Influence of non-biodegradable wastes on mechanical properties of concrete – A Neural Network approach

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Abstract. The environmental pollution due to different non-biodegradable waste is not only making the surroundings vulnerable but also makes a serious defect on the humans. Because of the non-biodegradable property of plastics, decomposition is not possible which makes them remain in the environment for a longer period creating ecological problems. These non-biodegradable materials will be a significant source of plastic waste management if these materials can be substituted as a construction material by using in concrete. An experimental investigation is made on the usage of Non-Biodegradable plastic ravage materials as fine aggregates in M20 concrete with substitution from 0%, to 50% by weight of fine aggregate. Subsequently, the ravage glass powder is included in concrete as a substitution for cement with a percentage of replacement of 0% and 5% by weight of cement. Specimen for concrete in compression, tension and flexure are tested for 28 days curing. The experimental outcome shows that concrete with 10% replacement of plastic waste by weight of fine aggregate with 5% replacement of glass powder by weight of cement had an elevated influence on the mechanical properties. Further Artificial Neural Network Analysis is performed to validate the experimental results. The classification of Neural networks (NN), such as -Leven Berg-Marquardt (NN-LM) and Gradient Descent (NN-GD) is used to perform the analysis.

Keywords: Concrete, Non-biodegradable, Plastic waste, Glass powder, compressive strength, split tensile strength, flexural strength and Neural Network

1. Introduction

Plastics are taken into account as a significant technical breakthrough in recent years, such that they influenced new inventions substituted alternative materials in the existing product. They are lightweight, robust, adaptable and immune to humidness, chemical product, and degradation. Plastics utilization has reduced the problem of solid urban waste accumulation and in turn, promoted plastic containers [1]. The waste plastic may be a key concern for the property of the surroundings because it pollutes rivers, land, and oceans. However, its light-weight, flexibility, moisture-resistant, and price effectiveness will build it a substitute for several existing composite materials like concrete [2]. The current trend in concrete research revolves around sustainability [3].

Large quantities of plastic waste can be used for concreting if a compromise is made on their strength [4]. Plastics are utilized in concrete as fine aggregates and plastic fibres. Between the two, plastic aggregates are cheap and involve less variety of process steps for usage compared to fibres. [5] PET may be a quite polyesters manufactured from the antifreeze and terephthalic acid’s composition and its chemical name is synthetic resin Terephthalate or “PET” [6]. Analysis relating to the employment of plastic waste as an associate combination for surface microstructure study shows some
progress worth considering. [7]. PET fibres have been used as a fractional and complete substitute for sand in concrete with the proportion varying from 2%–100% [8]. Concrete with PET 15% established lower modulus of the physical property and splitting tensile strength with relation to standard concrete and an increasing trend for compressive strength and flexural strength with 5% of PET replacement for fine aggregate [6].

The compressive strength of concrete reduces with the increase of waste plastic ratios at different ages of curing. Compressive strength improves by the addition of retarders to the mix. Flexural strength of waste plastic concrete reduces with the rise in the proportion of plastic ravage [4].

Higher compressive strength and Young’s modulus will be obtained for PET particle sizes of 2.5% volume which is cured for twenty-eight days [9]. No effects will be found on the density of concrete with hydrogen peroxide solution (H₂O₂) and calcium hypochlorite treated plastic waste whereas the slump due to roughened face of treated plastic aggregates reduces [5]. The addition of Nano-SiO₂ effectively improves the mechanical properties, however, magnifies its autogenic shrinkage when compared to standard mortar [10]. When PET used as aggregate in concrete it reduces the compressive strength [11]. Plastic waste substitution for sand in concrete increases the compressive strength up to 5% to 10% replacement and reduces for 15% and 20% substitution.

The flexural and split tensile strength can be improved up to 100% addition of the sand with PET [12]. Concrete in compression and tension decreases with the rise in recycled plastic substance [13]. In concrete containing waste plastic mechanical properties reduces with rising the percentages of waste plastic bottle and waste plastic bags [14]

Compressive strength improves for concrete with glass powder as a substitution for binding material when compared to concrete without glass powder [15]. Concrete with the waste glass powder as a replacement for fine aggregate in various percentages of 5% to 50% improves for 25% glass powder replacement with fine aggregate for M20 concrete [16]. Lightweight concrete with 10% replacement of glass powder for cement shows higher compressive strength [17].

Based on the above research results, an attempt has been made to investigate the influence of plastic ravage as part of fine aggregates varied from 0% to 50% by weight with glass powder as substitution of 5% for cement. Mechanical properties such as compressive strength, tensile strength and flexural strength will be studied for different combinations.

2. Material Properties
2.1 Cement.
OPC of 43 grade with specific gravity 3.1 and initial setting time 32 min was used in this investigation and its physical properties comply the requirements as per Indian code provision of IS 8112-2013 [18].

