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# Engineering properties of concrete incorporating waste glass as natural sand substitution with tin can fiber: experimental and ANN application

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## Abstract

Disposal of waste material is causing environmental issues all around the world. Waste glass and tin can are two such products that impose detrimental effects on the environment. One feasible approach is to utilize these discarded materials as constituents of concrete. This study investigates the performance of concrete prepared with glass waste as fine aggregate (GWA) and tin can fiber (TCF) in terms of workability, fresh density, compressive, and splitting tensile strength as desired concrete properties. An Artificial Neural Network (ANN) approach has been adopted for developing predictive models to simulate the impact of these waste materials on concrete properties. Experimental findings demonstrate that the workability of concrete mix decreases with increasing GWA and TCF contents in the mix. Increasing TCF percentages results in an increase in fresh density of concrete; however, a declining pattern in fresh density has been observed with increasing GWA percentage in the concrete mix. Compressive strength at all curing ages shows positive trends till 20% GWA and 1% TCF incorporation in concrete. Similar pattern has been observed for splitting tensile strength up to 10% GWA and 0.5% TCF. Constructed models are feasible for prediction of the desired concrete properties as verified by various statistical parameters. Sensitivity analysis reports that TCF has a greater influence on concrete properties than GWA.

**Keywords:** Waste glass, Tin can fiber, Artificial neural network, Workability, Density, Compressive strength, Splitting tensile strength

## Introduction

The rapid urbanization, population growth, excessive industrial, manufacturing, and construction activities have resulted in increase of waste materials [1]. Each year, 2.12 billion tons of waste are being dumped without recycling or any type of treatment [2]. As majority of the waste are non-biodegradable, these wastes are causing serious pollution in the surrounding environment [3–5]. Waste glass and discarded tin cans, generated enormously in daily basis, are directly disposed of to the landfills. Waste glass disposal is considered a central environmental problem around the world. Annually, glass waste

are production rate is more than a million tons around the globe. This discarded waste has a big threat to the ecology based on its long degrading period. However, recycling of waste glass as fine aggregate in concrete production is beneficial [6]. Recycling of such waste contributes to the conservation of natural resources, reduces spaces in landfills, and saves money and energy [7]. In addition, Salahaddin et al. [6], and Taher et al. [8] found chemical and physical properties of glass close to river sand. Very fine glass powder has good filler effect which results in high performance of concrete. Also, the waste glass powder having particle size of 100  $\mu\text{m}$  or smaller plays pozzolanic reactivity in concrete [9].

On the other hand, the demand of basic concrete constituents are rising immensely. It is the most widely-utilized construction material after water owing to its relatively low price and good performance [10, 11]. The annual consumption rate of stones and rocks for construction purposes is 10–12 billion tons [12]. For concrete production, the large-scale sand mining from natural resources causes alteration of riverbed, changes of river course, eroding of bank, and flooding [13]. It also affects groundwater recharge and disrupts the ecosystems of aquatic animals and microorganisms. Production of concrete having glass waste mixed with tin fiber can be an effective solution to reduce environmental impacts by ensuring the efficient use of the natural resources [2, 14].

Glass has been using for over 9000 years due to its low cost, ease of use and unique qualities [15, 16]. But most glass waste cannot be utilized to transform into new glass items because of variable chemical composition of mixed glass [17]. Problem arises in recycling of mixed glass at the variations in their melting points [18]. Several previous research of using mixed glass waste material as concrete constituents reported a beneficial solution for waste glass recycling [19–21]. Chen et al. [22], Degirmenci et al. [23], Ismail and AL-Hashmi [12], and Turgut and Yahlizade [24] registered better compressive strength of glass aggregate concrete compared to control concrete. Batayneh et al. [25] reported that compressive strength of glass aggregate concrete rose up to 20% replacement of glass waste. A strength rise of concrete with glass compared to control concrete was found in the study of Evangelista and de Brito [26, 27], Khatib [28]. The highest compressive strength increment for 10%, 30%, and 50% replacement ratio was 3.7%, 5%, and 16%, respectively. The improvement was imputed to the filler effect of glass that made concrete denser and more compact, reduced early propagation of cracks. Another possible reason was the rough surface texture and angular shape of glass particles that improved strength of concrete because of better interlocking between particles. In case of splitting tensile strength, Wang [29] reported concrete with 20% and 40% glass and design strengths of 35 MPa and 21 MPa obtained higher splitting tensile strengths than the control. Yildirim et al. [30] stated that the glass had a positive effect on the tensile strength of the concrete. However, Adaway and Wang [31], Ali and Al-Tersawy [32], Park et al. [33] and Taha et al. [34] discovered decreasing trend for increasing glass waste. In the study of Haido et al. [35], concrete having waste glass exhibits higher flexural strength than conventional concrete. In addition, the substitution of fine aggregate with glass can improve workability [36], improve sulfate and chloride resistance [37], lessen drying shrinkage [38], and augment high-temperature resistance [39]. In addition, using glass as fine aggregates can be economical material of concrete in countries where natural river sands are limited [19, 40].

