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Investigation on tensile and flexural behaviour of fibre reinforced concrete using artificial neural network

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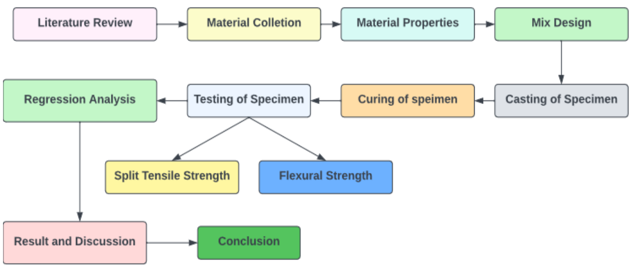
Graphical abstract



Abstract

The purpose of this study is to investigate the impact that using Marble Sludge Powder (MSP) as a partial replacement for cement in concrete can have. Experiments were conducted to investigate a variety of characteristics of Fiber-Reinforced Concrete (FRC) using both fresh concrete and concrete that had been allowed to solidify. The aim of this work is to determine the split tensile and flexural property of FRC. For the determination of results two water binder ratios, such as 0.35 and 0.40, as well as percentage re-placements of 0%, 5%, 10%, 15%, 20%, and 25% of marble sludge powder and 0.5% of polypropylene 3S fiber were used. After curing for 7, 14, 28, and 56 days, the samples were put through a battery of mechanical tests to evaluate their qualities. The flexural strength and split tensile strength of the material were evaluated throughout this investigation. In the end, an artificial neural network (ANN), was utilized to create a prediction model for split tensile and flexural strength. We displayed the experimentally obtained Split Tensile Strength and Flexural Strength against the regression analysis strength after 56 days for ANN. This was done so that we could compare the two. According to the findings of the experiments, using powder made from marble waste might lessen the damage that concrete causes to the environment while also providing economic benefits. In this study, dependable mechanical strength was developed by the use of a feed-forward back-propagation neural network, which consisted of eight input neurons, two hidden neurons, and one output neuron. According to the findings, it was discovered that the mechanical properties of concrete might be improved by using dry marble sludge powder as a substitute for up to 15% of the normal aggregate.

Keywords: Fibre reinforced concrete, polypropylene 3s, marble sludge powder and machine learning technique (MLT).

1. Introduction

Building practices that are less harmful to the surrounding ecosystem are necessary for the development of human civilization (Abed and Eyada 2012; Akbulut and Gürer 2007; Almeida *et al.* 2007; Alyamaç and Ince 2009). There is a demand for more long-lasting construction materials that are capable of withstanding unfavorable weather conditions (Arora and Ameta 2014; Aruntas *et al.* 2010; Aukour 2009; Bentz *et al.* 2015; Kofteci and KocKal 2014). This demand is a direct result of technical improvements as well as the rapidly expanding requirement for increasingly complicated building structures. Concrete, which is comprised of cement, aggregate, and water, is the material that is being utilized for construction all over the world with the greatest frequency (Narmatha and Felixkala *et al.* 2016). The aforementioned outcome may be attributed to the widespread accessibility of the essential constituents of concrete, the simplicity and straightforwardness with which it can be controlled, and the relatively affordable expense associated with the substance. Building materials that are more durable and have a longer lifespan are required (Suresh and Nagaraju 2015; Vikram Singh Kashyap *et al.* 2023; Dhanalakshmi Ayyanar *et al.* 2023) to fulfill the continuous and unending demands that are placed on an infrastructure that is in a state of perpetual change. By increasing its resistance to deterioration over time, concrete's performance may be improved by the use of appropriate mineral additives in proportions that are just right (Dhanalakshmi and Hameed 2022; Dhanalakshmi *et al.* 2023a, 2023b; Sukontasukkul *et al.* 2023; Puvaneshwaran and Vipurajan 2023; Valarmathi *et al.* 2009). Enhancing the performance of concrete in this way is one of the techniques available. Utilizing the waste marble sludge powder that is generated by manufacturing facilities such as marble-cutting factories may make it feasible to achieve improved economic viability and long-term sustainability (Indira and Valarmathi 2014;

