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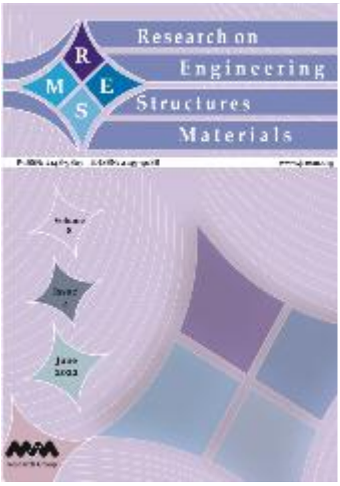

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Research Article

Experimental investigation on bamboo fibre reinforced mortar using artificial neural network – a comparative study

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Abstract

The increase in population promotes the construction industry to exploit the conventional building materials. This phenomenon leads to use of alternative building materials in the construction field. One of the effective natural materials is bamboo. In this paper, the Bamboo Fibre (BF) is used as an additive in the mortar at various percentages (1% to 4%) and Bamboo Stem Ash (BSA) is used as an alternative binder material to replace the cement at different proportions (2.5% to 10%). To increase the property of mortars, Styrene butadiene rubber (SBR) is used a super plasticizer from 0.5% to 2%. Due to high raising demand of river sand, Copper slag (CS) is used partially to replace the fine aggregate at constant percentage (50%) for all the mix proportion. W/B ratio is proportioned from 0.35 to 0.5 at different level. The design of experiment is conducted through Taguchi's design and the experimental values are validated by Artificial Neural Network (ANN) tool for obtaining the predicted results with respect to dry density, water absorption, compressive strength and flexural strength. The experimental investigation proved that BF and BSA have a potential sign to be used as an alternative sustainable building material. From the comparative analysis of experimental results with ANN, it is revealed that the mortars show an acceptable prediction of physical and strength properties with a maximum error of 8.11%.

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1. Introduction

Bamboo is a perennial sustainable grass which falls under "Poaceae" family [1]. The use of bamboo in construction field is in practice since ancient time due to its significant engineering properties [2]. Many researches are carried out to replace the conventional construction materials by many naturally available materials [3–5]especially in the field of bamboo to use bamboo and its derivatives in the construction industry [6,7]. Bamboo's stem can be used as reinforcement and its culm can be peeled off to obtain Bamboo Fibre (BF) that can be used as an additive in cement mortar and concrete to strengthen its mechanical properties [8]. The use of bamboo fibre in concrete may result in the reduction of density and at the same time increases the flexural properties of the concrete. Though it has significant advantages, it promotes the water absorption and thus swelling of concrete takes place [[9]. To overcome this phenomenon of moisture content due to addition of natural fibres into the concrete, proper treatment should be done to the fibres before adding it into the concrete to serve its need [10]. To replace the ordinary Portland cement content by alternative pozzolanic materials, bamboo stem ash and bamboo leaf ash can be a better solution. The waste culm parts and the leaves of bamboo are abundantly available which the solid waste to be disposed. The bamboo stem and leaf can be burnt into an ash to be used for the partial replacement of conventional cement material since Bamboo Stem Ash (BSA) possess good pozzolanic property [11]. The use of

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BF and BSA in cement mortar and concrete influences the compressive and flexural strength. It also reduces the density and water absorption capacity of the concrete which therefore, reduces the self-weight and moisture content as well respectively. The optimization of water-cement ratio and the percentage of superplasticizer was studied by using bamboo leaf ash to obtain high performance concrete [12]. The experimental results proved the optimization at 0.128% for superplasticizer and 0.360 for water-cement ratio.

Due to high raise in the demand of the river sand, there is a need for alternative fine aggregate. Copper slag is one of the important waste products in the manufacture of copper. This possesses good mechanical properties to be used as aggregate and also significant chemical compositions to be used as a replacement of cement [13,14]. Styrene butadiene rubber (SBR) has a potential to reduce the early strength of the concrete and also decreases the water absorption capacity of the concrete [15].

