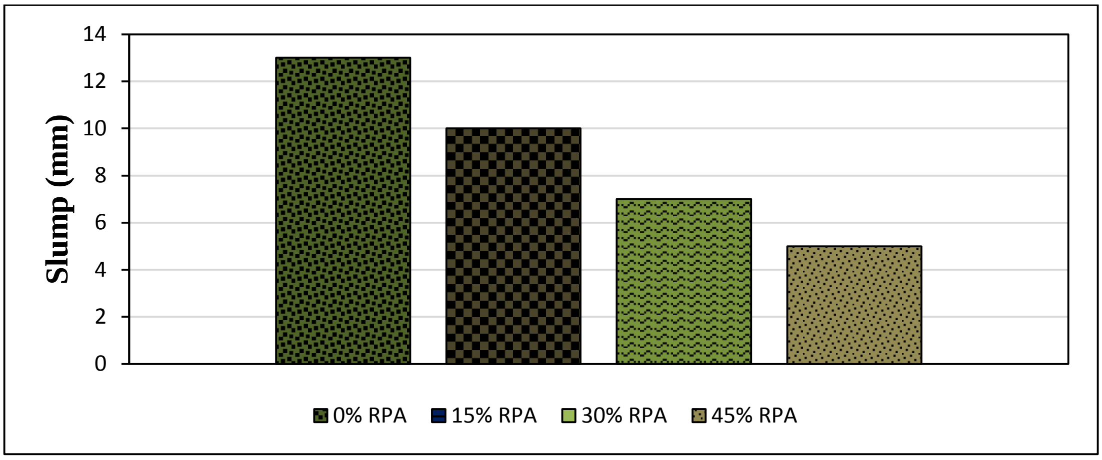

*Figure 2: Slump result of concrete containing MPA*

Analyzing the results in Table 3 and Figure 2, the highest slump value of 30 mm was observed in the 15% MPA mix, followed by the control and 30% MPA mixes, each with a slump value of 20 mm. The 45% MPA mix recorded the lowest slump value of 10 mm. The increased workability in the 15% MPA mix can be attributed to the addition of a superplasticizer, which enhanced water release from the interfacial transition zone, as noted by Jiang et al. (2020). Superplasticizers improved particle dispersion and reduced water demand, mitigating the negative impact of MPA on workability. Higher MPA replacements required additional water to maintain suitable workability levels.

### 3.2.2 Density

The average densities of MPA concrete samples cured in water for 28 days are shown in Table 4 and Figure 3.

**Table 4: Densities of MPA concrete cubes cured in water at 28 days (kg/m$^3$)**

| Replacement level | 3 cubes at 28 days<br>1st | <br>2nd | <br>3rd |
|---|---|---|---|
| Control mix | 2361.38 | 2363.56 | 2349.33 |
| Average | | 2358.09 | |
| 15% MPA | 2137.55 | 2187.21 | 2156.52 |
| Average | | 2160.43 | |
| 30% MPA | 1954.56 | 1966.28 | 1973.25 |
| Average | | 1964.70 | |
| 45% MPA | 1840.02 | 1825.65 | 1837.13 |
| Average | | 1834.27 | |

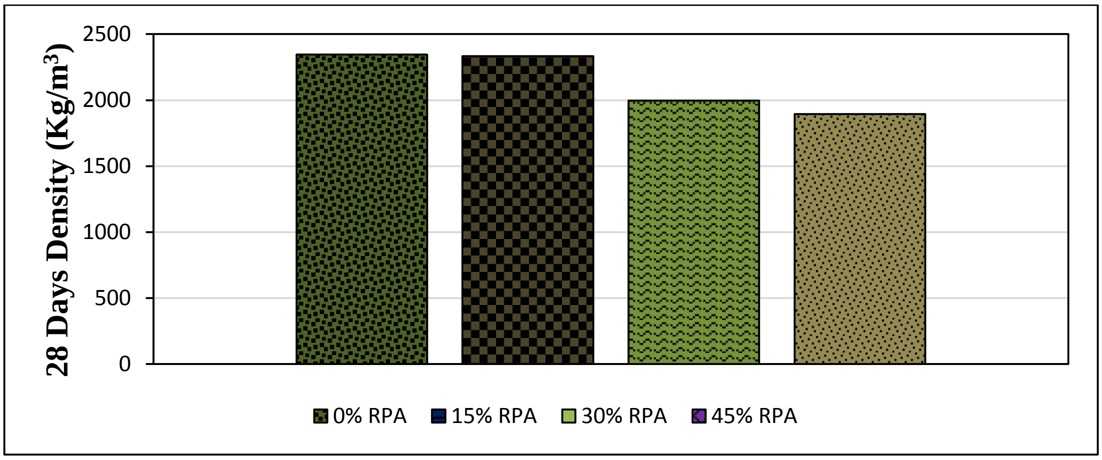

*Figure 3: Density of concrete containing MPA at 28 days*

Referring to the experimental test results in Table 4 and Figure 3, it is evident that the addition of MPA in the concrete mix has caused a reduction in the density of the MPA concrete. The 28-day density of the control specimens was 2347 kg/m³, followed by 15%, 30%, and 45% MPA samples with a density of 2135 kg/m³, 1996 kg/m³, and 1895 kg/m³, respectively. This represents approximately a 9.03%, 14.96%, and 19.26% reduction in density compared to the control samples. This reduction aligns with the structural lightweight concrete range specified by BS EN 206-1 (2013), making the 30% and 45% MPA mixes suitable for structural applications.

### 3.2.3 Compressive Strength

The average compressive strength of MPA concrete samples is shown in Table 5and Figure 4 respectively.