Petchinathan *et al.* 2014; Surya Abisek Rajakarunakaran *et al.* 2022). This may be the case since such facilities create waste marble sludge powder. Because of this, it will minimize the burden that is placed on the environment as a consequence of the production of concrete and rubbish. This is because it will lower the strain that is imposed on the environment. In addition to this, this will lessen the amount of stress that is put on the environment. The major purpose of this body of work is to investigate the use of marble sludge powder in concrete as a partial substitute for cement and to identify the impact that this has on both the mechanical properties of concrete as well as the cement and mortar that are used in the combination. This combination of concrete also called green concrete. This will be accomplished by determining the effect that this has on both the mechanical properties of concrete as well as the cement and mortar that are used in the mixture. The usage of marble sludge powder reduces the environmental pollution. The findings of this study will be presented in the form of a conclusion that summarises the economic concrete as well as green concrete. In addition, the inquiry will investigate how the incorporation of marble sediment powder influences these features and how they are changed. Making an educated guess regarding the compressive strength of concrete that contains marble sludge powder may be accomplished via the application of various machine-learning strategies. The purpose of this study is to assess the effect of adding marble sludge powder in the concrete and its effects on partial cement replacement in terms of the concrete's mechanical characteristics, such as compressive strength, split tensile strength, and flexural strength and analyzed the results using MATLAB.

2. Materials and methods

2.1. Materials

As the binder material, ordinary Portland cement (OPC) of grade 53 was applied. The powder that was ccollected from marble waste was used in this work as an alternate material for cement. It was necessary to make use of both fine aggregate (FA) and coarse aggregate (CA) in this endeavor. To achieve the optimum level of workability, it is essential to make use of a water-reducing superplasticizer (SP). Gelenium B233 was included in the mix as a component. The mixture's proportions were calculated using the 20 mm of coarse aggregate and M-Sand as a fine aggregate was used in the study, as per IS 10262 (2009). The MSP having the specific gravity of 2.72. In order to achieve the physical transformation of marble sludge into marble powder, it is necessary to sift all ground material through a mesh with a size of 0.125 mm. Figure 1 depicts the image of marble powder.

Figure 1. Marble Powder

2.2. Concrete mix proportions

For this study, we chose to focus on two different water binder ratios, 0.35 and 0.40. Table 1 provides the recommended concrete design mix proportions based on the chosen water binder ratios. Cement replacement with marble sludge powder ranged from 0% to 25% by weight.

Table 1. Mix Proportions of Fibre Reinforced Concrete

Mix Id	w/c ratio	Cement (Kg/m³)	MSP (Kg/m³)	FA (Kg/m³)	CA (Kg/m³)	Fibre (Kg/m³)	Water (Kg/m³)	SP (Kg/m³)
FRC1	0.35	429	0	1300	700	2.14	150.15	12.87
FRC2	0.35	407.55	21.45	1300	700	2.14	142.64	12.87
FRC3	0.35	386.1	42.9	1300	700	2.14	135.13	12.87
FRC4	0.35	364.65	64.35	1300	700	2.14	127.62	12.87
FRC5	0.35	343.2	85.8	1300	700	2.14	120.12	12.87
FRC6	0.35	321.75	107.25	1300	700	2.14	112.61	12.87
FRC7	0.40	401	0	1300	700	2.01	160.4	12.03
FRC8	0.40	380.95	20.05	1300	700	2.01	152.38	12.03
FRC9	0.40	360.9	40.1	1300	700	2.01	144.36	12.03
FRC10	0.40	340.85	60.15	1300	700	2.01	136.34	12.03
FRC11	0.40	320.8	80.2	1300	700	2.01	128.32	12.03
FRC12	0.40	300.75	100.25	1300	700	2.01	120.3	12.03

3. Experimental investigation

3.1. Split tensile strength

Because of its brittleness and poor tensile strength, concrete is rarely put to the test in tension. To determine the load at which concrete members may fracture, it is necessary to calculate the material's tensile strength. Cast and tested were cylindrical specimens with a diameter of 150 mm and a height of 300 mm. The load needs should be applied gradually at a constant rate rather than suddenly. To determine the effect of partially substituting cement with marble slurry on concrete, the cylinders were evaluated at 28 and 56 days of curing. Water binder ratios of 0.35 and 0.40, as well as percentage replacements ranging from 0% to 25%, were examined for optimal dosage and long-term efficacy. The split tensile strength testing of concrete cylinders is depicted in Figure 2 for this study.