In this research, the promotion of the use of bamboo wastes in the construction filed was addressed. Many researches was undergone for the use of natural fibres (BF) [16] and ashes (BSA) [14] in the mortar and concrete but the combination of both BF and BSA in the same mortar and concrete was not addressed. The novelty in this research is to use BF and also BSA by utilising BSA has a complementary binder and BF has an additive to the same mortar. BF was added at various percentages (1%, 2%, 3% and 4%) to the mortar and BSA was used at different percentages (2.5%, 5%, 7.5% and 10%) to replace the cement. To improve the workability and enhance the property of the mortar, SBR was used at different percentages (0.5%, 1%, 1.5% and 2%) at different levels. To obtain the good combination of proportions, Taguchi's method of design of experiment was adopted. The experimental values and the predicted results by ANN validation obtained an acceptable percentage of error.

2.Material Properties

2.1. Bamboo Fibre (BF)

Bamboo fibre was used as an additive in the mortar mix after proper treatment to remove the wax and moisture content [10]. The bamboo culm was cut into pieces to extract fibre mechanically. Each fibre was cut for a length of 25 mm by maintaining a diameter of 1 mm. After the extraction process of fibre, it was treated by immersing in 10% concentration of a sodium hydroxide solution for two days. Then the treatment of fibre was ended by washing the fibre with water and drying in sun for 48 hours [16]. The compositions of BF are listed in Table 1.

Table 1.Constituents of bamboo fibre

Constituents of BF	Chemical Compositions (%)
Cellulose (%)	73
Hemicellulose (%)	13
Lignin (%)	12
Wax (%)	2

2.2. Bamboo Stem Ash (BSA)

To replace the cement by BSA, the stem of bamboo was cut into small pieces and dried completely in sun for 24 hours [14]. Then it was incinerated using furnace for about 120 minutes at 800°C. The burnt BSA was sieved using 0.075 mm diameter sieve to replace the ordinary Portland cement (OPC). The composition of OPC and BSA are shown in Table 2.

Table 2.Chemicalconstituents of OPC and BSA

Chemical Composition	Ordinary Portland Cement (%)	BSA (%)
SiO_2	20	69.74
MgO	0.8	8.83
Al_2O_3	5.2	0.25
CaO	62.7	18.92
Na_2O	0.35	0.74
Fe_2O_3	3.5	0.16
K_2O	0.74	0.86
LOI	6.71	0.5

2.3. Copper Slag

At the process of extraction of copper metal, the waste material is obtained from the refinery plants called as copper slag [17]. For the effective use of CS in the concrete or cement mortar and to get reduced moisture absorption and voids, river sand can be replaced by CS up to 50% [18]. The properties of CS are observed in Table 3.

Table 3. Properties of Copper Slag

Properties	Value
Silica (%)	33.5
Water absorption (%)	0.24
Bulk density (kg/m^3)	1899
Fineness modulus	3.3
Specific gravity	3.47

2.4. Styrene Butadiene Rubber (SBR)

SBR is a super plasticizer used in the cement mortar and concrete due to its high bonding efficiency, resistance to abrasion and crack and aging characteristics [15]. It is a copolymer liquid in white colour with a specific gravity and solid content of 1.04 and 45% respectively [19]. Use of SBR at 1.5% in the mortar performed good compressive strength.

3. Methodology

3.1. Design of Experiments

In this research, four parameters are considered to study the performance of bamboo fibre reinforced mortar are: (i) water-cement ratio, (ii) binder (cement+BSA), (iii) Super plasticizer (SP) and (iv) Bamboo Fibre (BF). Each parameter is concentrated for four levels and shown in Table 4. To minimise the number of trials, Taguchi's design of experiment is adopted [20–22]. The layout of the developed combination of trials is shown in Fig. 1.

The ratio maintained for Bamboo fibre reinforced mortar was 1:2.75 with respect to ASTM C109 standard [10]. The sixteen trials obtained from the taguchi's design of experiment are illustrated in Table 5. Fine aggregate for all the trials was replaced constantly by 50% of copper slag.