**Table 5: Compressive Strength of MPA concrete cubes in N/mm$^2$ (At 7, 14 and 28 days)**

| | **3 cubes at 7 days** | | | **3 cubes at 14 days** | | | **3 cubes at 28 days** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Replacement level** | **1st** | **2nd** | **3rd** | **1st** | **2nd** | **3rd** | **1st** | **2nd** | **3rd** |
| Control mix | 16.3 | 18.8 | 20.4 | 24.1 | 23.4 | 24.5 | 27.67 | 31.39 | 32.24 |
| Average | | 18.5 | | | 24 | | | 30.43 | |
| 15% MPA | 15.2 | 13.7 | 17.3 | 21.1 | 22.13 | 23.18 | 27.4 | 25.95 | 28.5 |
| Average | | 15.4 | | | 22.14 | | | 27.28 | |
| 30% MPA | 13.76 | 15.1 | 13.3 | 19.75 | 18.56 | 20.34 | 23.3 | 24.2 | 22.5 |
| Average | | 14.05 | | | 19.55 | | | 23.33 | |
| 45% MPA | 10.06 | 12.72 | 13.5 | 15.87 | 16.53 | 18.23 | 19.73 | 18.85 | 19.65 |
| Average | | 12.09 | | | 16.88 | | | 19.41 | |

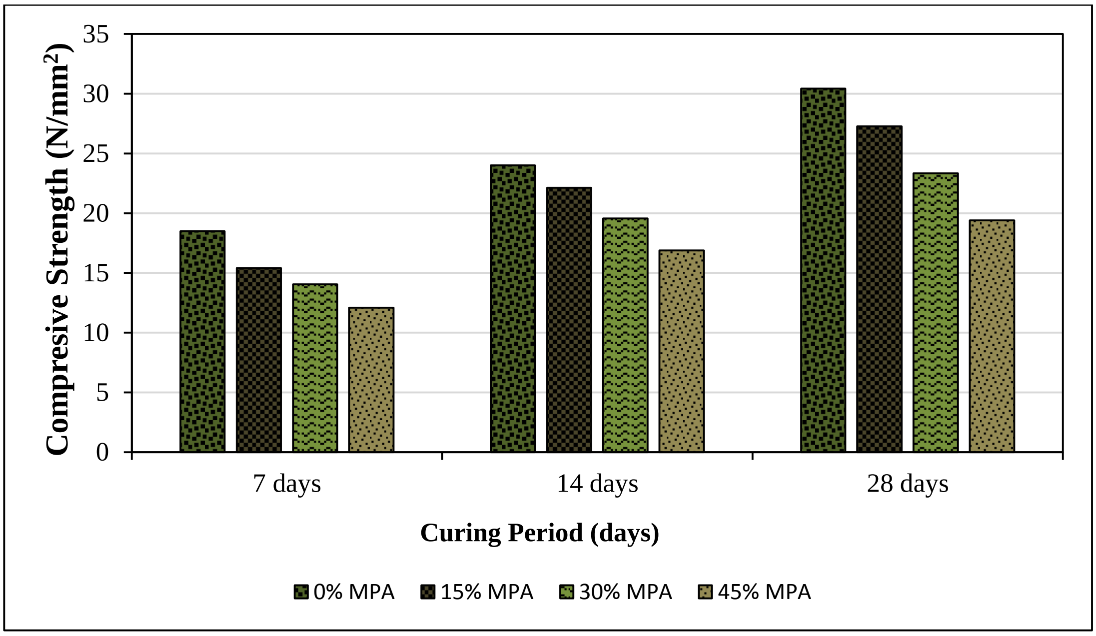

*Figure 4: Compressive strength of concrete containing MPA*

Table 5 and Figure 4 shows the compressive strength results for lightweight concrete with MPA replacing 15%, 30%, and 45% of conventional coarse aggregates, using a water-cement ratio of 0.52 for the control and 0.4 for replacement samples, tested at 7, 14, and 28 days. Replacing conventional aggregates with MPA reduced both density and compressive strength, likely due to variations in MPA properties, such as size, shape, and quality, causing inconsistent performance in concrete mixtures (Raj *et al.*, 2020). The control achieved the highest compressive strength of 30.43 N/mm² at 28 days. A linear reduction in compressive strength was observed for MPA concrete, with decreases of 10.94%, 14.65%, and 15.69% for 15%, 30%, and 45% MPA content, respectively. Higher MPA replacements (30% and 45%) reduced workability, making compaction difficult and leading to increased porosity and lower strength (Smith et al., 2018). Despite this, all MPA concrete samples exceeded the BS EN 206:2000 minimum requirement of 17 N/mm² for 28-day compressive strength of structural lightweight concrete. MPA is thus viable for producing structural lightweight concrete with up to 30% replacement without significant strength loss.

### 3.2.4 Ultrasonic Pulse Velocity (UPV)

The average UPV of MPA concrete samples is shown in Table 6 and Figure 5 respectively.