Fiber reinforced concrete is a composite material produced by the addition of discrete reinforcing fibers in concrete [41–43]. Incorporation of fiber in concrete, resolve the brittle behavior of concrete, improves the energy absorption capacity and ductility of concrete [44, 45]. FRC can develop compressive strength and tensile strength over 150 MPa and 8 MPa respectively [46]. Tin can as fiber reinforcement for production of fiber reinforced concrete have gained popularity in recent years [1, 47, 48]. Compressive strength of concrete having tin fiber is prominent up to 1% addition [47]. Meanwhile, 1.0% inclusion of tin fiber in concrete have 8.2% higher flexural strength than conventional concrete [47].

Therefore, models need to be developed between input variable as GWA and TCF and output variable as workability, fresh density, compressive strength, and splitting tensile strength at 7, 28, and 56 days. Nowadays, ANN has received ample priority for modeling and predicting concrete properties. Topçu and Saridemir [49] used artificial neural network for simulation of characteristics of concrete for incorporation of waste AAC aggregate, and found good accuracy of ANN model. Ince [50] reported viable and promising results of an ANN-based two-parameter model (TPM) of concrete. Similarly, good coherence with experimental result of compressive strength was registered by Kewalramani and Gupta [51] using ANN.

This research intends to explore the effect of GWA and TCF on experimental values of the workability, fresh density, compressive, and splitting tensile strength of concrete at 7, 28, and 56 days as well as modelling of these values using ANN. This study also wishes to perform sensitivity analysis of the variables on the properties of concrete. To our knowledge, this is the maiden paper focusing on modeling of concrete having glass waste and tin fiber using ANN. In addition, this research is unique in terms of finding relative effect by sensitivity analysis.

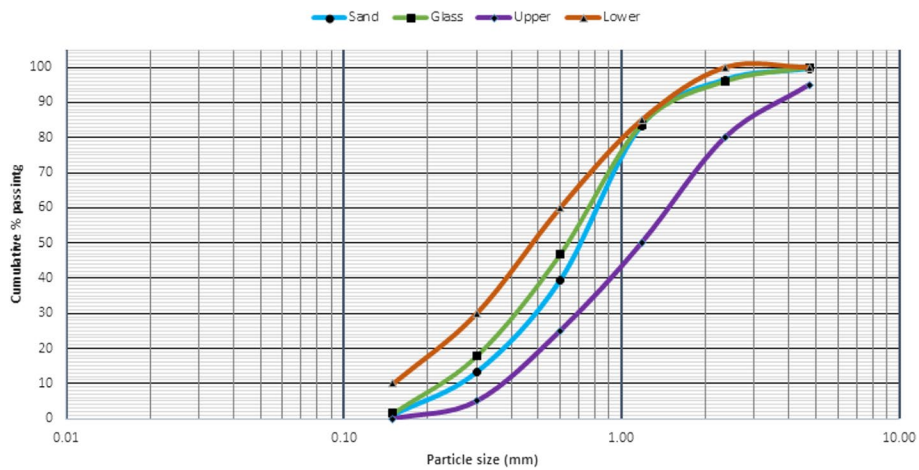
## Experimental program

### Properties of raw materials

The properties of sand, stone, glass and fiber are displayed in Table 1. Natural sand and waste glass have been incorporated as fine aggregates in concrete. Waste glasses were achieved from mechanical crushing of window glasses of different vehicles. The gradation curve of glass and sand have been shown in Fig. 1. The curve were compared with the ASTM (C33) specified lower and upper gradation curve and found that particle distribution curve of sand and glass fall within the allowable limit [52].

**Table 1** Characteristics of materials used

Variable	Density (kg/m <sup>3</sup> )			Specific gravity (kg/m <sup>3</sup> )		Water absorption (%)	Fineness modulus
	Bulk	OD	SSD	OD	SSD		
Sand	1543.32	2518.94	2569.32	2.53	2.57	2	2.67
Stone	1640.46	2821.5	2850	2.83	2.86	1.01	-
Glass	1367.12	2479.08	2493.75	2.48	2.5	0.59	2.54
Tin	805.29	-	-	-	-	-	-



**Fig. 1** Gradation curve of glass waste aggregate and natural sand



Glass Waste



River Sand



Stone



Tin Fibre

**Fig. 2** Raw materials

The condensed milk can waste were processed to make tin can fiber having 20 mm length and 2 mm width. All characteristics of crushed glass waste have been found lower than sand. As binding agent in concrete mixing, Ordinary Portland Cement (ASTM Type I) was chosen to use. The used materials has been displayed in Fig. 2.

### Mix proportioning

There were two types of concrete mixes created in this experimental work (Table 2). The control concrete mix (M0) containing cement (400 kg/m<sup>3</sup>), stone (1200 kg/m<sup>3</sup>), sand (600 kg/m<sup>3</sup>) and water (200 kg/m<sup>3</sup>). The rest mixes were prepared with GWA of 10%, 20%, and 30% as a partial substitution of sand and with the addition of TCF from 0.5 to 1.5% in step of 0.5%. In all mixes, a constant ratio of 1:1.5:3 (M20) has been maintained for concrete production. M20 is mostly used for reinforced cement concrete structures and has a water-cement ratio of 0.5. Since the workability behavior of concrete having waste glass is not well known and the flow of control concrete containing M20 grade is well established hence M20 was taken in in this study to avoid unexpected workability of concrete incorporating glass waste.

