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RESEARCH ARTICLE

Mechanical Properties and Prediction Based on ANN Model of Basalt and Polypropylene Fiber Reinforced Concrete

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Abstract

Objectives: Utilization of steel fiber increases concrete strength and ductility however, the cost of steel fiber is high and ultimately leads to an increase in the cost of concrete. Basalt fiber is a new type of fiber with high strength and toughness and can effectively replace the place of steel fibers. In this paper, concrete reinforced with polypropylene fibers and basalt fibers was tested for its mechanical properties and compared with the same predicted through a simulated model created by the Artificial Neural Network. **Methods:** The percentage of polypropylene fiber was kept at 0.25%, and different amounts of basalt fiber were added as 0%, 0.25%, 0.5%, 0.75%, and 1%. Based on traditional testing methods compressive strength, tensile strength, and flexural strength of normal concrete, Fiber reinforced concrete and Hybrid fiber reinforced concrete have been found. To forecast the concrete qualities, the model was simulated after the datasets were trained using a neural network fitting tool. **Findings:** In comparison to concrete that had only 0.25% polypropylene fiber, a hybrid fiber-reinforced concrete mix including 0.5% basalt fiber and 0.25% polypropylene fiber demonstrated a 9.69% improvement in compressive strength. In comparison to the concrete made only of polypropylene, the mix containing 0.25% polypropylene fiber and 0.75% basalt fiber showed a 26.12% increase in flexural strength and a 39.25% increase in split tensile strength. The error percentage between predicted and experimental values is below 10%. **Novelty:** Utilization of basalt fiber in concrete is very rare and this proposed work focused on the hybridization of basalt fiber in the place of steel fibers, which is prone to corrosion and reduces the cost of material effectively. The concrete's flexural and tensile strengths were significantly increased by the addition of basalt fibers. The mechanical characteristics of hybrid fiber-reinforced concrete are well predicted by the simulated ANN model.

Keywords: Basalt fiber; Polypropylene fiber; Artificial Neural network; Fiber reinforced concrete; Hybridization

1 Introduction

Concrete is being utilized more and more in the construction of diverse technical constructions as civilization advances. The longevity of conventional concrete is greatly impacted by its high brittleness, which results in low flexural characteristics and fracture toughness as well as simple cracking. Fiber-reinforced polymer strengthening and fiber addition are currently successful ways to increase the toughness and decrease the brittleness of concrete. The most well-known and efficient way to increase the fracture toughness of concrete is to blend steel fiber with polypropylene fiber (PF) [1]. Tensile and flexural crack patterns cause reinforced concrete structures to collapse. To avoid these types of failure and improve the overall strength and longevity, it is necessary to investigate the concrete's qualities. Fibers are added to concrete to increase their strength and stop micro cracks that could cause severe failure [2]. Although concrete has several benefits, its low tensile strength in comparison to its compressive strength is one of its primary disadvantages. Concrete's compressive strength is roughly ten times greater than its tensile strength. Therefore, internal or external influences can cause concrete to crack in both its plastic and hardened phases, which negatively impacts the structural concrete elements' compressive, tensile, and flexural strengths [3]. A new kind of high-performance, environmentally friendly fiber, basalt fiber has been employed extensively in various fields and performs exceptionally well. Cement matrix composites' flexural strength, toughness, and fracture energy can all be enhanced with basalt fiber [4]. Concrete blended with polypropylene and basalt fibers has successfully increased its tensile, splitting, and bending strengths while also greatly increasing its ductility, toughness, and impact resistance. Consequently, hybrid fiber-reinforced concrete differs greatly from regular concrete [5]. When exposed to short-term or sustained loads, high-strength concrete often becomes brittle. The performance of high-strength concrete raises concerns over its use in construction, particularly in seismically active areas. By preventing cracks from growing, fiber addition to concrete improves its tensile properties while also increasing its toughness, energy-absorbing capacity, flexural strength, fatigue resistance, and ductility [6]. Lately, there has been an increasing focus on the use of synthetic fibers, like polypropylene fibers. Additionally, concrete reinforced with various hybrid fiber types—known as hybrid FRC, or HFRC—generally has better mechanical qualities than concrete reinforced with mono-fiber. The mixture's random distribution of reinforcing fibers is the main cause of the increase in tensile and flexural forces, fracture resistance, and damage control [7]. Shi et al. carried out research on the mechanical characteristics of concrete reinforced with basalt-macro polypropylene hybrid fibers that had different compressive strengths. The study examined the effects of several parameters on the slump, compressive strength, and flexural capacity of the concrete, such as fiber volume fractions (0.3, 0.7, and 1 %), concrete compressive strengths (30 and 60 MPa), and basalt fiber volume fraction (0.1 %). While there is no discernible increase in compressive strength, the addition of basalt fiber greatly increases the tensile strength, flexural strength, and toughness index. Concrete characteristics are improved in a restricted range when reinforced with a single type of fiber. On the other hand, hybrid fiber reinforced concretes offer better qualities because they are reinforced with two or more types of properly chosen fibers. The employment of different fibers with varying lengths is a smart technique to solve the issue of fractures in concrete, which can emerge at different stages and sizes. Because of the advantageous interactions between the fibers in a well-designed composite system, the hybrid system performs better than the mono fiber composite. Controlling cracks at various cementitious material zones, at various size levels, and during various loading stages is the primary goal of combining various fiber types. It is uncommon to use basalt fibers in structural concrete applications. They are derived from basalt ore and work well with concrete. When compared to other fiber kinds, the production techniques for basalt fiber are known for using less energy. Additional benefits like their relatively low cost, high modulus of elasticity, and strong resistance to high temperatures and chemicals allow basalt fiber to be a viable substitute for fibers frequently employed in reinforcing concrete composites [8]. The utilization of steel, polypropylene, and hybrid fibers made of steel and polypropylene in concrete are the primary subjects of the study. In this system, polypropylene fiber, which is more ductile and flexible, enhances toughness and strain capacity in the post-cracking zone, whereas steel fiber, which is stronger and stiffer, improves the first crack load. In this regard, replacing steel fibers with basalt fiber, reduces the material cost and also eliminates the rusting issue in the steel fiber. The majority of the strength models or analytical expressions that have been produced were created for steel fiber reinforced concrete, while numerous experimental researches have been conducted on steel, synthetic, and hybrid FRC. The usage of various fiber combinations (synthetic fibers with or without steel fibers) has grown in popularity because using a single type of fiber has a limited impact on the mechanical properties of FRC. This research uniquely investigates the hybridization of polypropylene and basalt fibers to enhance ductility and crack resistance while maintaining cost-effectiveness. By combining the high tensile strength of basalt fibers with the flexibility and crack-bridging properties of polypropylene fibers, the study aims to achieve improved performance compared to monofiber systems.