**Table 6: UPV of MPA concrete cubes in M/s (At 7, 14 and 28 days)**

| Replacement level | 3 cubes at 7 days | | | 3 cubes at 14 days | | | 3 cubes at 28 days | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 1st | 2nd | 3rd | 1st | 2nd | 3rd |
| Control mix | 3773 | 3891 | 3802 | 4054 | 4081 | 4049 | 4255 | 4246 | 4283 |
| Average | | 3822 | | | 4061 | | | 4261 | |
| 15% MPA | 3502 | 3527 | 3484 | 3802 | 3773 | 3745 | 3952 | 3921 | 4008 |
| Average | | 3505 | | | 3774 | | | 3961 | |
| 30% MPA | 3174 | 3189 | 3165 | 3509 | 3533 | 3515 | 3656 | 3642 | 3630 |
| Average | | 3176 | | | 3519 | | | 3643 | |
| 45% MPA | 2812 | 2828 | 2837 | 3279 | 3257 | 3241 | 3407 | 3397 | 3384 |
| Average | | 2826 | | | 3259 | | | 3396 | |

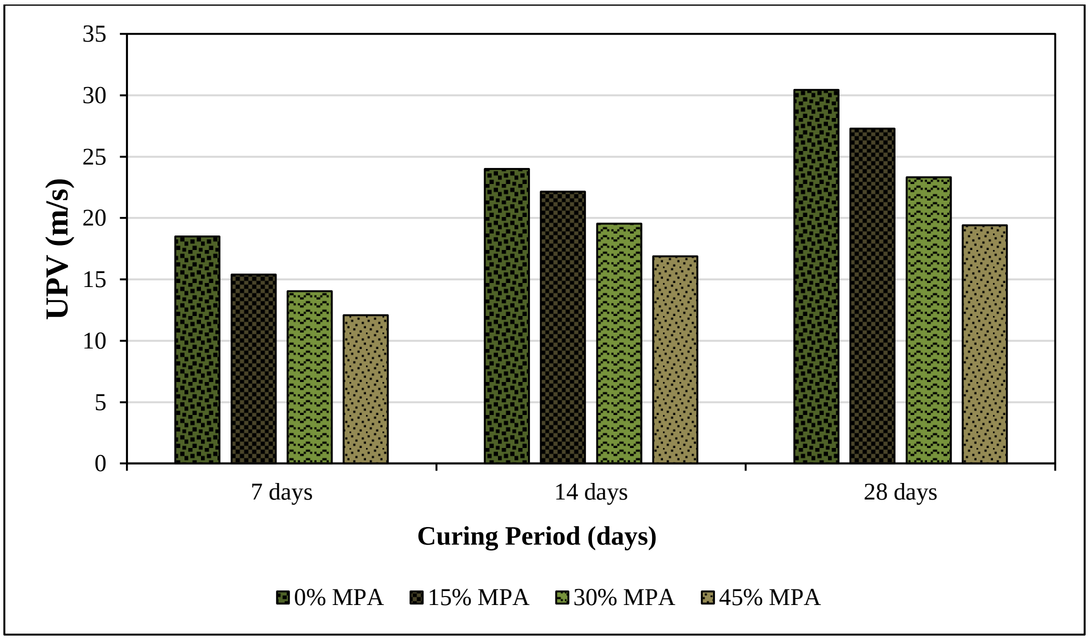

*Figure 5: Ultrasonic pulse velocity of concrete containing MPA*

Table 6 and Figure 5 show that the control sample recorded the highest UPV readings of 3822, 4061, and 4261 m/s at 7, 14, and 28 days, respectively, while the 45% MPA samples exhibited the lowest readings of 2826, 3259, and 3396 m/s at the same intervals. This reduction is attributed to increased porosity in the concrete due to MPA incorporation, which disrupts the ultrasonic wave paths and lowers UPV values compared to the control (Razaqpur *et al.*, 2015). Despite this, all lightweight concrete samples with MPA replacement satisfied the BS 1881-203:1995 minimum requirements for structural lightweight concrete.

### 3.2.5 Splitting Tensile Strength

The splitting tensile strength results of concrete with MPA as coarse aggregate supplement at various replacement levels are shown in Table 7 and Figure 6 respectively.

**Table 7: Splitting Tensile Strength of Concrete at (7, 14 and 28 days)**

| Replacement | 3 cubes 7 days | | | 3 cubes 14 days | | | 3 cubes 28 days | | |
|---|---|---|---|---|---|---|---|---|---|
| **level** | 1st | 2nd | 3rd | 1st | 2nd | 3rd | 1st | 2nd | 3rd |
| Control mix | 2.48 | 2.52 | 2.47 | 3.49 | 3.55 | 3.69 | 3.88 | 3.94 | 3.94 |
| Average | | 2.49 | | | 3.58 | | | 3.92 | |
| 15% MPA | 2.48 | 2.47 | 2.35 | 3.16 | 3.29 | 3.36 | 3.78 | 3.76 | 3.68 |
| Average | | 2.43 | | | 3.27 | | | 3.74 | |
| 30% MPA | 2.22 | 2.25 | 2.13 | 3.03 | 3.36 | 3.09 | 3.36 | 3.31 | 3.48 |
| Average | | 2.20 | | | 3.16 | | | 3.38 | |
| 45% MPA | 1.96 | 1.89 | 2.06 | 2.39 | 2.46 | 2.28 | 3.12 | 2.98 | 3.07 |
| Average | | 1.97 | | | 2.38 | | | 3.06 | |