### Preparation of specimens

Molds having a height of 200 mm and a diameter of 100 mm were greased properly to guarantee no loss of water during the casting process and to avoid concrete adhesion with molds for ensuring effortless demolding. The concrete was cast in two layers of 100 mm each where every layer was given 25 blows using a 5-mm tamping rod. Figure 3 shows the preparation of concrete sample preparation. The molds were left to dry for 24 h at 25°C before the concrete specimens were demolded from them. After that, concrete cylinders were submerged in fresh water immediately to ensure proper curing for 7, 28, and 56 days. Table 3 exhibits the adopted experimental standards for this study.

### Artificial neural network (ANN)

ANN is a mathematical modeling tool that mimic the nervous systems of human brain (Fig. 4). It has machine learning, adaptive learning, abilities to recognize patterns and self-organization. A artificial neural network contains neurons, input, hidden (one or many) and output layers, weight, bias, sum, activation and learning function. Neurons

**Table 2** Mix proportions of concrete

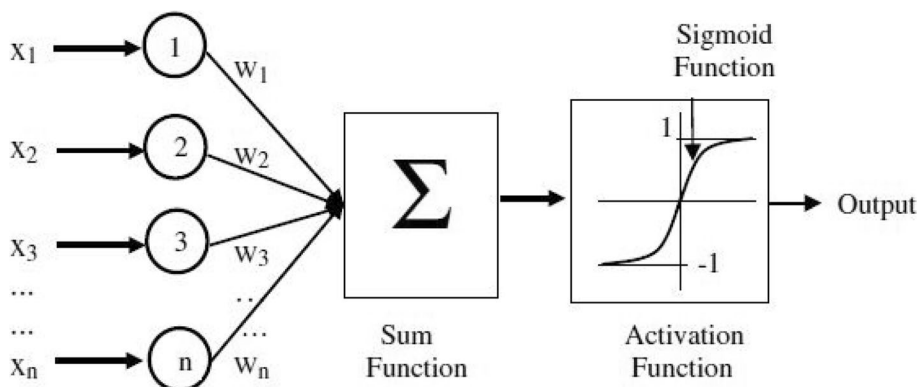
Mix code	Cement (kg/m <sup>3</sup> )	Stone (kg/m <sup>3</sup> )	Sand (kg/m <sup>3</sup> )	GWA (%)	GWA (kg/m <sup>3</sup> )	TCF (%)	TCF (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )
M0	400	1200	600.00	0.00	0.00	0.00	0.00	200
M1	400	1200	537.31	10.00	59.70	0.50	11.94	200
M2	400	1200	477.61	20.00	119.40	0.50	11.94	200
M3	400	1200	417.91	30.00	179.10	0.50	11.94	200
M4	400	1200	537.31	10.00	59.70	1.00	23.76	200
M5	400	1200	477.61	20.00	119.40	1.00	23.76	200
M6	400	1200	417.91	30.00	179.10	1.00	23.76	200
M7	400	1200	537.31	10.00	59.70	1.50	35.47	200
M8	400	1200	477.61	20.00	119.40	1.50	35.47	200
M9	400	1200	417.91	30.00	179.10	1.50	35.47	200
M10	400	1200	600.00	0.00	0.00	0.50	11.94	200
M11	400	1200	600.00	0.00	0.00	1.00	23.76	200
M12	400	1200	600.00	0.00	0.00	1.50	35.47	200
M13	400	1200	537.31	10.00	59.70	0.00	0.00	200
M14	400	1200	477.61	20.00	119.40	0.00	0.00	200
M15	400	1200	417.91	30.00	179.10	0.00	0.00	200



**Fig. 3** Preparation of concrete specimens

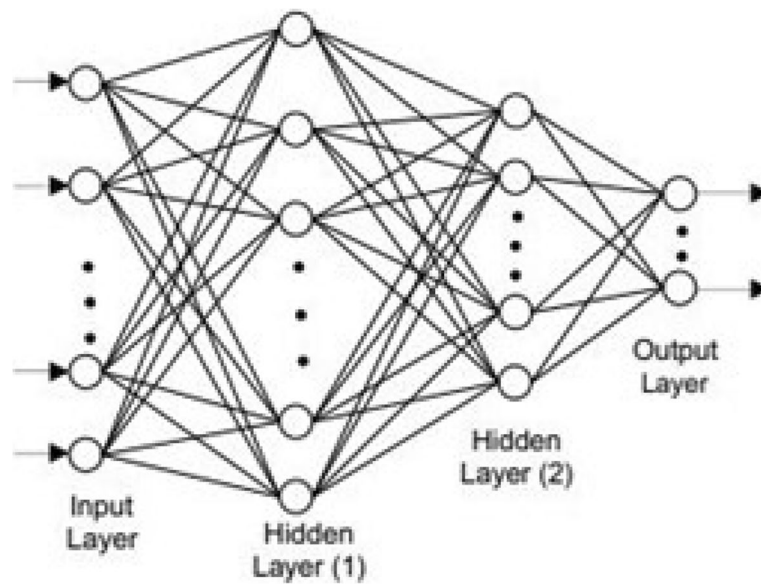
**Table 3** Specifications of tests conducted

Test name	Code
Sieve analysis	ASTM C33
Bulk density	ASTM C29
Specific gravity of coarse aggregate	ASTM C127
Specific gravity of fine aggregate	ASTM C128
Workability	ASTM C143
Fresh density	ASTM C138
Compressive strength	ASTM C39
Splitting tensile strength	ASTM C496



**Fig. 4** A simple neuron model [49]

are processing unit which are grouped in the layers (Fig. 5). Each connection between neurons in the layers has a coefficient assigned to it called weight. Within the same layer, there are usually no interconnections between units. Sum function calculates the product of inputs and weight along with addition of bias (Eq. 1). Activation processes determines the cell output through processing of the weighted sum (Eq. 2). ANN learns autonomously from the given training process and forms a connection between input and output variables [53]. It can produce meaningful outcomes even when the provided data have errors or are incomplete [54].