3.2. Flexural strength

Concrete beams or prism can be evaluated by measuring their flexural strength. It determines how much pressure and stress an unreinforced concrete slab, beam, or other structure can take before cracking or breaking under bending loads. Concrete prisms with dimensions of 150 mm x 150 mm x 750 mm were cast and evaluated. The effect of partially substituting cement with powdered marble dust was investigated by evaluating concrete prisms at 28 and 56 days after curing. All combinations of water binder ratios of 0.35, 0.4, and percentage replacements of 0% to 25% were evaluated for optimal dosage and long-term effect. Concrete prism flexural strength testing is shown in Figure 3 for this study.

Figure 2. Split Tensile testing of a cylinder

Figure 3. Flexural testing of a Prism

4. Results and discussion

4.1. Split tensile strength

Test results for the split tensile strength of concrete with varying percentages of dried marble sludge powder as a cement replacement can be seen in Figure 4. The percentages used ranged from 0% to 25%. The outcomes obtained are comparable to compressive strength findings to some extent.

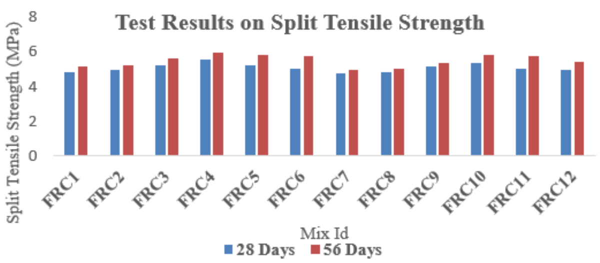


Figure 4. Test results on Split Tensile Strength

High dosages of superplasticizer employed for lower water binder ratios result in a strength gain for up to 15% replacement at both the 0.35 and 0.40 w/b ratios. This points to an improvement in the strength of the interface between the cement matrix and the pore structure. At 15% replacement, tensile strength reaches a maximum and then begins to decrease.

4.2. Flexural strength

The flexural strength test results for concrete contains 0%, 5%, 10%, 15%, 20%, and 25% by weight of dry marble sludge powder are shown in Figure 5. There is a pattern that parallels that of compressive and split tensile strengths. The flexural strength increases by 15% for both the 0.35 and 0.40 w/b ratios.

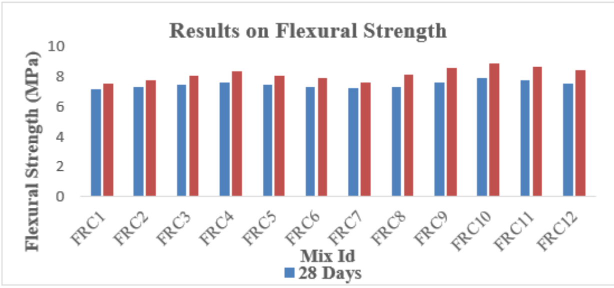


Figure 5. Test results on Flexural Strength

5. Regression analysis in concrete

The trends for strength ratios should be the same regardless of the type of specimen being examined assuming optimal casting, testing, and curing conditions are maintained. It is challenging to maintain consistent conditions for creating and testing samples, even when using the same concrete. This is one of the reasons why extraordinary events do occur in the actual world. This led to the discovery that the strengths of the various concrete samples had to be compared separately and that they did not always correspond. A generic formula for the regression analysis of split tensile strength, and flexural strength for concrete containing marble sludge powder may be derived from the ratios of the strengths involved. The connection may be determined using strength ratios regardless of the type of specimen employed.