Therefore, the primary objective of this investigation is to examine the mechanical characteristics of hybrid fiber reinforced concrete (HFRC) made of polypropylene and basalt fibers. This study aims to measure and discuss how basalt fiber improves the mechanical properties of FRC. It also suggests models for forecasting the strengths of reinforced materials with varying volume fractions of basalt and polypropylene fiber. Finding the ideal amounts of polypropylene and basalt fibers to greatly improve the mechanical properties of HFRC is another goal of this study. In addition to simulating models for HFRC's prediction of compressive, splitting tensile and flexural strengths and validating them with our experimental test results. This paper presents the test results of 36 concrete cube specimens to assess concrete compressive strength, 36 concrete cylinder specimens to determine splitting tensile strength, and 36 concrete prisms to determine flexural strengths.

2 Methodology

2.1 Materials

The binding material utilized herein is Portland cement, and its properties are stated in Table 1. The M-Sand was utilized as a fine aggregate, with a maximum particle size of 4.75mm and a fineness modulus of 2.8. Figure 1 shows the particle size distribution of the fine aggregate. Crushed granite with a maximum particle size of 20mm and a minimum particle size of 12mm was used for coarse aggregate. The specific gravity of coarse aggregate is 2.72. The above ingredients were mixed using drinking tap water and conplast SP - 430. The properties of fiber reinforcement materials include Basalt Fiber and Polypropylene Fiber as shown in Table 2.

Table 1. P hysical Properties of Portland Cement

Sl No.	Properties	Observed Values
1.	Normal Consistency	29%
2.	Fineness	4.45%
3.	Specific Gravity	3.11
4.	Setting Time (Initial)	35 min
5.	Setting Time (Final)	600 min

Table 2. P roperties of Basalt and Polypropylene Fiber

Sl No.	Properties of Fiber	Basalt Fiber	Polypropylene Fiber
1.	Length	14 mm	12 mm
2.	Diameter	13μm	0.05 mm
3.	Specific Gravity	2.70	0.92
4.	Tensile Strength	2700 MPa	445 MPa
5.	Elongation at break	12.5%	18.25%
6.	Aspect Ratio	1076	240

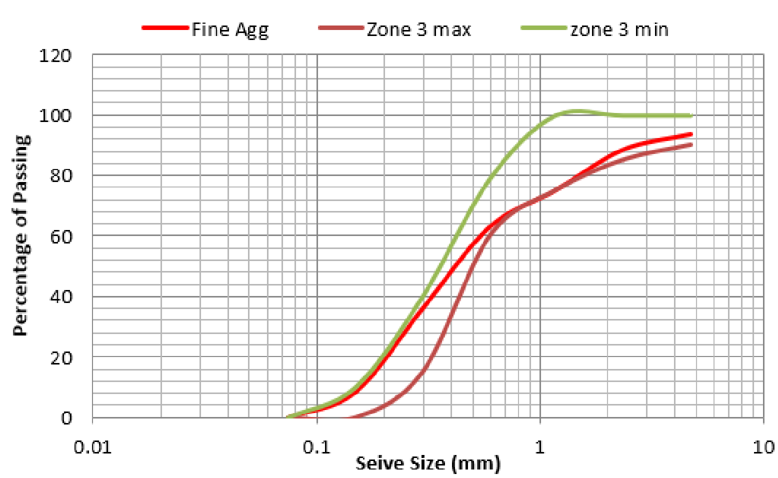

Fig 1. Particle size Distribution of Fine Aggregate

The hybrid fiber reinforced concrete mixture of M30 grade compositions designed are shown in Table 3, wherein CS represents the conventional concrete, CPPBF0 represents specimen with 0.25% PPF and 0% BF, CPPBF0.25 represents specimen with 0.25% PPF and 0.25% BF, CPPBF0.5 represents specimen with 0.25% PPF and 0.5% BF, CPPBF0.75 represents specimen with 0.25% PPF and 0.75% BF, CPPBF1.0 represents specimen with 0.25% PPF and 1% BF.

Table 3. Hybrid Fiber Reinforced Concrete Mixture Compositions

Sl No.	Designation	w/c Ratio	Water content (kg)	SP (kg)	Cement (kg)	Coarse Aggregate (kg)	M- Sand (kg)	PPF(%)	BF (%)
1	CS	0.45	168	2.8	350	1257	311.4	0	0
2	CPPBF0	0.45	168	3.15	311.5	1257	311.4	0.25	0
3	CPPBF0.25	0.45	168	3.15	311.5	1257	311.4	0.25	0.25
4	CPPBF0.5	0.45	168	3.15	311.5	1257	311.4	0.25	0.5
5	CPPBF0.75	0.45	168	3.15	311.5	1257	311.4	0.25	0.75
6	CPPBF1.0	0.45	168	3.15	311.5	1257	311.4	0.25	1.0

Mixing Methods

To prepare FRC and HFRC mixture pan mixture has been used. In a pan mixer, cement and M-sand were mixed for 2 minutes, then Coarse aggregate was added to the mixture and stirred for another 2 minutes, polypropylene fibers and Basalt fibers were added to the above mixture and mixed again till attaining uniform dispersion, finally, water pre-mixed with superplasticizer was added and stirred for 2 mins. Immediately after mixing, a slump test was conducted using a slump cone, and the values were tabulated in Table 4.