**Fig. 5** Structure of ANN [54]

$$net_j = \sum_{i=1}^n (w_{ij}x_i) + b \tag{1}$$

where  $net_j$  represents weighted sum of  $j$  neuron for the input obtained from previous layer,  $w_{ij}$  represents weight value between  $j$  neurons in the preceding layer,  $x_i$  stands for output of the  $i$  neuron,  $b$  represents bias value.

$$out_j = \frac{1}{1 + e^{-\alpha(net_j)}} \tag{2}$$

where  $out_j$  represents output of  $j$  neuron, and  $\alpha$  stands for a constant which controls the slope value within the semi-linear region.

Because log-sigmoid is utilized as an activation function between the input and hidden layers in ANN, data normalization was required. Normalized sets of actual data could improve learning speed, and the training process’s performance, accuracy, and stability [55]. Normalized values were measured using the following equation. Equation (3)

$$X^{norm} = \frac{X^{act} - X^{min}}{X^{mzx} - X^{min}} \tag{3}$$

where  $X^{act}$  signifies experimental value,  $X^{min}$  signifies the lowest value,  $X^{max}$  signifies highest value, and  $X^{norm}$  signifies normalized value.

**Sensitivity analysis**

Details about the target outputs are contained in input parameters. More input parameters usually imply more detail and simulation capacity. However, few parameters might be immaterial that can deceive the training process and degrade the function of learning algorithm. The determination of effect of variables on the responses in ANN is unlike

the classic statistical models because of relative complexity of neural network [56]. Contribution of the independent variables on the target concrete properties were measured by following equation depending on the value of weights, Eq. (4)

$$IF = \frac{\sum_{j=1}^M \frac{w_{ij}}{\sum_{r=1}^N w_{rj}} \times w_{jk}}{\sum_{i=1}^N \left( \sum_{j=1}^M \frac{w_{ij}}{\sum_{r=1}^N w_{rj}} \times w_{jk} \right)} \quad (4)$$

where  $\sum_{r=1}^N w_{rj}$  implies the summation of the associated weights between the hidden neuron  $j$ . and input neurons  $N$ .  $IF$  denotes the proportion of influences of the input variable  $x_i$  on the output  $y_k$  [57].

### Model performance evaluation

In this research, the ANN models were trained on training data (60%), applied to validation data (20%), and evaluated final model fitted on training data set (20%). The model's simulation accuracy was determined through statistical parameter coefficient of correlation ( $R$ ), coefficient of determination ( $R^2$ ), mean absolute error (MAE), mean square error (MSE), and root mean square error (RMSE) using Eqs. (5)–(9) respectively.

$$R = \frac{\sum_1^n (a_i - \bar{a})(p_i - \bar{p})}{\sqrt{\sum_1^n (a_i - \bar{a})^2 \sum_1^n (p_i - \bar{p})^2}} \quad (5)$$

$$R^2 = \left( \frac{\sum_1^n (a_i - \bar{a})(p_i - \bar{p})}{\sqrt{\sum_1^n (a_i - \bar{a})^2 \sum_1^n (p_i - \bar{p})^2}} \right)^2 \quad (6)$$

$$MSE = \frac{\sum_1^n (p_i - a_i)^2}{N} \quad (7)$$

$$RMSE = \sqrt{\frac{\sum_1^n (p_i - a_i)^2}{N}} \quad (8)$$

$$MAE = \frac{1}{N} \sum_1^N |p_i - a_i| \quad (9)$$

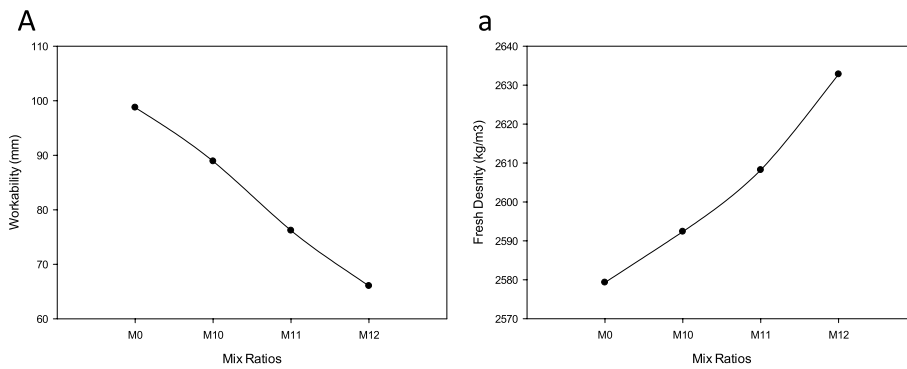
Here  $a_i$  is experimental data,  $p_i$  is simulated data,  $\bar{a}$  and  $\bar{p}$  are mean of experimental and simulated data, respectively, and  $N$  represents the number of total samples.