5.1. Artificial neural network model

When marble sludge powder is used as a partial cement substitute, this section of the study presents an artificial neural network (ANN) model to conduct a regression analysis of the effect of marble sludge powder re-placement ratio and admixture content on the with different proportions of materials of concrete. One of the following choices can have a significant impact on a neural network's efficiency: Transfer function, training function, and performance function. Network structure. Network algorithm. Amount of training and testing data (Figure 6).

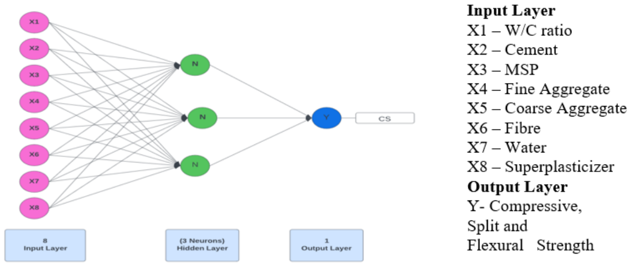


Figure 6. ANN Structure Model

5.2. Regression analysis model using ANN

MATLAB was used to generate Figures 7–16. Figure 7 depicts the ANN structure used in this study, which is a two-layered feed forward network. Technical parameters for ANNs are detailed in Table 2. Mechanical strength performance indicators are depicted in Figures 8 and 9. The obtained minimum Gradient of 0.00102 at epoch 13 and 0.0011601 at epoch 10 for split tensile strength and flexcural strength respectively.

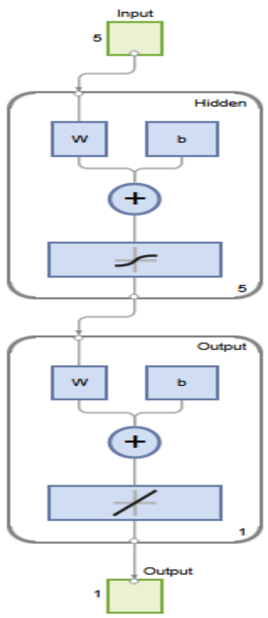


Figure 7. Feed Forward Neural Network

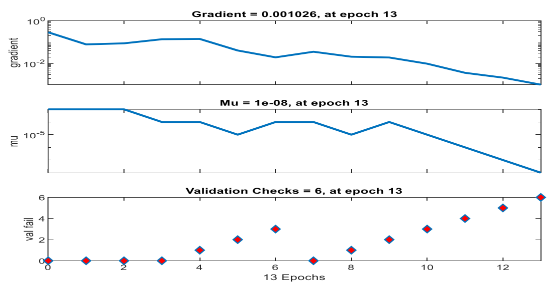


Figure 8. Performance State of Split Tensile Strength

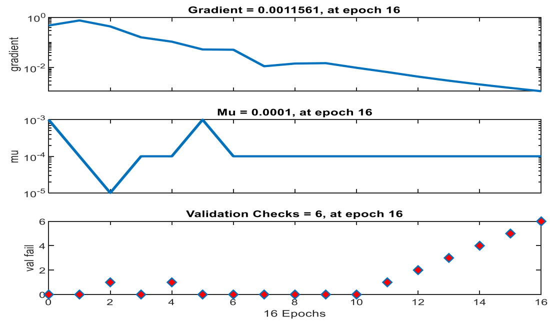


Figure 9. Performance State of Flexural Strength

Figures 10 and 11 refers the Training state of mechanical strength parameters. In this training, validation, testing and best parameters were analysed and find out the best validation performance ranges. The split tensile strength attained MSE in the range of 10^0-10^{-1} and the best validation is achieved at epoch 11 of 0.028108. The flexural strength attained MSE in the range of 10^0-10^{-4} and the best validation is achieved at epoch 3 of 0.0033608.