Table 4. Slump Value for Hybrid FRC Mixtures

Sl No	Mixture ID	Slump (mm)
1	CC	95
2	CPPBF0	78
3	CPPBF0.25	81
4	CPPBF0.5	82
5	CPPBF0.75	79
6	CPPBF1.0	77

Hybrid fiber reinforced concrete mixture was poured into the 150 x 150 x 150 mm cubic moulds, 150 x 300 mm cylinder moulds and 100 x 100 x 500 mm prism moulds. All the moulds were compacted on a vibrating table. After 24 hrs, all moulds were demoulded and the specimens were cured in water for 28 days before testing.

2.2 Testing Methods

2.2.1 Compressive Strength Test

The compressive strength of HFRC specimens was measured with an electro-hydraulic pressure servo testing system. The specimen measuring 150 mm $\times$ 150 mm $\times$ 150 mm was tested at a loading rate of 0.5 MPa/s. Six specimens were evaluated for each HFRC mixture proportion, three for 7 days and three for 28 days, with the average value of the test findings used to determine the final experimental outcome. A total of 36 specimens were used to test the compressive strength of HFRC. The test setup is shown in Figure 2. The compressive strength values of all the mixes were tabulated in Table 5.

From the above test results, it is known that the addition of polypropylene fiber to the concrete enhanced the compressive strength by 8.12% compared to the normal concrete. Hybrid fiber reinforced concrete with 0.25%, 0.5%, 0.75%, and 1% basalt fiber increases the compressive strength by 4.04%, 9.70%, 4.62%, and 1.92% compared to the polypropylene fiber reinforced concrete. However, addition of basalt fiber beyond 0.5% reduced the compressive strength.

Fig 2. Compressive Strength Test Setup

Table 5. Compressive Strength of HFRC Cubes

Days / Mix ID	7 Days	28 Days
CS	28.46	38.44
CPPBF0	31.25	41.56
CPPBF0.25	37.22	43.24
CPPBF0.5	39.3	45.59
CPPBF0.75	37.17	43.48
CPPBF1.0	32.29	42.36

2.2.2 Flexural Strength Test

Prism specimens were evaluated in a loading frame with a capacity of 100 kN. Specimens of size 150 x 150 x 500 mm were used. The test span was fixed at 400 mm. The results for each specimen type were calculated using an average of six replicate specimens, three for 7 days and three for 28 days, respectively. A total of 36 specimens were utilized to assess the flexural strength of HFRC. The flexural strength experiments followed IS 516:2021. The test setup is shown in Figure 3. The flexural strength values of all the mixes were tabulated inTable 6.

Table 6. F lexural Strength of HFRC Prisms

Days / Mix ID	7 Days	28 Days
CS	4.72	7.96
CPPBF0	5.38	8.35
CPPBF0.25	5.64	8.84
CPPBF0.5	6.04	9.45
CPPBF0.75	6.29	10.53
CPPBF1.0	5.75	8.92

Fig 3. Flexural Strength Test Setup

From the above test results, it is known that the addition of polypropylene fiber to the concrete enhanced the flexural strength by 4.90% compared to the normal concrete. Hybrid fiber reinforced concrete with 0.25%, 0.5%, 0.75%, and 1% basalt fiber increases the flexural strength by 5.87%, 13.17%, 26.11%, and 6.83% compared to the polypropylene fiber reinforced concrete. However, addition of basalt fiber beyond 0.75% reduced the flexural strength.

2.2.3 Split Tensile Strength Test on Cylinders

As seen in Figure 4, the cylinder specimen of 150 mm in diameter and 300 mm in height, was examined at a loading rate of 0.5 MPa/s in an electro hydraulic pressure servo testing machine. Each mixture proportion of HFRC was tested on six specimens, three at 7 days and three at 28 days. The final experimental result was determined by averaging the test data. A total of 36 specimens were used to test the split tensile strength of HFRC. The test setup is shown in Figure 4. The tensile strength values of all the mixes were tabulated in Table 7.

Table 7. Tensile Strength of HFRC Cylinders

Days / Mix ID	7 Days	28 Days
CS	3.6	3.82
CPPBF0	3.95	4.28
CPPBF0.25	4.67	4.98
CPPBF0.5	4.96	5.34
CPPBF0.75	5.27	5.96
CPPBF1.0	4.34	4.72

From the above test results, it is known that the addition of polypropylene fiber to the concrete enhanced the tensile strength by 12.04% compared to the normal concrete. Hybrid fiber reinforced concrete with 0.25%, 0.5%, 0.75%, and 1% basalt fiber increases the tensile strength by 16.36%, 24.77%, 39.25%, and 10.28% compared to the polypropylene fiber reinforced concrete. However, addition of basalt fiber beyond 0.75% reduced the tensile strength.