## Results and discussion

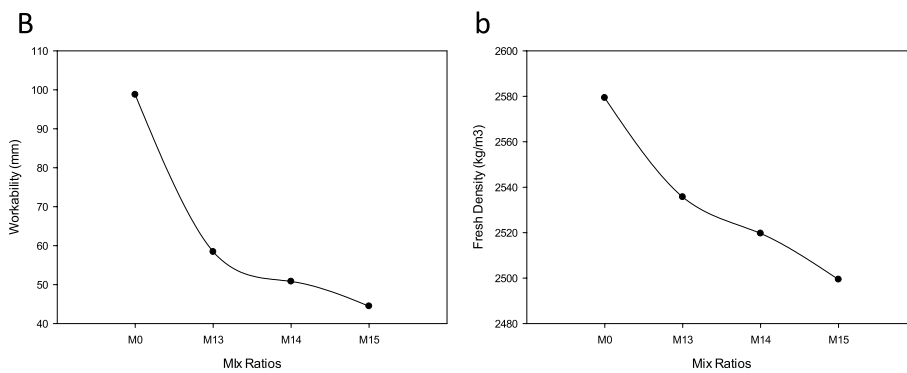
### Experimental result

In order to investigate the characteristics of concrete having tin can fiber and waste glass with different ratios tests of workability, fresh density, compressive and splitting tensile strength at 7, 28, and 56 days were carried out. The outcomes of the tests have been displayed in the Figs. 6, 7, 8, 9, 10, and 11.