Table 4. Description of parameters and variation levels

Parameters	Parameter label	L1	L2	L3	L4
W/B ratio	A	0.5	0.45	0.4	0.35
Binder (Cement + BSA) (%)	B	97.5 + 2.5	95 + 5	92.5 + 7.5	90 + 10
SP (%)	C	0.5	1	1.5	2
BF (%)	D	1	2	3	4

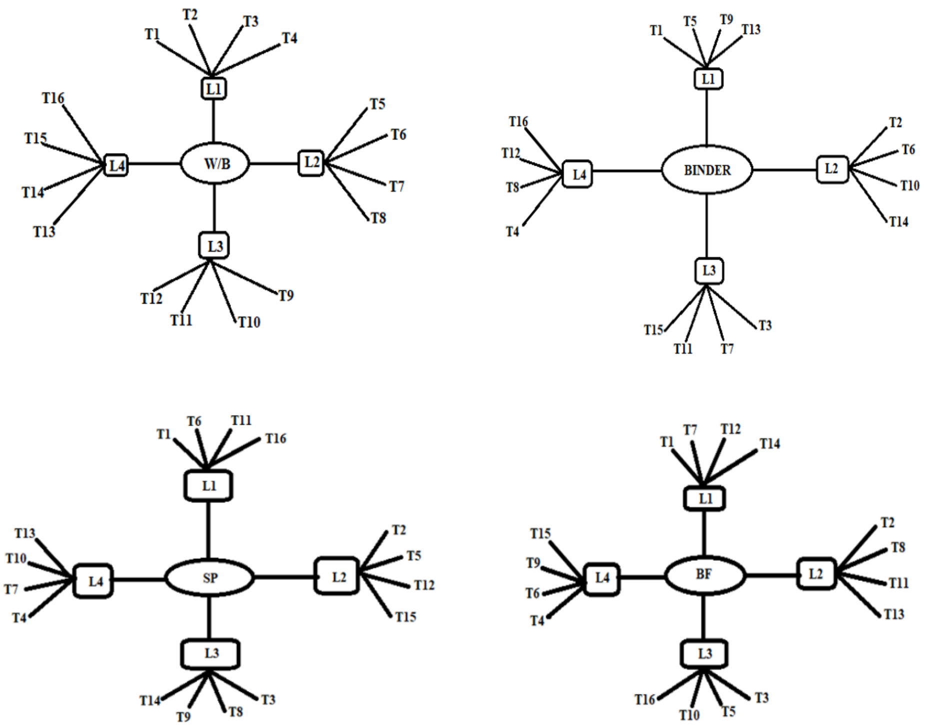


Fig. 1 Orthogonal array of Taguch's design of experiment (L16)

3.2. Artificial Neural Networks (ANN)

ANN is a framework designed to analyze and process the information activity like the human brain. This neural network has an ability to recognize and generalize from the accessible data and bring pertinent solutions from the incomplete or inaccuracy input parameters [23–25]. ANN tool is implemented to rectify and distinguish the investigation results obtained from the other methods. It holds enormous neuron which is interlinked like networks and each and every neuron from the input (Xi) will produce individual output (Y) with the mentioned equation (1). The terms (f) represent the activation function and (H) denotes input parameters that are obtained from the equation (2). The term (b) in the equation (2) is used to direct the function and commonly known as bias co-efficient [26–30].

$$Y = f(H) = \frac{1}{1+e^{-H}} \quad (1)$$

$$H = \sum_{i=1}^{n} X_i W_i + b \quad (2)$$

Table 5. Mix Proportion of Mortar

Exp. No	W/B	Binder (Cement + BSA) (%)	SP (%)	BF (%)	FA (Sand + CS) (%)
Ctrl	0.5	100 + 0	0	0	50 + 50
T1	0.5	97.5 + 2.5	0.5	1	50 + 50
T2	0.5	95 + 5	1	2	50 + 50
T3	0.5	92.5 + 7.5	1.5	3	50 + 50
T4	0.5	90 + 10	2	4	50 + 50
T5	0.45	97.5 + 2.5	1	3	50 + 50
T6	0.45	95 + 5	0.5	4	50 + 50
T7	0.45	92.5 + 7.5	2	1	50 + 50
T8	0.45	90 + 10	1.5	2	50 + 50
T9	0.4	97.5 + 2.5	1.5	4	50 + 50
T10	0.4	95 + 5	2	3	50 + 50
T11	0.4	92.5 + 7.5	0.5	2	50 + 50
T12	0.4	90 + 10	1	1	50 + 50
T13	0.35	97.5 + 2.5	2	2	50 + 50
T14	0.35	95 + 5	1.5	1	50 + 50
T15	0.35	92.5 + 7.5	1	4	50 + 50
T16	0.35	90 + 10	0.5	3	50

The ANN is identified as Multilayer Perception (MLP) due to its three apparent layers. The feeding of network with outside data is done in the first layer. The connection between the input and output layer is performed in the second layer which is commonly known as computational or hidden layer. The prediction is executed in the output form in the third component which is preferably known as output layer. The input layer consist of five independent parameters and the output layer contains four dependent variables using which ANN predicts the dry density, water absorption, compressive and flexural strength.