Fig 4. Splitting Tensile Strength Test Setup

2.2.4 Modelling with Artificial Neural Network

To reduce the material cost and time, many researchers considering the use of neural networking models to generate predictions. Based on the predictions we can derive a few ideas to pursue, which ultimately save time and cost. Using ANN three models were simulated to forecast compressive strength, splitting tensile strength, and flexural strength respectively. To simulate a model to forecast the above mentioned mechanical attributes, datasets that included 541, 356, and 259 entries for compressive strength, tensile strength, and flexural strength respectively. All these data were collected from the previous literature which are relevant to the present study. Collected data were normalized and utilized to simulate the ANN model. For efficient evaluation of the model's success, the dataset was split into three subsets: training (70%), validation (15%), and testing (15%). This division was based on common machine learning approaches for balancing model training and performance evaluation. Three distinct layers make up a neural network as a whole. The first layer is the input layer, and they are contents of cement, SCM, FA, CA, Water, Fiber 1, Fiber 2, Super plasticizer, and W/C Ratio. The hidden layer owns 20 neurons and case-wise outputs are taken in the last layer. Using the neural fitting (NF) tool, the above neural networks were trained repeatedly until the accuracy of the training regression, validation regression, and overall data regression was close to 1. Once the models are trained properly error histogram and regression plot for compressive strength, tensile strength and flexural strength have been derived from the neural fitting tool. The NF tool will simulate the model to predict the above properties. The simulated models were used to predict the experimental results of our current work and check the error percentage. Neural network models, error histograms and regression plots for the compressive, tensile and flexural strength are shown in Figure 5.

The relationship between the predicted and experimental values of compressive strength, tensile strength, and flexural strength is shown in Figure 6.

Based on the experimental and predicted results, the coefficient of correlation (R^2), Root mean squared error (RMSE), Mean absolute percentage error (MAPE) have been calculated and tabulated in Table 8.

One frequent issue that comes up during modeling is the interdependency of the input variables. As the strength of the model under examination increases, the produced model's efficiency decreases. The Correlation Coefficient R, which should be smaller than 0.8, is computed in order to get around this problem [9]. The minimal difference between experimental and predicted results

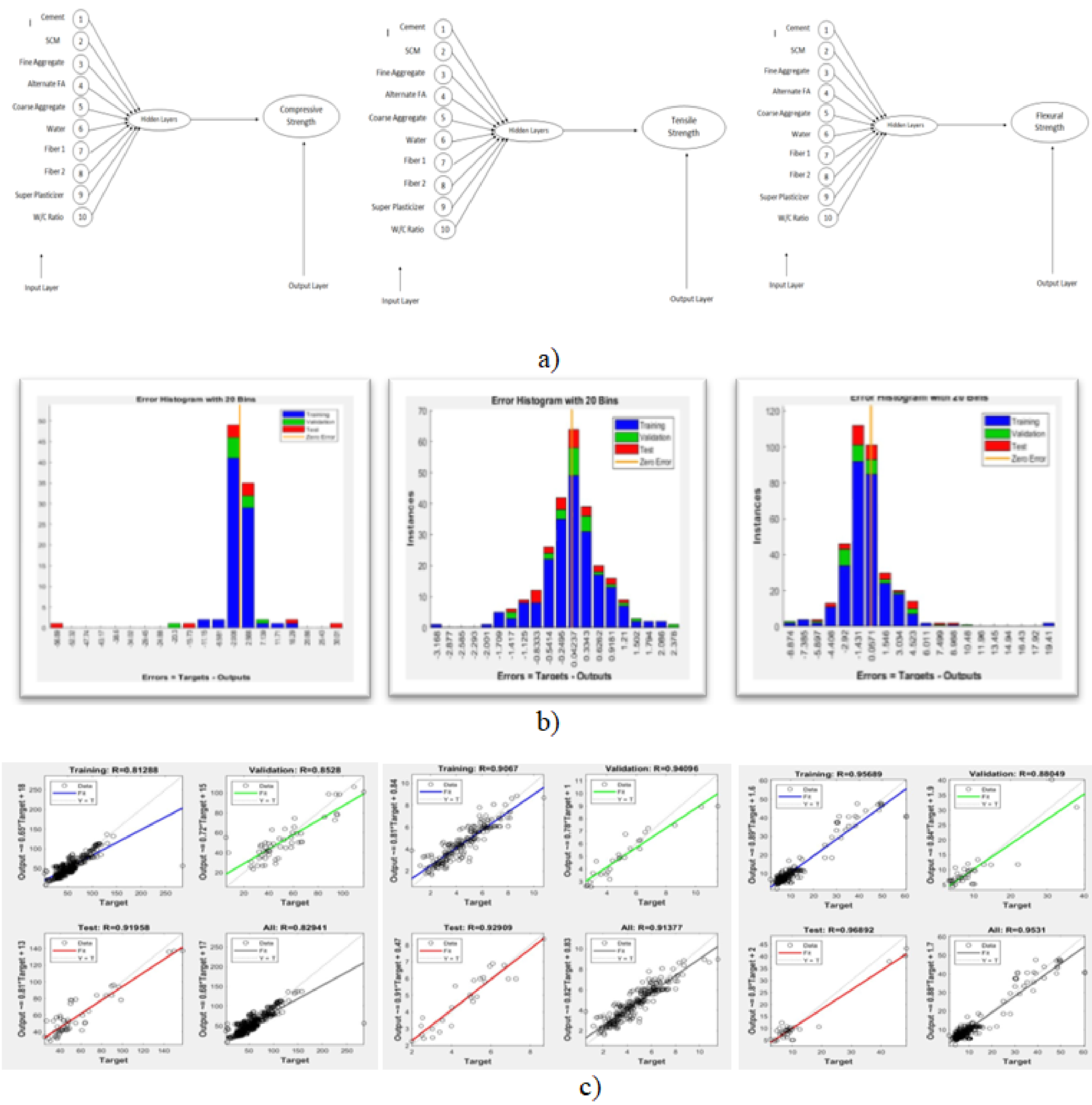

Fig 5. a) Neural Networks b) Error Histogram c) Regression Plot

Table 8. tatistical Indicators

Sl No.	Mechanical Properties	R^2	RMSE	MAPE
1.	Compressive Strength	0.99	6.45	9.45
2.	Tensile Strength	0.97	5.30	4.99
3.	Flexural Strength	0.95	9.01	6.26