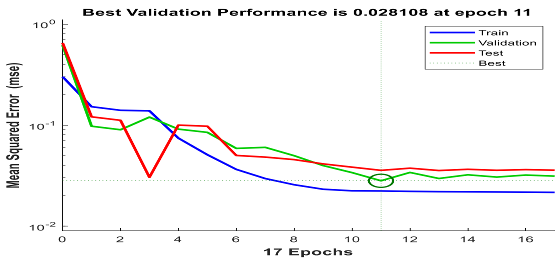


Figure 10. Training state of Split Tensile Strength

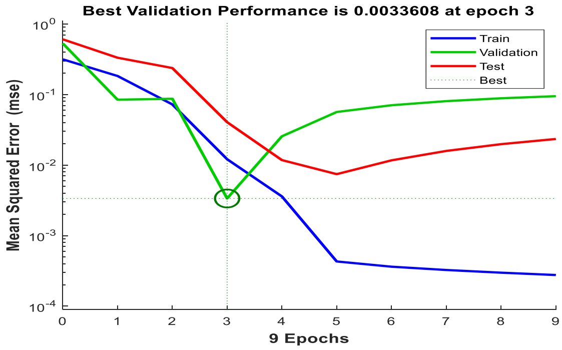


Figure 11. Training state of Flexural Strength

Table 2. ANN Technical Parameters

Details	Selection
Number of inputs	8
Number of hidden layers	3
Number of outputs	1
Number of iterations	1000
Training Gradient	$1x10^{-7}$
Validation Checks	6

Figures 12 and 13 shows the Error histogram analysis of concrete mechanical strength. It is the error findings between targeted values and predicted values after training a feedforward neural network using machine learning techniques. Totally 12 data were analyzed. From the analysis error values of split tensile strength indicate that the error of 0.139 for 3 instances, 2 instances of error -0.25265 was achieved. The flexural strength indicates that the error of -0.009758 for three instances, and 2 instances of error 0.46351 was obtained.

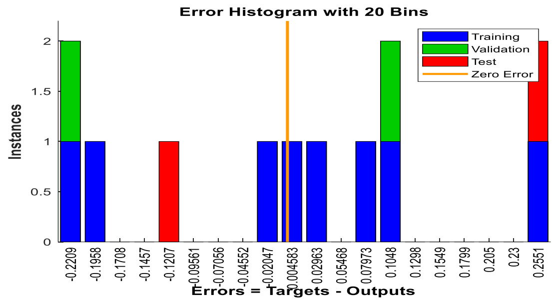


Figure 12. Error Histogram of Split Tensile strength

The relationship between experimental data and the training, validation, and testing sets of compressive strength, split tensile strength, and flexural strength of fibre reinforced concrete employing marble sludge powder is depicted in Figures 14-15.