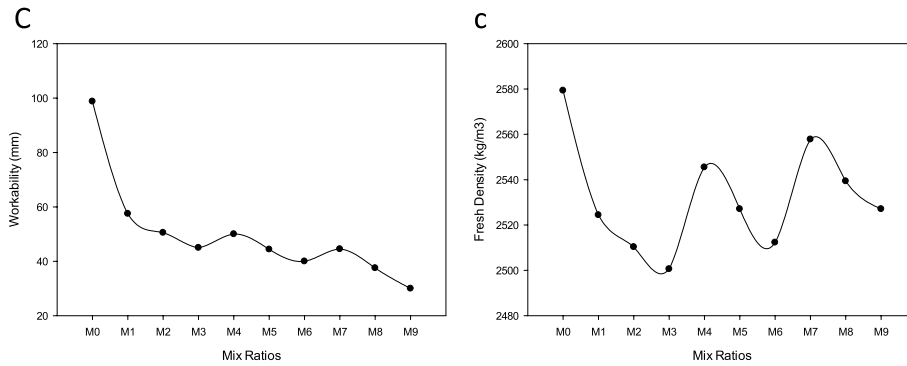




**Fig. 6** Workability (A) and fresh density (a) of concrete having TCF

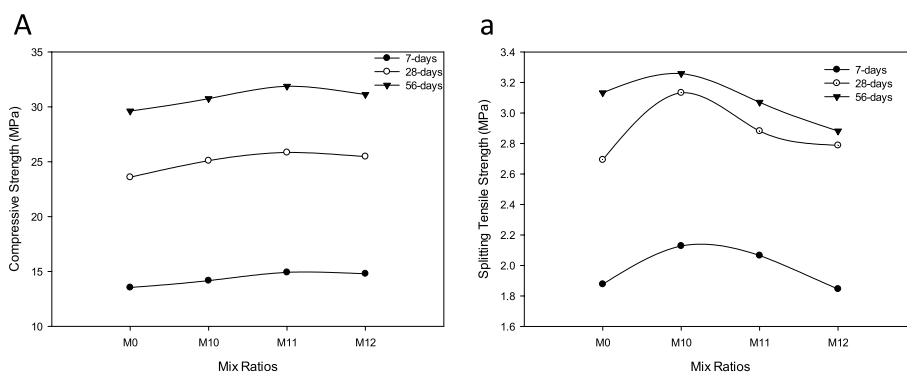


**Fig. 7** Workability (B) and fresh density (b) of concrete having GWA

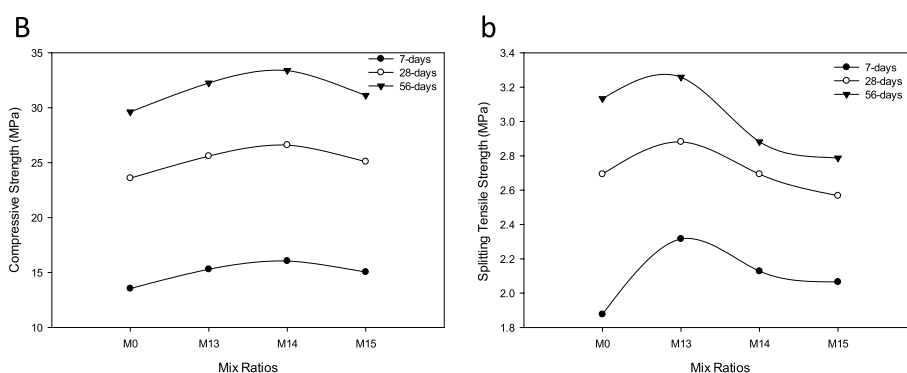


**Fig. 8** Workability (C) and fresh density (c) of concrete having TCF and GWA

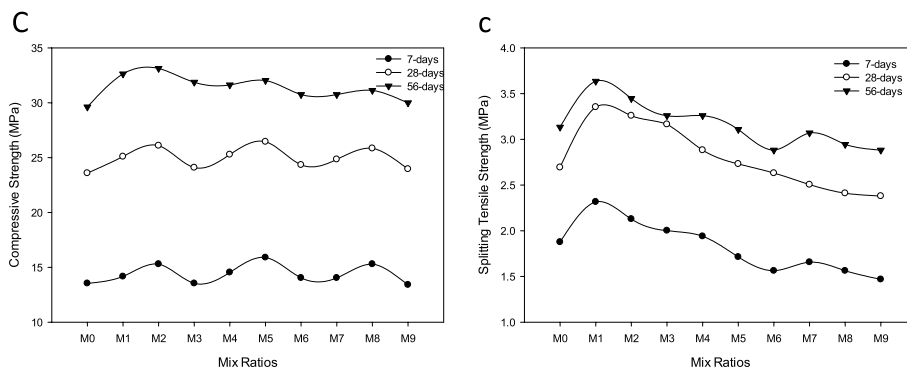
The outcomes of the workability test for incorporation of GWA and TCF are presented in Figs. 6A, 7B, and 8C. The slump height for control concrete was found 98.75 mm. In Fig. 6A, the slump height gets decreased for augmentation of TCF owing to low weight as a consequence of water absorption reduction [48]. Similar lessening of the slump height can be visualized in Fig. 7B for inclusion of GWA from 10 to 30%. This reduction of workability can be imputed to the sharp edges of GWA which lessen the fluidity of concrete mixes [2]. Conversely, in Fig. 8C, workability of all mix proportions containing



**Fig. 9** Compressive strength (A) and splitting tensile strength (a) of concrete having TCF



**Fig. 10** Compressive strength (B) and splitting tensile strength (b) of concrete having GWA



**Fig. 11** Compressive strength (C) and splitting tensile strength (c) of concrete having TCF and GWA

GWA and TCF was found to be less than control batch. The results showed that for the combination of 0.5% TCF with 10–30% GWA (from mix M1–M3), the slump value was within 57–45 mm. The slump further decreases as TCF increases within the range of GWA. According to the Fig. 8C, the combination of 0.5%TCF and 10–30% GWA showed a higher slump compared with other amounts of GWA and TCF.

Figures 6a, 7b, and 8c demonstrate the concrete’s density values immediately after mixing. Fresh density gets significantly reduced with increasing replacement of GWA

(Fig. 7b). This trend is explained by the distinction of particles density between river sand and waste glass aggregate [58]. The similar result was reported by Adaway and Wang [31], Taha and Nounu [59], Topçu and Canbaz [60] which supports the claim that fresh concrete with GWA has a smaller density than conventional concrete. Meanwhile, Fig. 6a shows an increment of density of concrete with an increase of TCF. A similar result has been obtained by Wijatmiko et al. [48]. In Fig. 8c, the range of fresh density of concrete for mixes 1–9 was observed to be from 2557 kg/m<sup>3</sup> to 2500 kg/m<sup>3</sup>. These values of the density were below the density of conventional concrete (Mix M0). Mix 7 having 10% GWA with 1.5% TCF showed highest strength in comparison with other mixes having these two variables. At any content of TCF, the decrement of density was found with the rising GWA from 10 to 30%.

The variations of concrete compressive strength having different proportions of TCF and GWA have been presented in Figs. 9A, 10B, and 11C. It can be noticed from Fig. 9A that rise of the strength happen from 13.5 to 14.9 MPa at 7-day, 23.6 to 25.9 MPa at 28-day and 29.6 to 31.9 MPa at 56-day for inclusion of TCF up to 1% but beyond this percentage the strength decreases due to diminishing of concrete's bonding strength by high amount of TCF content [47]. On the other hand, for inclusion of GWA up to 20% the strength shows accretion (Fig. 10B) owing to filler behavior of glass particles [2]. However, following 20% GWA, genesis of voids occur which resulted curtailment of the strength [2]. Moreover, improvement of strength can be seen in the graph of early stage (28 days) compared to later stage (56 days) due to silane effect that supplies more free water in the mix, that is essential to accelerate the hydration process. Moreover, the rise in the 7 days' compressive strength of glass waste concrete mixtures could be attributed to the pozzolanic effect of waste glass. Whereas, less increment of 56 days' strength might be due to reduced dispersion that lessen the hydration process [61]. Taher et al. [8] stated that decrement in compressive strength might be a result of the poor geometry of waste glass owing to a homogeneous distribution of aggregate.

The investigation from Fig. 11C reveals that the compressive strength at all ages displayed similar trends. According to the plot, the highest compressive strengths were recorded to be 15.90 MPa, 26.5 MPa, and 33.1 MPa at 7, 28, and 56 days, respectively. These maximum responses referred to the 20% GWA with 1% TCF at 7 and 28-day respectively, whereas 20% GWA with 0.5% TCF at 56 days. Overall, the 7, 28, and 56 days strength curve show similar trend.