2.2 Aggregates.
Coarse aggregate of size 20mm and sand conforming to zone II were utilized as per IS 10262-2019 [19]. The specific gravity of fine aggregate and coarse aggregate is 2.69 and 2.81 respectively.

2.3 Plastic waste.
Plastic waste particles obtained from PET bottles and plastic bags ground to a maximum size of 4.75mm as shown in figure 1 are used as fine aggregates in concrete. The specific gravity was found to be 1.11 g/cm³. It has an adsorption property and so it increases the water requirement, as plastic is elastic in nature it will boost the tensile strength of the concrete for only some percentage of replacement.

2.4 Glass powder.
Glass powder shown in figure 2 as fine as cement can be used as a replacement of cement in concrete. Glass powder in concrete increases the mechanical properties efficiently when compared with the conventional concrete. The specific gravity is 2.5.

2.5 Concrete mix design. The concrete mixture has been designed as per IS 10262 2019 [19] for M20 grade of concrete. The proportion of the concrete mixture is 1:1.5:2.5 with w/c ratio 0.44. To review the mechanical properties of concrete the mix was made ready in specified partial substitution of fine aggregate with plastic wastes starting from 0% to 50% by weight and cement was partially replaced from 0% and 5% by weight by glass powder. Coarse aggregate of 1113 kg/m³, the sand of 637 kg/m³,
the cement of 204 kg/m$^3$ and water of 81 litres/m$^3$ were adopted for all proportions studied. The particulars of the other ingredients of the concrete mix proportions are given in Table 1.

![Figure 1. Plastic powder.](image1)

![Figure 2. Glass powder.](image2)

### Table 1. Concrete Mix Proportion

| Mix designation | Plastic waste (%) | Glass powder (%) | Plastic powder (kg/m$^3$) | Glass powder (kg/m$^3$) |
|-----------------|------------------|-----------------|--------------------------|--------------------------|
| CPG0            | 0                | 0               | 0                        | 0                        |
| CPG1            | 0                | 5               | 0                        | 10.2                     |
| CPG2            | 10               | 0               | 63.7                     | 0                        |
| CPG3            | 10               | 5               | 63.7                     | 10.2                     |
| CPG4            | 20               | 0               | 127.4                    | 0                        |
| CPG5            | 20               | 5               | 127.4                    | 10.2                     |
| CPG6            | 30               | 0               | 191.1                    | 0                        |
| CPG7            | 30               | 5               | 191.1                    | 10.2                     |
| CPG8            | 40               | 0               | 254.8                    | 0                        |
| CPG9            | 40               | 5               | 254.8                    | 10.2                     |
| CPG10           | 50               | 0               | 318.5                    | 0                        |
| CPG11           | 50               | 5               | 318.5                    | 10.2                     |

2.6 Experimental investigation. For each of the above mix proportions mentioned in table 1 concrete cubes of size, 15 cm × 15 cm × 15 cm, cylinders of size 30 cm × 15 cm and prisms of size 10 cm × 10 cm x 50 cm were cast. The cube specimens were tested for compression, a cylindrical specimen for split tensile strength and prism were assessed for flexural strength for 28 days of curing as per IS 516 1959 [20]. The strength of concrete under compression and Split tension and flexure was found with Universal testing machine with capacity 1000kN.

3. Artificial Neural Networks

Artificial neural networks (ANNs) are unit calculations recreating human neurons. They are an assortment of Artificial Intelligence, that puts forth an attempt to make the organizations of the neuron of the life central system framework named ‘nervosum’ a man-made nerve cell, conjointly known as a unit or a hub, which takes many key affiliations (dendrites inside the existence neuron) that are unit or node. The unit at that point decides the all out of the weighted information sources and applies for an opening work (closely resembling body inside the natural neuron). The result of the unit is then passed mistreatment the output association (axon function). In the ongoing years, such smart skilled frameworks are with success applied in a few fields of engineering, among that, they are broadly utilized for foreseeing the mechanical properties of homogenized cement-based concrete. It was proven that
ANN-based strength prediction might be successful to calculate the strength of concrete for different combinations of ingredients for different curing period [7]. In the present work, Artificial Neural Network has been set up utilizing MATLAB code, Neural Network chest.

3.1 Network Architecture. Artificial neural organization might be significant information demonstrating instrument that can keep and represent troublesome input and output affiliations. The design of the ANN model needs to recognize the necessity (i.e., an assortment of input neurons, output neurons, hidden layers, and neurons in each concealed layers) and the organization settings (activation function). As shown in Figure.3 three neural networks carry with at least 3 layers, i.e., a partner in the nursing input layer, one or many hidden layers, and partner in nursing an output layer. The adopted requirement consists of the following:

(i) Six neurons (Ni =6) inside the input layer, that imply the factors of cement content (CC; kg), fine aggregate content (FA; metric weight unit), coarse aggregate content (CA; kg), water content (W; litres), Plastic waste substance (PW; kg), and Glass powder content (GP; kg)

(ii) One vegetative cell inside the output layer, that represents the value of the corresponding compressive strength (MPa), splitting tensile strength (MPa), and flexural strength (MPa).