In this research work, the ANN framework was created in MATLAB R2018a to estimate the mechanical strength developed at 7 and 28 days of experimental mortars. Figure 2 shows the Lavenberg-Marquardt algorithm of the ANN framework.

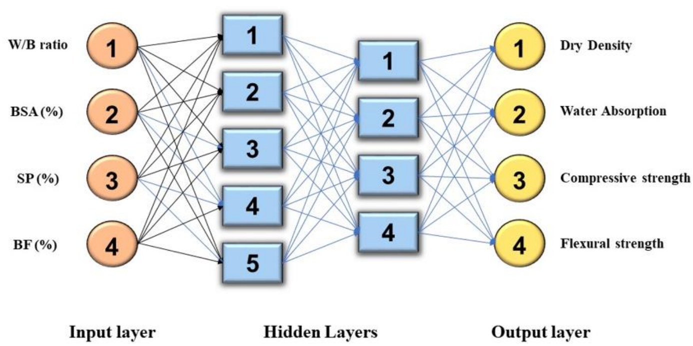


Fig. 2 ANN framework of the present research

3.3. Test Samples Preparation

All the materials were weighted as per the mix proportions followed by dry mixing. Then the wet mixing was carried out for 2 to 3 minutes by gradual addition of water. The total mix was transferred into a flat container and mixing was performed manually so that the fibre won't get segregated in the mortar mix. After even distribution of the bamboo fibres, the fresh mortar mix was casted by filling into the 100 x 100 x 100 mm3 and 40 x 40 x 160 mm3 mould sizes. Then the mortar was kept under curing to get hardened for testing its flexural and compressive strength.

3.4. Experimental Program

After the curing period of 7 and 28 days for the developed cubes, the compressive strength was conducted as per ASTM C109 with a compression testing machine of 2000 kN capacity and valued for each trial with an average of three samples. The load was applied gradually at a loading rate of 0.75 kN/s. The flexural test was performed on prism samples of size 40 x 40 x 160 mm^3 after 7 and 28 days of curing as per ASTM C348 on all the samples using 10 kN capacity, universal testing machine under three point loading. Physical testing of water absorption was done on all the sample cubes as per BS 1881-122 standard [31]. The water cured mortar specimens were taken at 28 days and dried using oven at temperature of 100°C for 24 hours. The oven dried mortar specimens were weighted for its mass to calculate the dry density. To determine the physical testing of water absorption, the specimens were immersed in water up to 240 minutes [32]. The wet mortar specimens were taken away from the water and weighted for its mass at 10 minutes, 20 minutes, 30 minutes, 60 minutes, 120 minutes, 180 minutes and 240 minutes, and finally the water absorption percentage was calculated.

4. Experimental and Predicted Results Using ANN Model

4.1. Effect of Addition of BSA and BF on Water Absorption and Dry Density

Dry density results of all the experimental samples with varying percentage of BF and BSA is shown in Fig. 3. It was observed that the increase in percentage of bamboo stem ash (BSA) decreased the dry density of the mortar due to its low density than cement. However, there was marginal increase in the dry density of mortar for 7.5% to 10% replacement of cement by BSA because of 3% to 4% addition of bamboo fibre. The replacement of cement by 5% of BSA and 1.5% of bamboo fibre reduced the dry density of mortar by 22.8% in comparison with the dry density of conventional mortar. The increase in bamboo fibre content had made cement composite more porous like other fibres[10]. The porous structure had given accommodation for the water molecules to occupy[16]. Bamboo fibre concentration seems to be directly proportional to the increase of moisture content of mortar. However, the water absorption percentage got decreased for all the trial mortars because of the NaOH treatment adapted to the bamboo fibre before adding it in the mortar mix. Figure 4 shows that all the trial mortar water absorption percentage was less in comparison with control mix. The maximum water absorption at 240 minutes for the conventional mortar was 12.19% and the maximum and minimum water absorption for the trial mortars were 5.89% and 1.47% respectively. This showed that there was maximum and minimum reduction of water absorption for the trial mortars by 6.3% and 11.43% respectively.