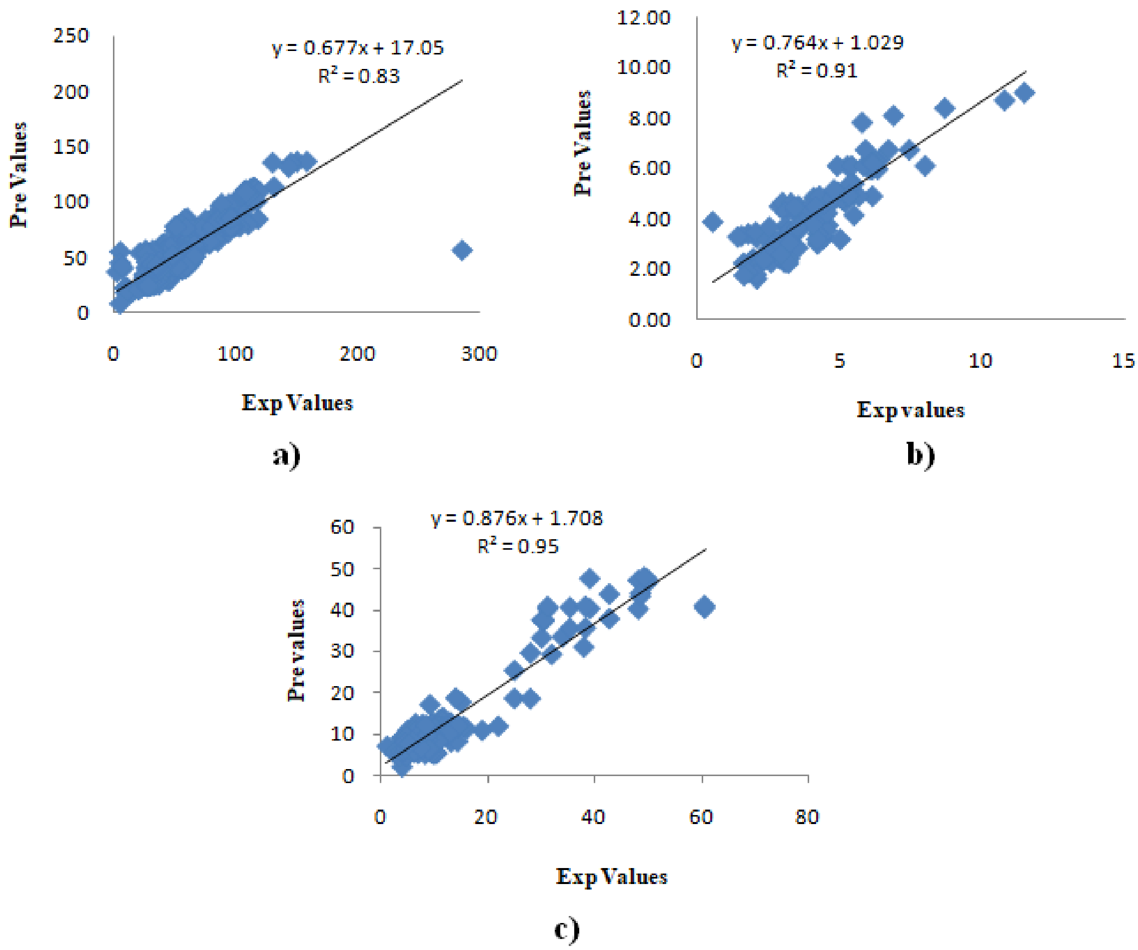

Fig 6. Experimental Vs Predicted values for a) Compressive Strength b) Tensile Strength c) Flexural Strength

demonstrates the model's strength and ability to accurately predict the required outputs. The predicted results closely align with experimental data, confirming the models' reliability in forecasting various FRC and HFRC mechanical properties. Given the high cost of experimental studies in many engineering fields, these models serve as an effective alternative tool for designing hybrid fiber-reinforced cement concrete.

3 Results and Discussions

3.1 Compressive Strength

Basalt fibers are high-modulus fibers, which means that at low-volume fractions, they cannot form a load-bearing skeleton within the matrix. As a result, the augmentation effect on the compressive strength of fiber-reinforced concrete (FRC) is less than the negative impact caused by fiber-induced flaws. However, as the basalt fiber concentration rises from 0.25% to 0.5%, the compressive strength improves. At 0.5% fiber content, CPPBF0.5 has a compressive strength of 45.59 MPa, 9.69% more than CPPBF0, which has the strength of 41.56 MPa and only includes 0.25% polypropylene (PP) fiber. In comparison to basalt fiber, PP fiber has a larger diameter, which increases the amount of trapped air in the mix and creates more pores and a weaker interaction between the PP fiber and the concrete matrix. Thus, the strength and durability of FRC can be improved by adding the ideal amount of fiber. The fibers are no longer uniformly distributed throughout the mixture, though, as the basalt fiber percentage rises above 0.5%. The dispersion becomes considerably more problematic when paired with PP fibers, resulting in fiber clumping that weakens the FRC [4]. Figure 7 shows the Variations in compressive strength with respect to the percentage addition of basalt fiber.

As seen in the figure, adding more than 0.5% basalt fiber reduces compressive strength. However, the two types of fibers can complement each other in terms of elastic modulus. Polypropylene fibers have a low elastic modulus, which helps to delay the creation and spread of micro-cracks during the initial phases of hardening, minimizing the number of crack sources. In contrast, basalt fibers have a higher elastic modulus, making them more effective at controlling fracture development in hardening concrete. Thus, both fibers contribute at distinct phases to increase the compressive strength of fiber-reinforced concrete [4]. There are substantially more basalt fibers in the concrete mix when the same amount of polypropylene fibers is used because basalt fibers have a much smaller diameter. Therefore, the impact of basalt fibers on increasing the compressive strength is more noticeable [1].