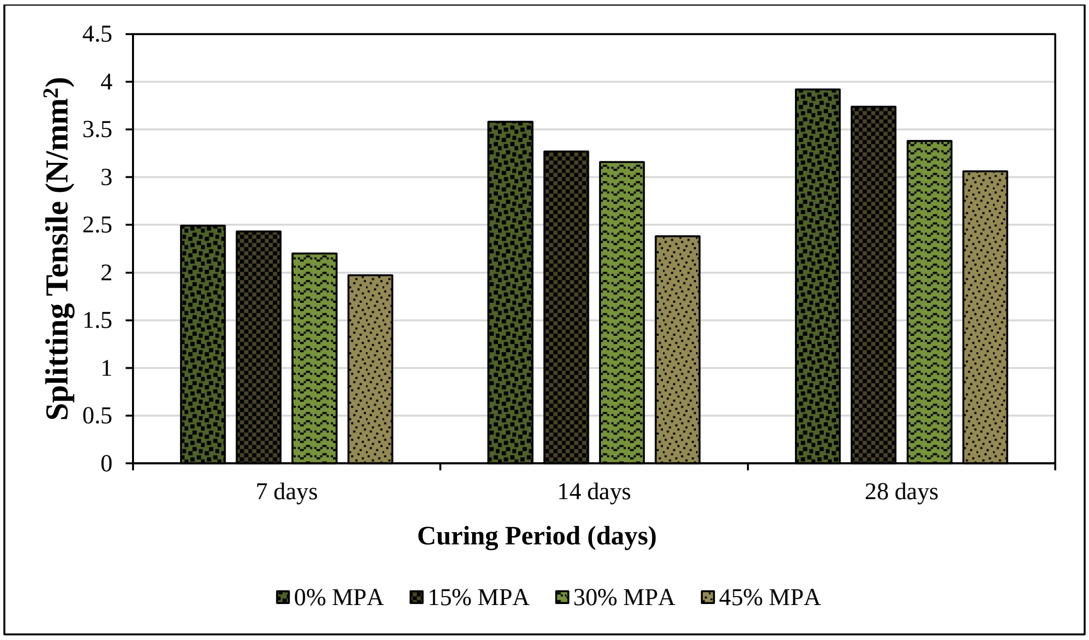

*Figure 6: Splitting tensile strength of concrete containing MPA*

The splitting tensile strength results of concrete with MPA at various replacement levels was tested at 7, 14, and 28 days. The average result of three specimens for each curing period was reported. The results indicate that adding MPA reduced the tensile strength of the concrete. At 28 days, the tensile strengths for 15%, 30%, and 45% MPA replacements were 3.74 N/mm², 3.38 N/mm², and 3.06 N/mm². This represents a 4.59 % decrease in tensile strength for the 15% replacement over the 0% control. Similarly, a reduction in tensile strength for 30% and 45% MPA replacement were observed likely due to the porous nature of MPA concrete samples, leading to increased water absorption as noted by (Rezvan, *et al.*, 2023). Despite this reduction, all MPA concrete specimens met the 28-day minimum tensile strength requirement set by BS EN 12390-6 (2009). This suggests that MPA can be effectively used as a coarse aggregate supplement in concrete.

### 3.2.6 Flexural Strength

The flexural strength test results of concrete with MPA as coarse aggregate supplement at various replacement levels are shown in Table 8 and Figure 7 respectively.

**Table 8: Flexural Strength of Concrete at (7, 14 and 28 days)**

| Replacement | 3 cubes 7 days | | | 3 cubes 14 days | | | 3 cubes 28 days | | |
|---|---|---|---|---|---|---|---|---|---|
| **level** | 1st | 2nd | 3rd | 1st | 2nd | 3rd | 1st | 2nd | 3rd |
| Control mix | 2.79 | 3.02 | 2.88 | 4.18 | 4.26 | 4.43 | 4.64 | 4.59 | 4.73 |
| Average | | 2.90 | | | 4.29 | | | 4.65 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 15% MPA | 2.73 | 2.88 | 2.87 | 3.79 | 3.94 | 4.03 | 4.44 | 4.64 | 4.46 |
| Average | | 2.83 | | | 3.92 | | | 4.51 | |
| 30% MPA | 2.23 | 2.26 | 2.15 | 3.61 | 4.02 | 3.70 | 4.13 | 4.00 | 4.16 |
| Average | | 2.24 | | | 3.77 | | | 4.10 | |
| 45% MPA | 2.31 | 2.23 | 2.45 | 2.85 | 2.90 | 2.75 | 3.64 | 3.51 | 3.74 |
| Average | | 2.31 | | | 2.81 | | | 3.63 | |