4.2. Effect of Addition of BSA and BF on Compressive and Flexural Strength

There was a decline of compressive strength on mortars with the addition of BSA and BF [10]. The water to binder ratio and dosage of super plasticizer also had significant effect in increase or decrease of compressive strength. The replacement of cement by 2.5% of BSA with 0.5% of BF had given equivalent compressive strength of control mortar. The strength of this trial mortar was achieved by adding 0.5% of SBR at w/b ratio of 0.5. With decrease in w/b ratio for the same dosage of BSA% and BF%, the decrease in strength was observed. However, the increase in SBR% gradually increased the strength of mortars of 5% to 10% replacement of cement by BSA and 3% to 4% addition of BF at 0.5 w/b ratio. The replacement of cement by 10% of BSA with 2% of bamboo fibre and 2% of SBR% at 0.5 w/b ratio increased the compressive strength by 77.89% as compared with the compressive strength of control mortar for 28 days. Figure 5(a) & (b) shows the compressive strength of control and all the trial mortar of 7 days and 28 days. The flexural strength was increased up to 20% than control mortar with fibre dosage of 1% at w/b of 0.5 and the flexural strength results of trials is shown in Fig. 6(a) & (b). The strength started to gradually decrease in increase with fibre percentage. However, this phenomenon was overcome by increased percentage of SBR%. For the same w/b ratio of 0.5, the flexural strength of mortar with 4% BF was increased with increase in SBR%. The treatment of BF with NaOH solution before using in mortar and increased percentage of SBR% are the important reason for the increase of flexural strength.

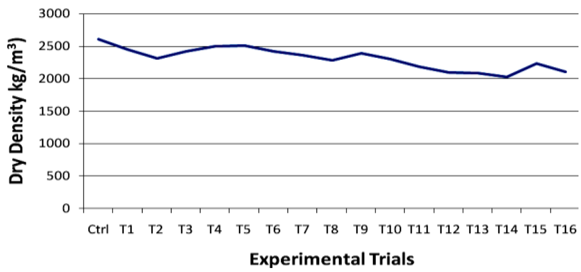


Fig. 3 Effect of BF and BSA incorporated mortar on dry density

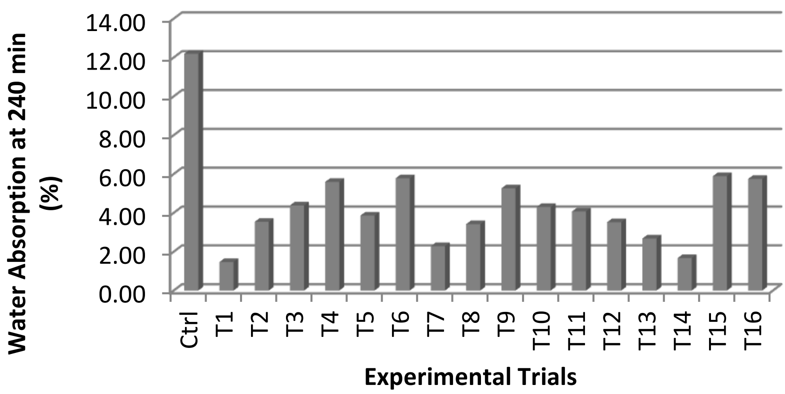
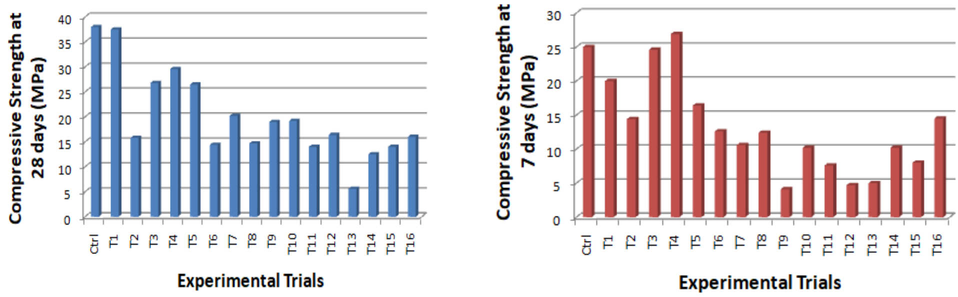