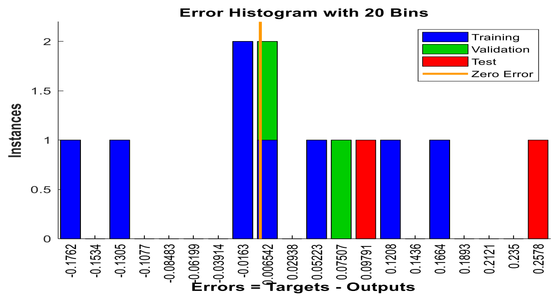


Figure 13. Error Histogram of Flexural strength

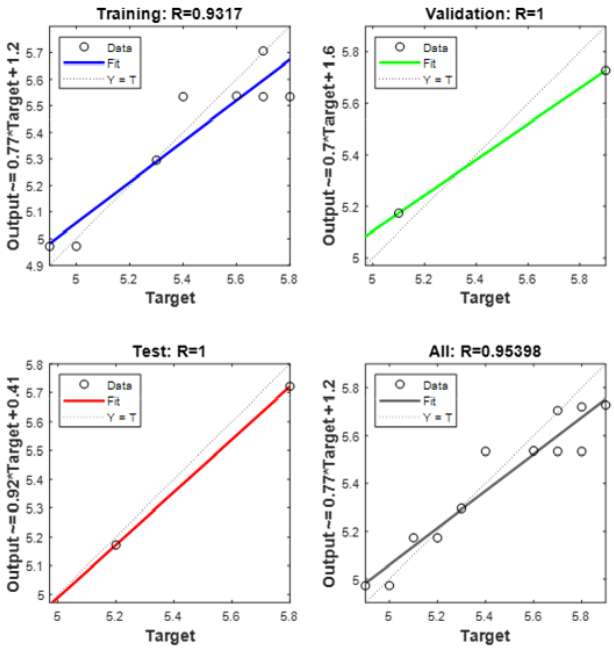


Figure 14. The Regression of split tensile strength

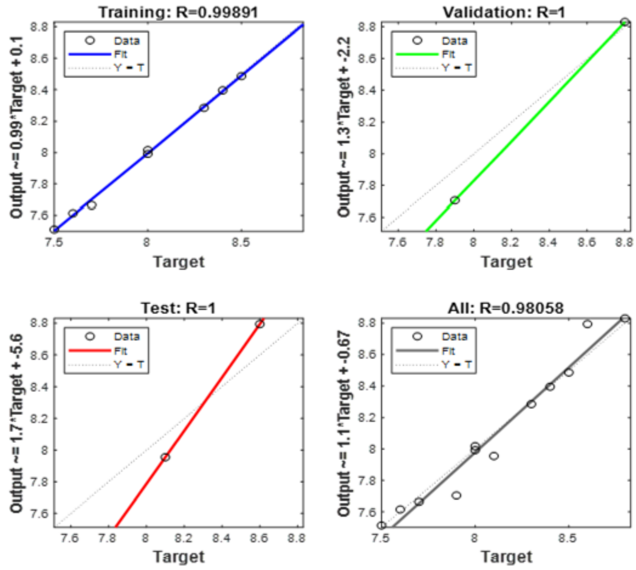


Figure 15. The Regression of flexural strength

Figure 16, shows that the relationship between the predicted and observed 56 days split tensile strength and flexural strength for fibre-reinforced concrete and the high correlation between all data sets are very clear. The coefficient of correlation for the 56-day compressive strength prediction was 96%.

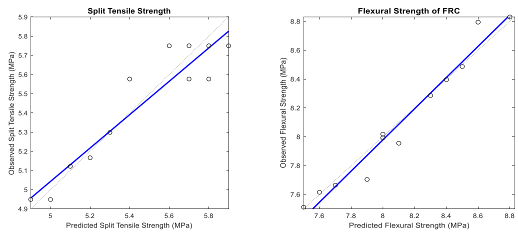


Figure 16. ANN Model Fitting of compressive strength, split tensile strength and flexural strength

6. Conclusion

The cementing ingredient that is responsible for concrete's compressive strength may have been lowered between the levels of 20% and 25% replacement, which may have caused the material to become weaker. With 15% replacement, mechanical properties such as split tensile strength, and flexural strength are improved in both the 0.35 and 0.40 w/b ratios. The timely and exact prediction of concrete's compressive strength has become a subject of study among an increasing number of academics due to its importance in engineering practices. One of the objectives of this study is to estimate the split tensile and flexural strength of concrete materials. In order to do this, the Artificial Neural Network (ANN) method, which is a machine learning technique based on lifting, is employed. The split tensile and flexural strength of concrete was used as a data source for a study that examined the interaction between cement, marble sludge powder, fine aggregate, coarse aggregate, water-to-cement ratio, polypropylene fibre, and superplasticizer. A MATLAB-based ANN model is used to predict the split tensile strength and flexural strength of fibre-reinforced concrete. This model takes into account the factors that influence the properties of concrete, and the obtained R value, which is very close to 1, demonstrates that there is a strong correlation between the predicted and observed values. It would be beneficial for the building sector to have an earlier and more precise calculation of strength prediction. As a direct consequence of this, we will be able to physically test a reduced number of different permutations, and we will be able to conduct our experiments in a shorter amount of time. These software programmes assist to determine how the strength of one raw material is affected by the strength of another raw material and how the raw materials relate to one another. This model helps with quality control and economics by lowering construction time and costs and enabling for the modification of mix proportions to prevent either concrete that is too weak to satisfy its design strength requirements or concrete that is too strong for its intended purpose. These problems can arise when concrete is either too weak or too strong for its intended purpose. An earlier and more exact estimate of strength prediction would yield advantageous outcomes for the building sector.

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