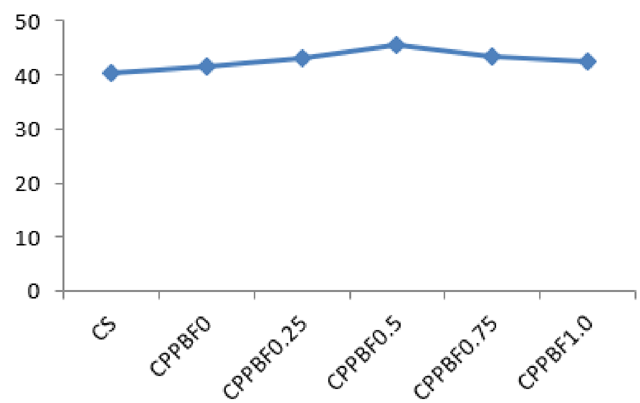

Fig 7. Variations in compressive strength with respect to % addition of basalt fiber

Basalt fiber-reinforced concrete mixtures had nearly identical compressive strength values, indicating that adding 0.5% basalt fibers had no significant effect on compressive strength. Increasing the fiber content above this level caused a minor loss in compressive strength. Because of the fibers' bridging effect, no spalling was seen in the hybrid fiber-reinforced concrete (HFRC) during testing. It is commonly known that adding fibers to concrete helps to reduce the shrinkage of the concrete. Therefore, basalt fibers (BF) improve the compressive strength of concrete by preventing fracture formation under applied loads and limiting shrinkage cracking inside the concrete matrix during curing [1].

3.2 Flexural Strength

With their different sizes and mechanical properties, basalt and polypropylene fibers complement each other on multiple levels, resulting in a synergistic effect. When the concrete hardens, the hydrates snugly embed the hybrid fibers and linked them together to produce a dense, randomly oriented mesh reinforcing structure. This increases the compactness of the concrete structure, decreases weak areas, and improves uniformity and overall integrity, resulting in increased strength and toughness in hybrid basalt-polypropylene fiber-reinforced concrete. Hybrid fibers outperform single-fiber reinforcement in terms of energy resistance and absorption, making them more effective at preventing and controlling fracture formation and growth [10]. Figure 8 shows the Variations in flexural strength with respect to the percentage addition of basalt fiber.

Basalt fiber is added to increase flexural strength and avoid cracking. In comparison to fiber-reinforced concrete (FRC) that solely contained polypropylene (PP) fiber, the flexural strength of hybrid fiber-reinforced concrete (HFRC) with basalt fiber contents of 0.25%, 0.5%, 0.75%, and 1% improved by 5.86%, 13.17%, 26.10%, and 6.83%, respectively. There is a positive association between increasing matrix strength and flexural strength. In contrast, adding both polypropylene and basalt fibers increases flexural strength regardless of matrix strength [1].

When compared to plain concrete, the flexural strength of basalt fiber-reinforced concrete with 2% fiber content rose by 75.6% but in the case of hybridization up to 0.75% strength increased and started reducing while adding more than 0.75%. As the volume fraction of basalt fiber rises, the improvement in flexural strength becomes more noticeable. In contrast to fiber-reinforced concrete (FRC), which has a 0.3% fiber volume percent of the total volume, there is a minor reduction in flexural strength when the fiber volume fraction reaches 0.5% however addition of basalt fiber up to 0.75% increases the flexural strength shows the compatibility of that fiber with the concrete. The impact of BF and PF on high-performance concrete's flexural characteristics, and found that adding BF or PPF alone or combined together might boost the concrete's flexural strength [1].

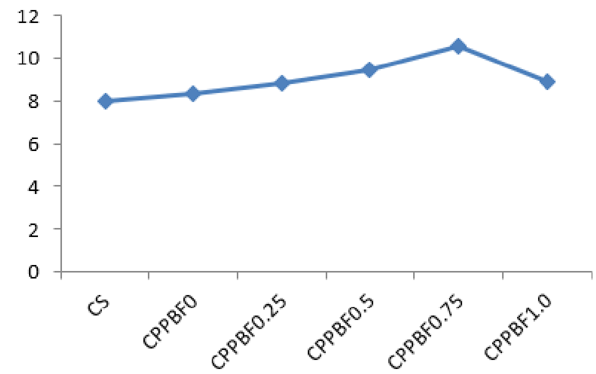

Fig 8. Variations in flexural strength with respect to %addition of basalt fiber

3.3 Split Tensile Strength

The increase in splitting tensile strength owing to fiber reinforcement is significant. The inclusion of basalt and polypropylene fibers in the concrete results in a 3D random distribution, which slows crack formation and boosts the splitting tensile strength of hybrid fiber-reinforced concrete. The splitting tensile strength of HFRC with 0.25%, 0.5%, 0.75%, and 1% basalt fiber concentration increases the strength by about 16%, 25%, 39%, and 10% respectively than concrete reinforced with only polypropylene fibers. The combination of 0.75% basalt fiber and 0.25% polypropylene fiber has a splitting tensile strength of 5.96 MPa, which is the optimum fiber concentration for the maximum tensile strength. However, when the basalt fiber concentration exceeds 0.75%, the hybrid effect lessens, resulting in a decrease in splitting tensile strength [4]. Figure 9 shows the Variations in splitting tensile strength with respect to the percentage addition of basalt fiber.