Fig. 4 Effect of BF and BSA incorporated mortar on water absorption

4.3. Prediction of Physical and Strength Properties from ANN Model

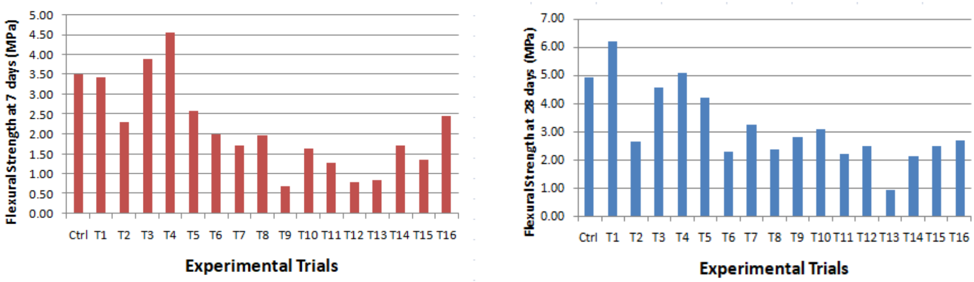
The selected range of variables of input and output in the ANN database is shown in Table 6 and the precision in the data obtained from the network are calculated by the prediction of error percentage formula [33]

$$\text{Prediction of error (\%)} = \frac{\text{Experimental results} - \text{ANN results}}{\text{Experimental results}} \text{ X } 100$$



(a) (b)

Fig.5(a) Compressive strength at 7 days (b) Compressive strength at 28 days



(a) (b)

Fig.6(a) Flexural strength at 7 days(b) Flexural strength at 28 days

Table 6. Range of variables in ANN database

Variables	Range	Remarks
W/B ratio	0.35 – 0.5	Input variables
BSA (%)	2.5 – 10	
SP (%)	0.5 – 2	
BF (%)	1 – 4	
CS (%)	50	
Dry density (kg/m3)	2030 – 2608	Target variables
Water absorption (%)	1.47 – 12.19	
Compressive strength (MPa)	4.1 – 38	
Flexural strength (MPa)	0.7 – 6.19	

The error percentage of bamboo fibre reinforced mortars for its dry density, water absorption, compressive and flexural strength were shown in Table 7. The percentage of error obtained from the ANN tool is acceptable as it is less than 10%. From all the trials, flexural strength of T1 for 7 days recorded a maximum error percentage of 8.11%.

Figure 7 illustrates the predicted and experimental dry density values of 16 trials and the control mortar at 28 days. Also, Figure 8 shows the experimental and ANN results of water absorption at the end of 28 days at 240 minutes. Figure 9 & 10 depicts the compressive strength and flexural strength comparison of experimental results with predicted results using ANN of all the trial mortars and control mortar at the end of 7 days and 28 days. From all these comparison graphs, it was indentified that the experimental results and the predicted results are marginal and equivalent.

Table 7. Error percentage values of physical and strength property values from the ANN model

Mix ID	Dry density	Water Absorption	Compressive Strength		Flexural Strength	
			7 days	28 days	7 days	28 days
Ctrl	0.22	-2.50	-0.84	-1.96	0.19	0.39
T1	-0.33	-2.72	-0.55	2.11	8.11	-2.10
T2	0.26	-1.13	-0.69	5.13	2.31	-3.56
T3	0.04	1.80	3.32	-0.52	-0.40	-0.57
T4	-0.65	-1.43	0.59	-1.96	1.09	-0.79
T5	-0.33	-1.90	-0.06	1.98	4.22	-0.66
T6	-0.32	-2.03	0.60	2.57	1.00	-5.58
T7	0.20	4.37	-0.65	0.23	-0.30	-0.55
T8	0.27	-2.34	-0.20	-2.18	-2.80	-0.26
T9	-0.03	-1.14	-2.52	0.26	-5.37	-2.61
T10	-0.27	1.91	-0.88	-2.45	3.07	-5.18
T11	0.26	-0.81	0.26	0.79	-4.65	2.23
T12	-0.36	5.35	-2.57	-0.79	2.50	-0.10
T13	0.11	-1.30	-7.60	0.34	-3.43	-0.65
T14	0.12	4.07	0.34	-2.31	-0.93	2.14
T15	0.21	-2.88	1.38	-0.14	0.30	-0.24
T16	0.13	-1.04	-6.83	-1.49	3.24	1.10