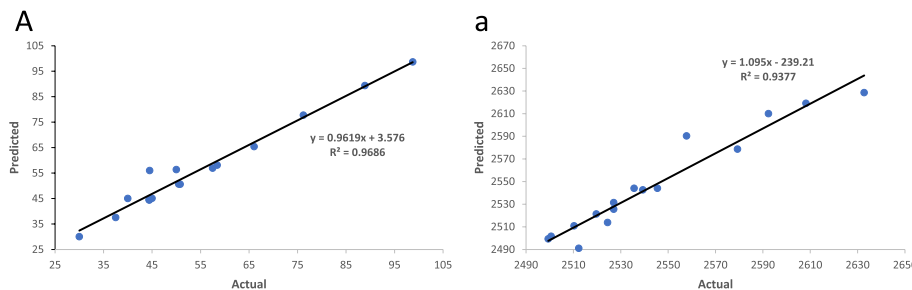
Figures 9a, 10b, and 11c demonstrate the influence of GWA and TCF on splitting tensile strength at the three ages. With the addition of 0.5% TCF, the strength increases by 1.13% at 7-day, 1.16% at 28-day and 1.04% at 56-day in comparison with control concrete (Fig. 9a). As the percentage of TCF increases after 0.5%, decrement of the strength was noticed. Whereas, in case of GWA (Fig. 10b), results observed in the range of 0–10% substitution level reflect rise in the splitting tensile strength. However, from 10% replacement of GWA, strength tends to drop due to smooth surface of glass particles [59].

The combined influence of GWA and TCF on splitting tensile strength at all ages can be seen in Fig. 11c. In comparison with control concrete, the higher strength was observed at mix 1–3 which contained 0.5% TCF with 10–30%. Turgut and Yahlizade [24] found similar higher strength than control concrete for 10–30% GWA replacement among all mixes. Mix 2 (10% GWA with 0.5% TCF) yielded the peak results of 2.3 MPa,

**Table 4** Statistical parameters of ANN models

Parameter	Workability	Density	CS-7	CS-28	CS-56	STS-7	STS-28	STS-56
<i>R</i>	0.984	0.968	0.956	0.969	0.973	0.982	0.960	0.957
<i>R</i> <sup>2</sup>	0.969	0.938	0.913	0.940	0.947	0.964	0.921	0.915
MSE	0.003	0.008	0.060	0.061	0.100	0.003	0.007	0.005
RMSE	0.052	0.088	0.245	0.247	0.316	0.053	0.086	0.073
MAE	0.025	0.056	0.106	0.094	0.131	0.023	0.065	0.029

CS Compressive strength, STS Splitting tensile strength



**Fig. 12** Actual vs predicted values of workability (A) and fresh density (a)

3.4 MPa, and 3.6 MPa at 7, 28, and 56 days respectively. The drop in the strength is mainly because to the existence of silane on the surface of the glass that could lessen the adhesion between the cement matrix and glass. Moreover, silane accelerate slippage and decrease the interlocking in the concrete mixtures [61].

**Performance of ANN models**

Back-propagation neural network having 16 neurons in one hidden layer was adopted to develop ANN model of the mentioned responses in this study. The input was divided into three sets of category in ANN where 70% were assigned for training sets and, testing and validation sets took 15% each. Table 4 exhibits the significance of constructed models in terms of *R*, *R*<sup>2</sup>, MSE, RMSE, and MAE. It can be noticed that the value of coefficient of determination (*R*<sup>2</sup>) for workability, fresh density, 7-day, 28-day, 56-day compressive and splitting tensile strength of concrete were 0.984, 0.938, 0.913, 0.940, 0.947, 0.964, 0.921, and 0.925 respectively. The values of *R*<sup>2</sup> indicate better fit of the developed ANN models as they can study above 91% of the data [62]. In all cases, correlation coefficient (*R*) values were found close to 1 indicate outstanding performance of the models [63]. The registered MSE, RMSE, and MAE values for workability were 0.003, 0.052, and 0.025 respectively which demonstrate less deviation in prediction [64]. Similar results can be seen in the models constructed for the other responses.

Figures 12, 13, 14, and 15 suggest that the developed ANN models can learn the correlation between input and output as the predicted outcomes in all models were close to that of the target outcomes. These figures also demonstrates that ANN model is adequate of simplifying between independent variables and responses variables with predictions of high accuracy [65]. From the figures, it can be inferred that the normally distributed errors in the ANN models as data were nearly distributed on straight lines [64].