The findings indicate that integrating two types of fibers can significantly improve tensile resistance. In the early stages of loading, the tensile stress in fiber-reinforced concrete is modest. As tiny fractures emerge, the basalt and polypropylene fibers help to withstand the stress and slow down the crack growth. When the tensile stress exceeds the bond strength between the fibers and the concrete matrix also goes beyond the limit and the fibers are pushed out, and their reinforcing function is reduced [4].

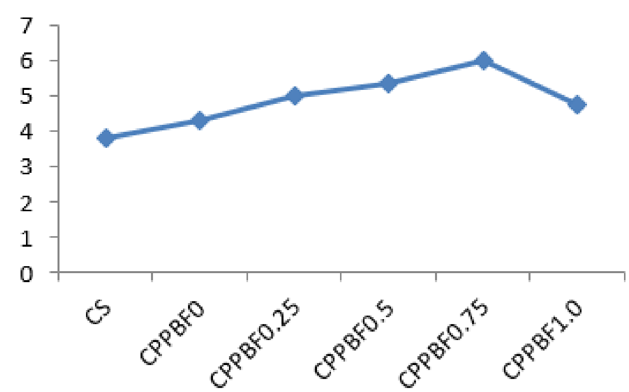

Fig 9. Variations in tensile strength with respect to % addition of basalt fiber

Compared to polypropylene fiber reinforced concrete, the process of prolonging and slowing down the crack has occurred in the HFRC. Hybrid fibers aid in changing the crack growth pattern and reduce its development to a certain extent because of the different properties of the fibers used in the HFRC. The tensile strength at the splitting of the concrete increased significantly as a result of the basalt fiber addition. The incorporation of basalt fibers in the concrete matrix increased splitting tensile strength, with a maximum improvement of 14% at 1% fiber concentration. However, reaching 1% fiber content in the combination resulted in a loss of splitting tensile strength.

3.4 ANN Trained Model

The trained model is validated using Experimental test results done in this study. The input data for the simulated model were given based on the experimental work. The predicted results were compared with the experimental results and the error percentage lies within 10% range showing the accuracy of the simulated models. The error percentage between experimental and predicted values of compressive strength, tensile strength and flexural strength of HFRC was given in Table 9.

Table 9. Error Percentage between Experimental and Predicted Values

Compressive Strength			
Mix ID	**Exp Values**	**Pre Values**	**Error %**
CS	38.44	35.24	8.32
CPPBF0	41.56	39.24	5.58
CPPBF0.25	43.24	41.57	3.86
CPPBF0.5	45.59	43.22	5.20
CPPBF0.75	43.48	40.57	6.69
CPPBF1.0	42.36	41.28	2.55
Tensile Strength			
Mix ID	**Exp Values**	**Pre Values**	**Error %**
CS	3.82	4.01	4.74
CPPBF0	4.28	4.54	5.73
CPPBF0.25	4.98	5.33	6.57
CPPBF0.5	5.34	5.64	5.32
CPPBF0.75	5.96	6.38	6.58
CPPBF1.0	4.72	5.04	6.35
Flexural Strength			
Mix ID	**Exp Values**	**Pre Values**	**Error %**
CS	7.96	8.64	8.54
CPPBF0	8.35	9.05	8.38
CPPBF0.25	8.84	9.57	8.26
CPPBF0.5	9.45	10.14	7.30
CPPBF0.75	10.53	11.24	6.74
CPPBF1.0	8.92	9.64	8.07

Utilization of the ANN model highly reduces the material cost and time invested in the experimental work. Using these models we can predict mix ratios for the particular strength and effectively minimize the experimental works. Using these models we can predict mix ratios for the particular strength and effectively minimize the experimental works. Simulating the model through artificial neural network effectively reduces the material cost and time.

The compressive strength of glass fiber reinforced concrete predicting through ANN model exhibited better prediction and lower error values, which is similar to our predicted methodology[(11)]. Experimental and predicted values of mechanical properties of FRC and HFRC through neural network models were compared. The error percentage of experimental and predicted values is below 10%, similar to our studies. In addition to the prediction, our study focused on the simulink model, using this model mechanical properties of similar mixes with various fibers can be predicted for future utilization[(12)]. Artificial neural network model predicted results showed a better prediction than the equation based models[(13)]. Prediction of fiber reinforced concrete using artificial neural network and coefficient of correlation R values close to 1 which is similar to our work. Whereas in this study, in addition to finding R value, error percentage was also found, and it showed less than 10%[(14)].

4 Conclusion

Based on the above experimental test results, it is obvious that basalt fiber can be effectively used as a replacement for steel fiber, which is prone to rust and also a higher cost. Basalt fiber increases the flexural and tensile strength of the concrete similar to the steel fiber. However, regarding compressive strength, basalt fiber neither increased nor decreased the strength when it is added in the range of 0.25% to 0.75%. Beyond 0.75% compressive strength shows a decreasing trend. This phenomenon may be because of irregular dispersion occurring in the concrete member when it is along with the polypropylene fibers. Since the behaviour of concrete under compression is different from the tension it also affects the tendency of basalt fiber under compression. However, basalt fiber performs significantly compared to steel fiber reinforced concrete.

This study is unique in that it investigates hybrid fiber-reinforced concrete with a combination of basalt and polypropylene fibers. While individual fiber types have been extensively explored, the synergistic effects of these two fibers in concrete—particularly in terms of increasing tensile strength, flexural strength have not received much attention. This study adds to our understanding of how various fibers interact and can be tuned to improve concrete qualities.