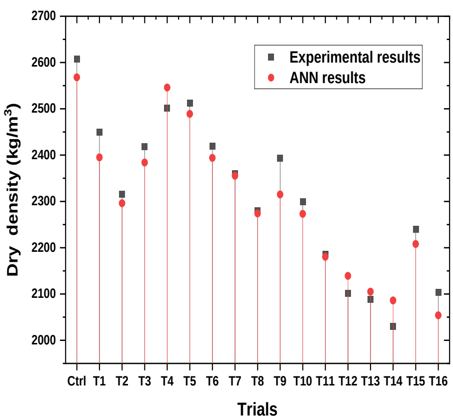


Fig. 7 Comparison of actual and ANN results of dry density

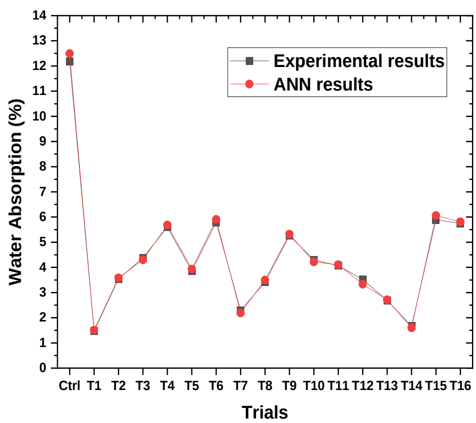


Fig. 8 Comparison of actual and ANN results of water absorption

Figure 11-16 shows the ANN predicted execution (regression plots) of dry density, water absorption, compressive and flexural strength (target variables). The three-phase combination correlation co-efficient recorded for compressive strength test at 7 days and 28 days are 0.96801 and 0.95995 respectively as shown in Fig.11 & 12. Similarly, the three phase combination correlation co-efficient obtained for flexural strength for 7 and 28 days are 0.97585 and 0.97686 respectively and for dry density and absorption are

0.96015 and 0.9683 respectively. This reveals the less error results of experimental results and ANN outcomes depicted in Fig 7-10.

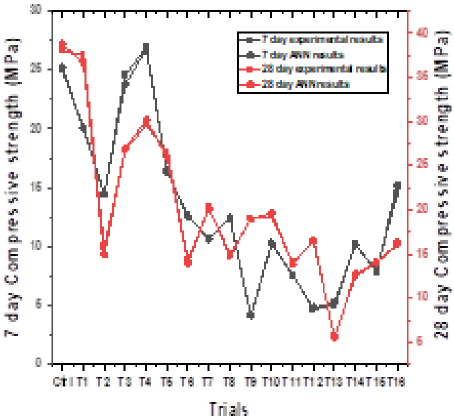


Fig. 9 Comparison of actual and ANN results of compressive strength at 7 and 28 days

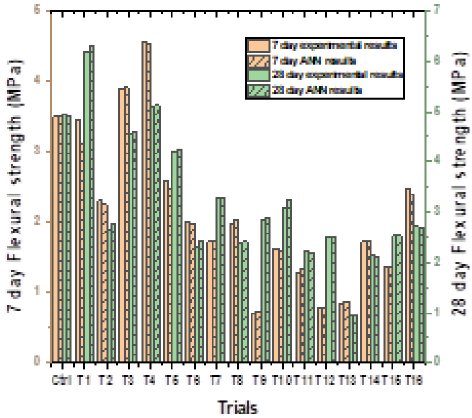


Fig. 10 Comparison of actual and ANN results of flexural strength at 7 and 28 days