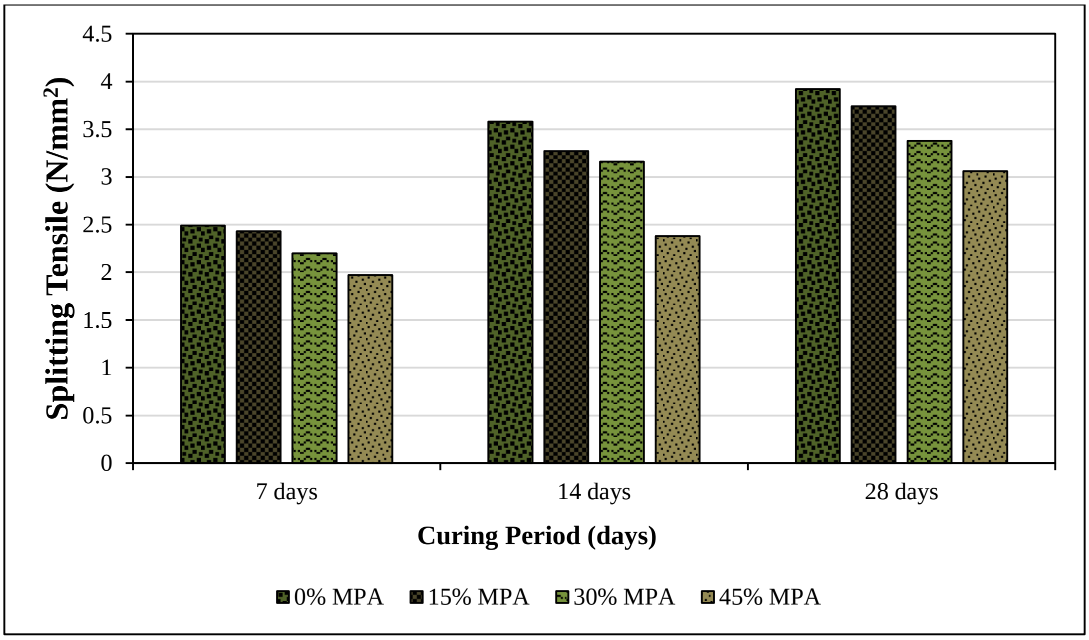

*Figure 7: Flexural strength of concrete containing MPA*

The flexural strengths of concrete with MPA at various replacement levels was tested at 7, 14, and 28 days. At 28 days, the most notable results were the flexural strengths for 15%, 30%, and 45% MPA replacements, which were 4.51 N/mm², 4.10 N/mm², and 3.63 N/mm², respectively, compared to 4.65 N/mm² for the control samples. This represents a 3.01% decrease at the 15% MPA replacement. Similarly, a reduction in flexural strength for 30% and 45% MPA replacement were observed likely due to the porous nature of MPA concrete samples, leading to increased water absorption. Despite this reduction, all MPA concrete specimens met the 28-day minimum flexural strength requirement set by BS EN 12390-5:2000.

### 3.3 Predictive Models Development

This section presents the predicted compressive strength of MPA concrete as a partial replacement for conventional coarse aggregate in lightweight concrete. MPA replaced conventional coarse aggregate at 0%, 15%, 30%, and 45%. The compressive strength of the MPA concrete was predicted using ANN. Experimental test results were used to generate additional data with CTGAN, a machine-learning library for synthetic data generation.

### 3.3.1 Simulation Results and Analysis

The study evaluated the compressive strength of modified plastic aggregate concrete using computational intelligence techniques. Initially, a dataset of 500 entries was generated from experimental and augmented data using the CTGAN library. This dataset included parameters such as cement content (C), water content (W), superplasticizer (SP), coarse aggregates (CA), fine aggregates (FA), MPA, testing age (A), slump value (S), density (D), Aggregate impact value (IV), Aggregate crushing value (CV), ultrasonic pulse velocity (UPV) and compressive strength (CS). The data was split into a training set (70%) and a testing set (30%). The training set developed the predictive model, while the testing set assessed the model's accuracy in predicting MPA concrete's later age compressive strength. Statistical analysis of the dataset revealed essential parameters such as maximum, minimum, mean, and standard deviation for input and output variables, as shown in Table 9. Measures were taken to handle outliers, with any identified outliers replaced by mean values to maintain data integrity. This process ensured the dataset maintained a consistent distribution, with no more than 5% outliers in any attribute, as shown in Tables 10 and Figure 8.

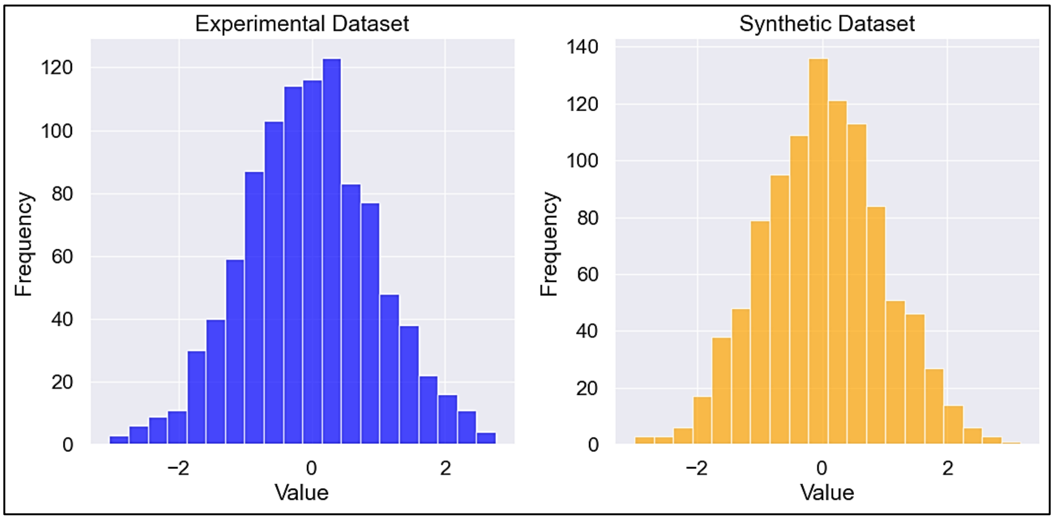

*Figure 8: The experimental and synthetic data generated used for compressive strength of MPA concrete*

**Table 9: The Statistical Parameters of Compressive Strength Model**

| Variables | Count | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| Water | 500 | 150.68 | 19.42 | 128.00 | 207.00 |
| Cement | 500 | 348.00 | 0.00 | 348.00 | 348.00 |
| Fine | 500 | 745.00 | 0.00 | 745.00 | 745.0 |
| Coarse | 500 | 836.60 | 210.92 | 338.00 | 1391.00 |
| SP | 500 | 1.99 | 1.64 | 0.00 | 4.48 |
| MPA | 500 | 75.56 | 42.32 | 0.00 | 174.00 |
| Age | 500 | 50.24 | 23.31 | 7.00 | 92.00 |
| Slump | 500 | 17.10 | 8.15 | 0.00 | 38.00 |
| Density | 500 | 1951.08 | 223.68 | 1393.35 | 2624.47 |
| Impact value | 500 | 2.95 | 1.50 | 1.20 | 7.40 |
| Crushing value | 500 | 3.79 | 1.38 | 2.23 | 8.96 |
| UPV | 500 | 4026.12 | 630.62 | 2276.86 | 5426.17 |
| Strength (N/mm$^2$) | 500 | 29.61 | 7.86 | 5.58 | 44.38 |

**Table 10: Analysis of the Outliers for all the Variables**

| | **Compressive Strength** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variables** | **W** | **C** | **F** | **C** | **SP** | **MPA** | **Age** | **S** | **D** | **IV** | **CV** | **UPV** | **CS** |
| **Outliers** | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

Figure 9 illustrates the correlation matrix of the data used in the models. The correlation matrix shows no correlation between the variables used in the computational models. Therefore, it can be said that the components are mostly independent of each other.