(iii) One hidden layer with ten neurons.

![Figure 3. Architecture of ANN](image)

The classification of Neural Network training functions, such as Leven Berg-Marquardt (NN-LM) and Gradient Descent (NN-GD) is for the analysis. Feed-forward backpropagation neural networks have been used in this study.

4. Results and discussions

4.1 Compression strength. To investigate the concrete under compression specimens with varied plastic wastes with glass powder were factory-made. Compressive strength is determined with samples of size 15 cm × 15 cm × 15 cm. As shown in figure 4 and table 2, initially the compressive strength increases with an increase in the percentage of substitution of sand by plastic waste, however, it decreases after a while. The maximum percentage increase in compressive strength of 16.61% was obtained for concrete specimen CPG3 i.e. 10% substitute of sand volume with plastic waste with 5% of glass powder replacement for cement. Also, the specimen CPG1, CPG2 and CPG3 have an increase in compressive strength of 2.56%, 6.77% and 6.07% respectively. Moreover, it observed that when the plastic waste substitution is increased beyond 10% for fine aggregate with 5% substitution of glass powder by weight of cement, compressive strength decreases.
4.2 Split tensile strength. Split tensile strength is determined with cylindrical samples of size 30 cm × 15 cm. In Figure 5 and Table 2, the effect of substituting plastic waste with various percentages of substitutes by weight of fine aggregate proportion with glass powder for cement is presented. The outcome shows that the highest percentage increase in split tensile strength of 51.17% was obtained for CPG3 i.e. concrete with 10% plastic waste by weight of fine aggregate with 5% glass powder by weight of cement. Whereas for CPG1, CPG2 percentage increases in split tensile strength were 18.31%, 28.17% respectively. For CPG4, CPG5, CPG6, CPG7 the percentage increase is 32.39%, 18.31%, 4.69% and 2.35% respectively. Moreover, the split tensile strength decreases by 1.41%, 1.88%, 7.04%, 13.15% for CPG8, CPG9, CPG10 and CPG11 respectively. In general, the trend of splitting tensile strength is escalating up to 10% substitution of fine aggregate by plastic wastes with 5% glass powder by weight of cement and after which the split tensile strength reduces. This may be because of the pessimistic result
of an even face texture on the bond strength of plastic wastes [6] and contribution of amorphous structure of finely grounded glass powder which offers excellent pozzolanic property [17]

4.3 Flexural strength. Table 2 and Figure 6 shows the flexural strength of Prism samples of size 10 cm \times 10 \text{ cm} \times 50 \text{ cm}. From the experimental results, it is obvious that maximum proportion of raise in flexural strength was obtained for CPG3 i.e concrete with 10% substitution of fine aggregate by PET waste with 5% glass powder for cement which is 49.13% superior to the control specimen. The percentage increase in flexural strength of specimen CPG1, CPG2, CPG4, CPG5, CPG6 and CPG7 is 4.96%, 19.85%, 29.78%, 18.11%, 4.96% and 2.98% respectively. Whereas the flexural strength decreases for specimen CPG8, CPG9, CPG10, CPG11 by 0.50%, 1.24%, 5.21% and 7.69 respectively. The flexural strength increases up to 10% substitution of fine aggregate by plastic ravage with 5% replacement of glass powder with cement, beyond which it decreases due to the increase of the waste plastic ratio which reduces bonding between plastic waste and cement paste [4].

![Figure 5. Split tensile strength of concrete](image1)

![Figure 6. Flexural strength of concrete](image2)

4.4 Prediction using NN. This segment determines the fundamental options of the joint result of plastic wastes with glass powder in concrete for mechanical properties. Here, the comparison uses the plastic waste of various proportions by weight fine aggregate and glass powder by weight of cement. The particular values of the combinations of plastic waste and glass powder combinations were already mentioned. Consequently, this segment compares the mechanical properties with a distinct grouping of plastic waste with 0% and 5% glass powder using Neural Network-Gradient Descent and Neural Network–Levenberg–Marquard. Initially, figure 7 and table 3 shows the evaluation of the experimental and predicted values of concrete. Here, 12 different combinations of the weight of plastic wastes with 0% and 5% glass powder are determined and further compared with the experimental values. The maximum percentage increase in compressive strength predicted by NN-LM was found maximum in case of CPG11 which is 11.39% higher than experimental values and maximum percentage in a decrease in compressive strength was obtained for CPG9 which 10.54% lesser than experimental values. Similarly, the percentage increase in the predicted compressive strength by NN-GD ranges from 2.01% to 11.02%. The percentage decrease in the predicted compressive strength by NN-GD ranges from 1.70% to 7.62%.