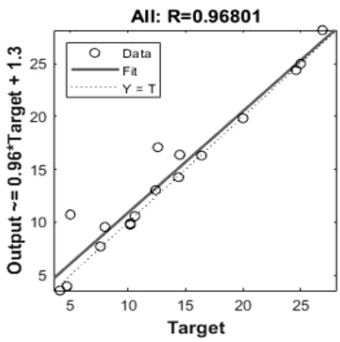


Fig.11 Prediction execution of Compressive strength for 7 days

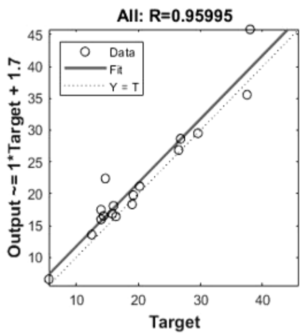


Fig. 12 Prediction execution of Compressive strength for 28 days

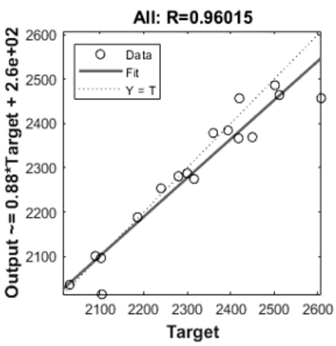


Fig. 13 Prediction execution of dry density for 28 days

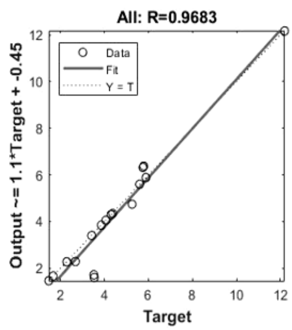


Fig. 14 Prediction execution of water absorption for 28 days

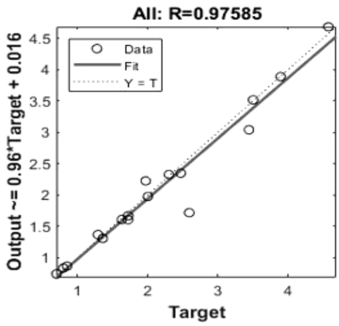


Fig. 15 Prediction execution of flexural strength for 7 days

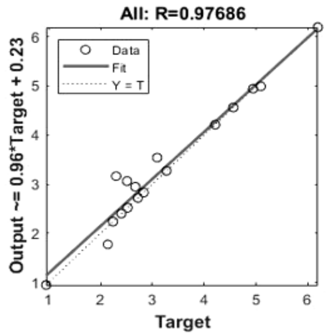


Fig. 16 Prediction execution of flexural strength for 28 days

5. Conclusions

This research focuses on incorporating an alternative sustainable building material by utilizing waste bamboo materials (BF and BSA) in mortar to enhance its mechanical strengths. Here are the following conclusions drawn from this experimental research.

- Bamboo stem ash (BSA) has potential to reduce the density of the mortar due to its low density than cement[11]. Due to addition of bamboo fibre (BF) from 3% to 4%, there was a marginal increase in the dry density of mortars for 7.5% to 10% replacement of cement by BSA. The BSA with 5% and BF with 1.5% can be chosen has an optimum dosage since it reduced the dry density by 22.8% than control mortar.
- The 10% concentration of NaOH treatment for BF as per the literature [16]reduced the water absorption capacity. For the control mortar, the maximum water absorption percentage was recorded as 12.19% at 28 days whereas, the maximum and minimum percentage of water absorption of trial mortars were 5.89% and 1.47%. The recorded results revealed that treated bamboo fibre reinforced mortar with the bamboo stem ash as a complementary binder has potential to reduce the water absorption capacity of the mortar.
- It is observed that compressive strength got declined with increase in the percentage of BF [10]and BSA. However, by increasing the SBR% at higher water cement ratio of 0.5, gradually increased the strength of mortars of 5% to 10% replacement of cement by BSA with 3% to 4% addition of BF. The mortar sample with 10% of BSA, 2% of BF and 2% of SBR% at water cement of ratio of 0.5, increased the compressive strength by 77.89% as compared to the control mortar.
- The flexural strength gradually decreased with increase in fibre percentage[10]. However, the flexural strength was raised up to 20% than control mortar. This was achieved by treatment of BF with NaOH solution and increased percentage of SBR.
- The ANN framework construction in this research was noticed to be suitable with results in judging the dry density, water absorption, compressive and flexural strength values of bamboo fibre reinforced mortar mixes.

Future Work

The output obtained from the experimental investigation should be analysed and validated through Taguchi's approach. The analysis of variance is to be performed to identify the percentage of contribution of each parameter. Finally the experimental program should be executed for the obtained optimum dosage of the mortar based on the output performance indices.

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