Based on the experimental work done, the results were pointed out below

1. The compressive, flexural, and tensile strengths of fiber-reinforced concrete improve with an increasing volume fraction of basalt fiber. However, the increase in compressive strength becomes less significant beyond 0.5% basalt fiber content. A similar trend is observed in flexural and tensile strengths when the basalt fiber content exceeds 0.75%.
2. The combination of the two types of fibers exhibits both positive and negative synergy effects. When the volume fractions were 0.75% of basalt fiber and 0.25% of polypropylene fiber (PPF), hybridization of the above mentioned ratio demonstrated a favorable effect. The compressive strength, tensile strength, and flexural strength increased by 4.62%, 39.25%, and 26.11%, respectively, compared to fiber-reinforced concrete that contained only polypropylene fiber.
3. The developed artificial neural network (ANN) model predicted compressive strength with a maximum error of 8.32%, tensile strength with a maximum error of 6.58%, and flexural strength with a maximum error of 8.54%. All models demonstrated errors of less than 10%, indicating a high accuracy rate for the developed models.

From the above results, it is observed that basalt fiber of 0.75% and PP fiber of 0.25% Hybrid fiber reinforced concrete mixture showed better results compared to all other mixes mentioned in the experimental work. Despite the fact that synthetic fiber and hybrid fibers reinforced concrete have been the subject of several investigations, the literature contains relatively few strength models that account for basalt fibers. To overcome that issue, the model simulated through this work shows a significant result.

The study successfully exhibits the advantages of hybrid fiber reinforcement, demonstrating that the combination of basalt and polypropylene fibers improves mechanical qualities and durability when compared to ordinary concrete. Furthermore, the usage of basalt fibers, a sustainable alternative, increases value by lowering environmental effects while enhancing performance. Furthermore, using artificial neural networks (ANN) to forecast the material properties of hybrid fiber-reinforced concrete is a revolutionary way to model and optimize concrete mixtures.

References

1) Fu Q, Zhang Z, Xu W, Zhao X, Zhang L, Wang Y, et al. Flexural Behavior and Prediction Model of Basalt Fiber/Polypropylene Fiber-Reinforced Concrete. *International Journal of Concrete Structures and Materials*. 2022;16. Available from: https://dx.doi.org/10.1186/s40069-022-00524-w.
2) Arokiaprakash A, Selvan SS. Experimental strength evaluation of steel-polypropylene hybrid fibre reinforced concrete. *Journal of Engineering Research*. 2022. Available from: https://kuwaitjournals.org/jer/index.php/JER/article/view/16345.
3) Guler S, Yavuz D, Korkut F, Ashour A. Strength prediction models for steel, synthetic, and hybrid fiber reinforced concretes. *Structural Concrete*. 2019;20(1):428–445. Available from: https://dx.doi.org/10.1002/suco.201800088.
4) Wang D, Ju Y, Shen H, Xu L. Mechanical properties of high performance concrete reinforced with basalt fiber and polypropylene fiber. *Construction and Building Materials*. 2019;197:464–473. Available from: https://dx.doi.org/10.1016/j.conbuildmat.2018.11.181.
5) Wen B, Gao G, Huang D, Zheng H. Adhesion and Sliding Constitutive Relationship between Basalt–Polypropylene Hybrid Fiber-Reinforced Concrete and Steel Bars. *Applied Sciences*. 2023;13(22). Available from: https://dx.doi.org/10.3390/app132212108.
6) Shaikh FUA, Luhar S, Arel HŞ, Luhar I. Performance evaluation of Ultrahigh performance fibre reinforced concrete – A review. *Construction and Building Materials*. 2020;232. Available from: https://dx.doi.org/10.1016/j.conbuildmat.2019.117152.
7) Azandariani MG, Vajdian M, Asghari K, Mehrabi S. Mechanical properties of polyolefin and polypropylene fibers-reinforced concrete–An experimental study. *Composites Part C: Open Access*. 2023;12. Available from: https://dx.doi.org/10.1016/j.jcomc.2023.100410.
8) Smarzewski P. Influence of basalt-polypropylene fibres on fracture properties of high performance concrete. *Composite Structures*. 2019;209:23–33. Available from: https://dx.doi.org/10.1016/j.compstruct.2018.10.070.
9) Asghar M, Javed MF, Khan MI, Abdullaev S, Awwad FA, Ismail EAA. Empirical models for compressive and tensile strength of basalt fiber reinforced concrete. *Scientific Reports*. 2023;13(1). Available from: https://dx.doi.org/10.1038/s41598-023-47330-2. doi:10.1038/s41598-023-47330-2.
10) Deng Z, Liu X, Yang X, Liang N, Yan R, Chen P, et al. A study of tensile and compressive properties of hybrid basalt-polypropylene fiber-reinforced concrete under uniaxial loads. *Structural Concrete*. 2021;22(1):396–409. Available from: https://dx.doi.org/10.1002/suco.202000006.

11) Sangeetha P, Shanmugapriya M. Artificial neural network applications in fiber reinforced concrete. *Journal of Physics: Conference Series*. 2020;1706(1). Available from: https://dx.doi.org/10.1088/1742-6596/1706/1/012113.
12) Wang JG, Staessen JA. Improved Outcomes with Antihypertensive Medication in the Elderly with Isolated Systolic Hypertension. *Drugs & Aging*. 2001;18:345–353. Available from: https://dx.doi.org/10.2165/00002512-200118050-00005.
13) Liu F, Ding W, Qiao Y, Wang L. An artificial neural network model on tensile behavior of hybrid steel-PVA fiber reinforced concrete containing fly ash and slag power. *Frontiers of Structural and Civil Engineering*. 2020;14:1299–1315. Available from: https://dx.doi.org/10.1007/s11709-020-0712-6.
14) Dhanalakshmi A, Nagamani S, Muthupriya P, Prasath CR, Devi AS. Investigation on Tensile and Flexural Behaviour of Fibre Reinforced Concrete Using Artificial Neural Network. *Global NEST Journal*. 2023;26(1):1–6. Available from: https://journal.gnest.org/sites/default/files/Submissions/gnest_05350/gnest_05350_published.pdf.