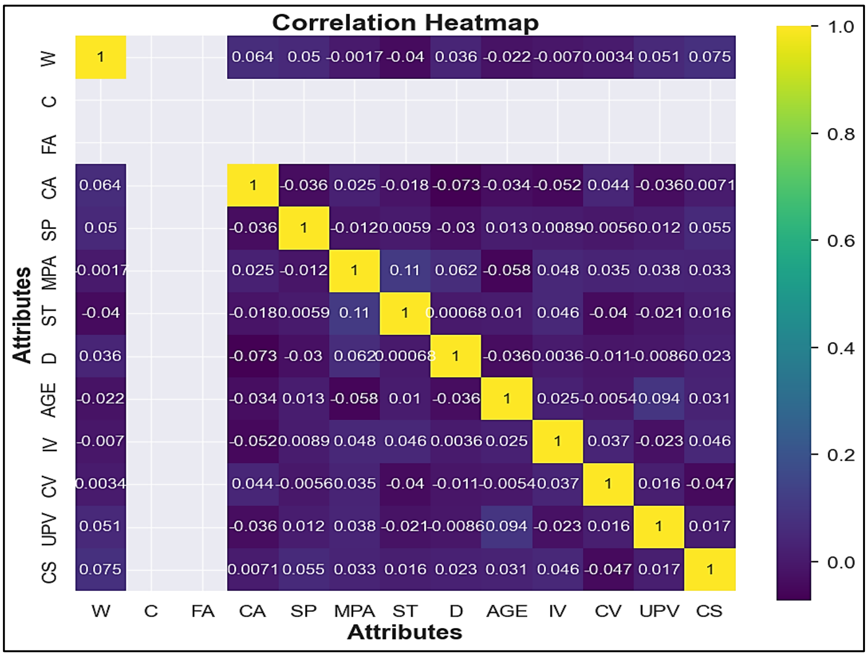

*Figure 9: Correlation between different attributes used in predicting water absorption property*

### 3.3.2 ANN Model Development and Validation

Table 11 shows the training and testing results for ANN model predicting the compressive strength of MPA concrete at various ages.

**Table 11: Performance Evaluation of Compressive Strength Models**

| Statistical Checks | $R^2$ | MAE | MSE |
|---|---|---|---|
| Training results | 0.99 | 0.1775 | 0.1170 |
| Testing results | 0.99 | 0.0973 | 0.0294 |

The ANN model used to predict the compressive strength of MPA concrete shows strong performance, as shown in Figure 10 and 11 presents the training $r^2$ value of 0.99 indicates that the model explains about 99 % of the variance in the training data, demonstrating its effectiveness in capturing the relationships within the dataset. The testing $r^2$ value of 0.99 is also high, reflecting the model's robust generalization to new data. This suggests that the model performs well in predicting the compressive strength of MPA concrete, as supported by similar findings in recent study of (Rezvan, *et al.*, 2023). Additionally, the low MAE and MSE values further underscore the model's accuracy and reliability. With MAE of 0.1775 and 0.0973 for the training and testing data, the model shows minimal average error in its predictions. Similarly, the MSE values were 0.1170 and 0.0294 for the training and testing dataset, indicate that the model effectively minimizes larger prediction errors. These results suggest that MPA can be used to produce structural lightweight concrete with up to 45% MPA replacement.

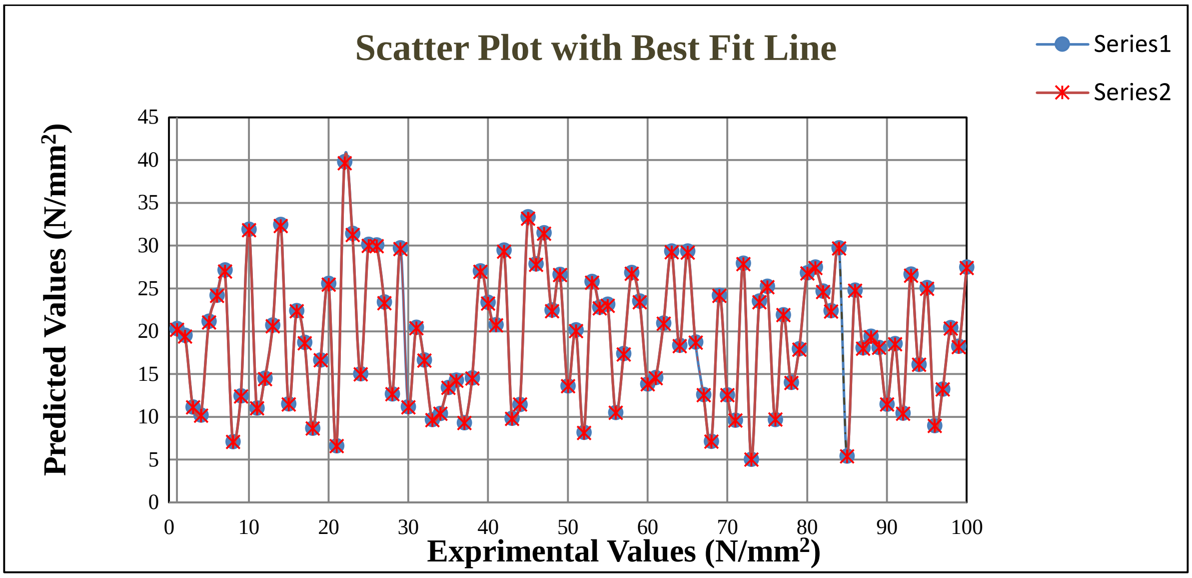

*Figure 10: Experimental test results versus predicted compressive strength for ANN model*