Figure 8 and Table 3 Illustrates the split tensile strength comparison of experimental and predicted values. The predicted values in NN-LM shows that the maximum percentage increase was obtained for CPG1 which is 11.51% higher than the experimental values and percentage decrease is maximum for BCPG3 which is 12.42% lesser than the experimental values. Similarly, the predicted valued in NN-GD the maximum percentage increase was obtained for CPG8 which is 8.10% higher than the actual values and percentage decrease is maximum for CPG4 which is 3.90% lesser than the predicted values. Figure 9 and table 3 shows the comparison of experimental and predicted values for flexural strength.
### Table 3. Comparison of experimental and predicted values of concrete

| Mix   | Compressive strength (MPa) | Split Tensile strength (MPa) | Flexural strength (MPa) |
|-------|---------------------------|-------------------------------|-------------------------|
|       | Experimental | Predicted | Predicted | Experimental | Predicted | Predicted | Predicted |
|       | NN-LM      | NN-GD      | NN-LM      | NN-GD      | NN-LM      | NN-GD      | NN-GD      |
| CPG0  | 31.30       | 31.07      | 31.93      | 2.13       | 2.16       | 2.28       | 4.03       | 4.03       | 4.10       |
| CPG1  | 32.10       | 32.75      | 33.00      | 2.52       | 2.81       | 2.52       | 4.23       | 4.29       | 4.60       |
| CPG2  | 33.42       | 33.41      | 32.44      | 2.73       | 2.72       | 2.73       | 4.83       | 4.96       | 4.67       |
| CPG3  | 36.50       | 35.84      | 33.72      | 3.22       | 2.82       | 3.20       | 6.01       | 5.90       | 5.83       |
| CPG4  | 33.20       | 33.10      | 31.79      | 2.82       | 2.81       | 2.71       | 5.23       | 5.22       | 5.16       |
| CPG5  | 31.20       | 30.19      | 30.50      | 2.52       | 2.57       | 2.52       | 4.76       | 4.89       | 5.02       |
| CPG6  | 25.97       | 26.03      | 24.88      | 2.23       | 2.25       | 2.23       | 4.23       | 4.65       | 4.44       |
| CPG7  | 20.27       | 21.02      | 20.32      | 2.18       | 2.24       | 2.18       | 4.15       | 4.23       | 4.48       |
| CPG8  | 17.69       | 16.68      | 17.39      | 2.10       | 2.08       | 2.27       | 4.01       | 4.00       | 3.99       |
| CPG9  | 16.98       | 15.19      | 15.77      | 2.09       | 1.92       | 1.93       | 3.98       | 3.97       | 3.90       |
| CPG10 | 12.88       | 13.80      | 14.30      | 1.98       | 1.98       | 1.98       | 3.82       | 3.82       | 3.87       |
| CPG11 | 12.20       | 13.59      | 12.83      | 1.85       | 1.86       | 1.86       | 3.72       | 3.75       | 3.80       |

**Figure 7** Graphical depiction of neural network in terms of Compression strength

**Figure 8** Graphical depiction of neural network in terms of Split tensile strength
The predicted values in NN-LM shows that the maximum percentage increase was obtained for CPG6 which is 9.93% higher than the experimental values and percentage decrease is maximum for CPG3 which is 1.83% lesser than the experimental values. The same performance is attained in the case of NN-GD based approach.

5. Conclusion
In this study, the mechanical properties of concrete containing plastic wastes as a substitution for fine aggregate and glass powder as a partial substitution for cement were investigated. Furthermore, the prediction of mechanical properties of concrete with plastic waste and glass powder were made using Network-Gradient Descent and Neural Network–Levenberg–Marquard methods. The conclusions achieved from the experimental and ANN outcomes are listed as follows:
1. The concrete specimens consisting of 10% substitution of fine aggregates with plastic wastes with 5% glass powder obtained the optimal compressive strength. In fact, for 10% of plastic waste content with 5% glass powder has a maximum percentage increase of compressive strength of 16.61%. Further increase in plastic waste contents beyond 10%, the compressive strengths decrease.
2. The split tensile strength strength was maximum for concrete with 10% plastic waste and 5% glass powder which is 51.17% superior to the control specimen.
3. The highest percentage increase in flexural strength was obtained for 10% plastic waste and 5% glass powder which is 49.13% higher than the control specimen.
4. Eventually, it can be said that usage of plastic wastes as fine aggregates in concrete enhances the mechanical properties of can be an eco-friendly solution for plastics.
5. The predicted mechanical properties using Neural Network–Levenberg–Marquard and Neural Network-Gradient Descent have attained its maximum performance.

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