y_pred (N/mm$^2$) = 0.9743*X + 0.6898 (R$^2$ = 0.99)
Where:
y_pred is the predicted value for compressive strength of MPA concrete exposed to $H_2SO_4$
X represents the variables values.
X is express as, $X = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \ldots\ldots\ldots\ldots\ldots + \beta n\, Xn + \epsilon$
$X_1, X_2, \ldots\ldots\ldots\ldots, Xn$ are the independent variables.
$\beta_0, \beta 1, \ldots\ldots\ldots\ldots, \beta n$ are the coefficients.
0.9743 is the gradient of the regression line.
0.6898 is the point where the line crosses the y-axis.

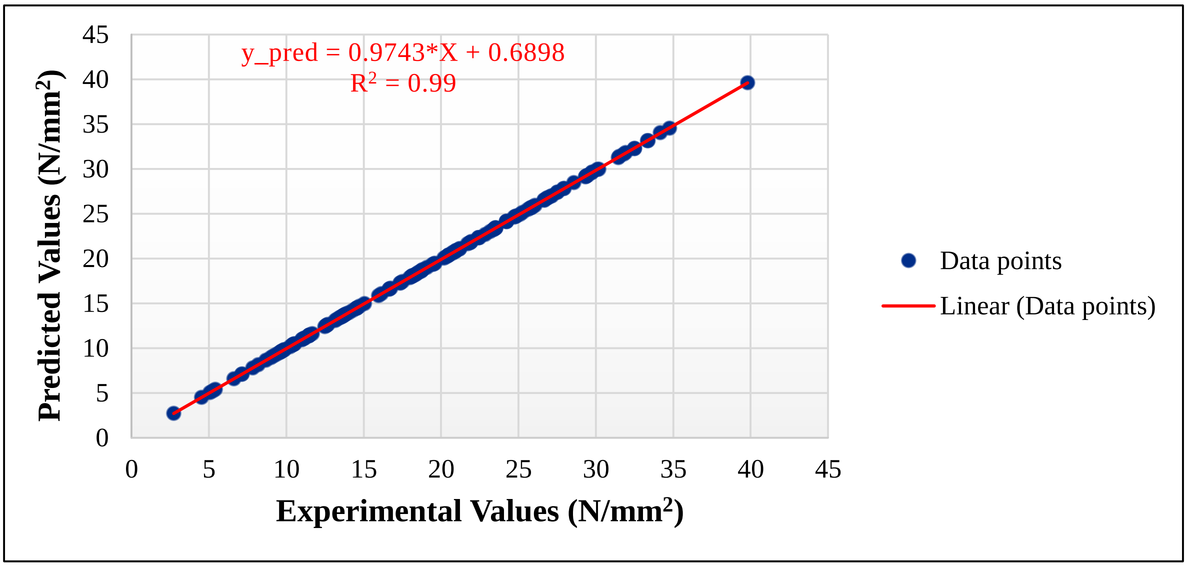

*Figure 11: Relationship between experimental test results and predicted compressive strength for ANN model*

## IV. Conclusion

This study examined the impact of Modified Plastic Aggregate (MPA) on concrete properties and the effectiveness of predictive models for strength forecasting. Fine and coarse aggregates met industry standards with suitable density, specific gravity, and mechanical properties, ensuring their applicability for high-performance concrete. MPA complied with British Standards, exhibiting a low water absorption rate of 0.50%, high void content of 58.96%, and lightweight characteristics with a bulk density of 337 kg/m³, making it suitable for applications in moisture-sensitive environments. Fresh concrete with 15% MPA replacement improved workability, achieving a slump value of 30 mm compared to 20 mm for the control mix, while higher MPA replacements reduced workability due to its irregular shape and surface texture. MPA replacement reduced concrete density from 2135 to 1895 kg/m³ (15% to 45%) and decreased compressive strength as replacement increased, attributed to MPA's lower rigidity. However, concrete with 30% MPA achieved a 28-day compressive strength of 23.13 N/mm², meeting BS EN 206-1 (2013) standards for structural lightweight concrete. While tensile and flexural strength declined with MPA replacement, mixes with 15% and 30% MPA replacement met the BS EN standards for the minimum tensile and flexural strength. Furthermore, ANN model accurately predicted compressive strength of concrete containing MPA as coarse aggregate supplement, achieving high R² values of 0.99 for both training and testing dataset, with low MAE and MSE.

## References

[1]. Agboola, S. A., Adamu, I. M., Suleiman, A. O., Simdima, G. G. (2021). Suitability Assessment of Sabon Kaura Pit Gravel as Coarse Aggregate in Concrete Production. International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS), 10, (9), ISSN 2278-2540.

[2]. Babafemi, A.J.; Sirba, N.; Paul, S.C.; Miah, M.J., (2022). Mechanical and Durability Assessment of Recycled Waste Plastic (Resin8 & PET) Eco-Aggregate Concrete. *Sustainability.*14, 5725.

[3]. Babafemi, A. J., Šavija, B., Paul, S. C., & Anggraini, V. (2018). Engineering properties of concrete with waste recycled plastic: A review. *Sustainable Environment Research*, 28(3), 107-116.

[4]. Bonifazi, G., Capobianco, G., Serranti, S., Eggimann, M., Wagner, E., Di Maio, F., & Lotfi, S. (2015). The ITZ in concrete with natural and recycled aggregates: Study of microstructures based on image and SEM analysis. *Proc. 15th Euroseminar Microsc. Appl. to Build. Mater*, 299-308.

[5]. BS EN 1097-6:2013- Tests for mechanical and physical properties of aggregates Part 6: Determination of particle density and water absorption

[6]. British Standards Institution. (2009). BS EN 12350-2:2009 Testing fresh concrete. Slump-test. BSI Group.

[7]. British Standards Institution. (2009). BS EN 12390-3:2009 Testing hardened concrete. Compressive strength of test specimens. BSI Group.

[8]. BS EN 12390-6. (2009). Testing hardened concrete. Tensile splitting strength of test specimens. British Standards Institution.

[9]. British Standards Institution. (2019). BS EN 12390-7:2019 Testing hardened concrete. Density of hardened concrete. BSI Group.

[10]. British Standard Institution (BSI). (2000). Concrete-Specification, performance, production and conformity, London, BS EN 206

[11]. British Standards Institution. (1995). BS 1881-203:1995 Testing concrete. Recommendations for measurement of velocity of ultrasonic pulses in concrete. BSI Group.

[12]. British Standard 812 part 2 (1995). Testing aggregate part 2. Methods of determination of bulk density. BSI Publication British Standard Institution, London.

[13]. BS 1881-203. (1995). Testing of Concrete - Part 203: Recommendations for measurement of velocity ultrasonic pulses in concrete. Pages 1-3, 15

[14]. BS 812-112: 1990. Testing aggregates - Part 112: Methods for determination of aggregate impact value (AIV).

[15]. BS 812: Part 110 (1990): Method for Determination of Aggregate Crushing Value (ACV). British Standard Institution, Linford wood, Milton Keyes, MK146LE, U K.

[16]. EN (European Standard) (2013). EN 206-1 2013. Concrete – Part 1: Specification, Performance, Production and Conformity. Brussels: European Committee for Standardization (CEN).

[17]. Goodfellow, I., Bengio, Y., & Courville, A. (2016). Deep Learning. MIT Press.

[18]. Haque, R., Poon, C. S., & Lo, Y. (2019). Reuse of waste plastic in concrete: A review. *Journal of Environmental Management,* 232, 429-448.

[19]. Islam, M.J., Meherier, M.S & Islam, M.R., (2016). Effects of waste PET as coarse aggregate on concrete's fresh and hardened properties. *Construction and Building Materials*, vol. 125, pp. 946–951, 2016.

[20]. Jiang, S., Huang, L., & Wang, R. (2020). Effects of superplasticizer on the rheology and properties of cement pastes. *Journal of Materials Science & Technology*, 36, 160-167.

[21]. Krizhevsky, A., Sutskever, I., & Hinton, G. E. (2017). ImageNet classification with deep convolutional neural networks. *Communications of the ACM*, 60(6), 84-90.

[22]. Kumar, P., Haque, R., & Poon, C. S. (2020). Feasibility study on the use of plastic waste in concrete. *Journal of Materials in Civil Engineering,* 32(8), 04020210.

[23]. Kumar, P., & Sharma, R. (2018). Environmental impacts of aggregate extraction and utilization in the construction industry. *Environmental Science and Pollution Research*, 25(15), 14617–14627.

[24]. Lee, S. J., Moon, H. J., & Shin, D. H. (2019). Chemical treatment of recycled aggregates for improving bond properties of concrete. *Materials*, 12(15), 2457.

[25]. Mustafa M.A., Abdullah M.Z., Dawoud, O., & Tayeh, B.A., (2021). Experimental and numerical investigations of the influence of partial replacement of coarse aggregates by plastic waste on the impact load, *International Journal of Sustainable Engineering*, 14:4, 735-742, DOI:10.1080/19397038.2020.1774820.

[26]. Poon, C. S., Shui, Z. H., & Lam, L. (2017). Influence of moisture states of natural and recycled aggregates on the slump and compressive strength of concrete. *Cement and Concrete Research*, 34(1), 31-36.

[27]. Raj, R., Kumar, S., & Prasad, K. (2020). Impact of recycled coarse aggregate on concrete properties. *Materials Today: Proceedings*, 27, 2396-2400.

[28]. Razaqpur, A. G., Fournier, B., & Fournier, L. (2015). Ultrasonic pulse velocity evaluation of lightweight concrete. *ACI Materials Journal*, 112(4), 485-495.

[29]. Rezvan, S., Moradi, M.J., Dabiri, H., Daneshvar, K., Karakouzian, M., & Farhangi, V. (2023). Application of Machine Learning to Predict the Mechanical Characteristics of Concrete Containing Recycled Plastic-Based Materials. Appl. Sci. https://doi.org/10.3390/app13042033

[30]. Smith, M., Love, P. E., & Watson, H. (2018). Environmental impact assessment of recycled aggregate concrete. *Construction and Building Materials*, 169, 95–102.

[31]. Smith, J., Johnson, M., & Williams, T. (2018). Workability and strength properties of lightweight concrete with recycled aggregates. *Journal of Civil Engineering and Management*, 24(7), 519–528.

[32]. Smith, M., Love, P. E., & Watson, H. (2017). A study of the mechanical properties of recycled aggregate concrete and the implications for sustainability. *Journal of Cleaner Production*, 142(4), 4041–4052.

[33]. Yeh, I. C. (2018). Modelling of the strength of high-performance concrete using artificial neural networks. *Cement and Concrete Research*, 28(12), 1797-1808.