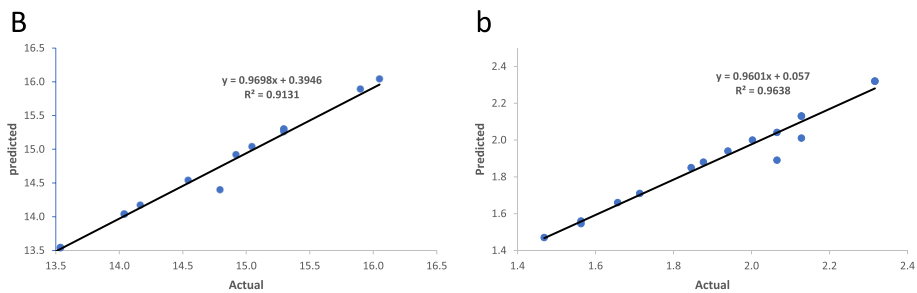


Fig. 13 Actual vs predicted values of 7-day compressive (B) and splitting tensile strength (b)

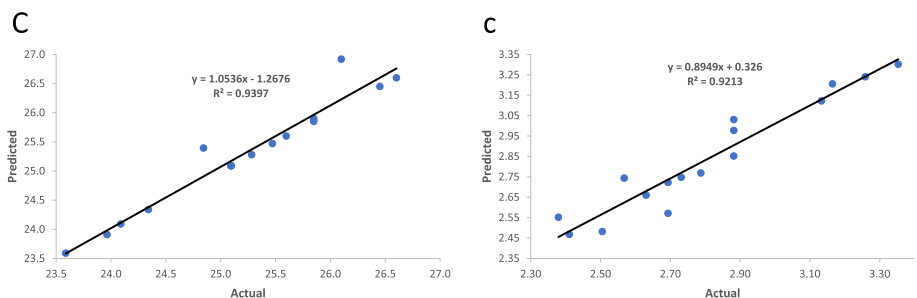


Fig. 14 Actual vs predicted values of 28-day compressive (C) and splitting tensile strength (c)

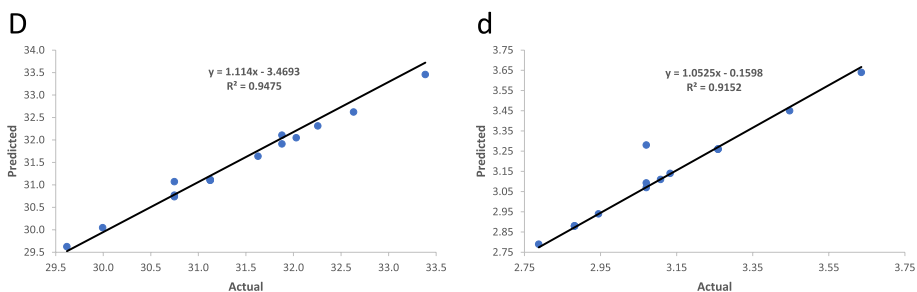


Fig. 15 Actual vs predicted values of 56-day compressive (D) and splitting tensile strength (d)

Table 5 Percentage influence of GWA and TCF on the responses

Variable	Workability	Density	CS-7	CS-28	CS-56	STS-7	STS-28	STS-56
GWA	32.62	59.69	52.62	17.13	35.67	1.26	22.56	38.49
TCF	67.38	40.31	47.38	82.87	64.33	98.74	77.44	61.51

**Sensitivity analysis of the variables**

The major objective of the sensitivity analysis was to explore the comparative influence of GWA and TCF on workability, fresh density, compressive strength and splitting tensile strength of concrete at 7, 28, and 56 days. Table 5 shows mean influence of the independent variables on the desired responses. The outcomes of sensitivity analysis seem to demonstrate that TCF have more influence than GWA on the responses except for fresh density. However, almost equal effect of both parameters can be observed in case of compressive strength at early days. Influence of TCF on the workability, 56-day compressive and splitting tensile strength was 67.38%, 64.33%, and 38.49% respectively, which

are double in magnitude than GWA. Similarly, TCF has four times importance than GWA on 28-day compressive strength and splitting tensile strength. On the other hand, GWA can be removed as its importance in predicting 7-day splitting tensile strength is close to zero (1.26%).

The above discussed results implies that inclusion of glass waste and tin fiber have positive effect on the strength of concrete. The results were verified through statistical analysis which indicate that the simulated models are authentic and can be used for navigation. Hence, the promising results for inclusion of glass waste and tin can solve the following potential problems. Firstly, protect the environment since both wastes are non-biodegradable. Secondly, reduce the demand of natural resources as excessive extraction causes serious problems on associated ecosystem, landscape, water tables, and riverbeds. Lastly, virgin lands can be saved that are supposed to be used for landfill of these waste materials.

## Conclusions

In this research, ANN models were developed for the simulation of workability, fresh density, compressive strength, and splitting tensile strength at 7, 28, and 56 days of concrete having tin can fiber and glass waste aggregate. Also, sensitivity analysis of the models was executed to investigate the relative influences of GWA and TCF on each response. However, optimization of variables as well as validation of the predicted results have not been done. To incorporate the bending effect in overall performance of concrete having GWA and TCF contents, the flexural strength could have been considered. The following conclusions have been obtained from above discussion.

- For inclusion of GWA and TCF, workability of fresh concrete have a tendency to drop continuously.
- Fresh density of concrete increases with rising TCF but decreases with rising GWA.
- Compressive strength at all ages shows positive trends till 20% GWA and 1% TCF.
- In each case of splitting tensile strength, up to 10% GWA and 0.5% TCF strength gets increased.
- The constructed models simulated the properties of concrete with good and high values of  $R^2$ . Other parameters also indicate the applicability of the developed model for accurate prediction.
- Sensitivity analysis of the models seem to reveal that TCF have more effect than GWA on the properties of concrete.

As a part of recommended future work, further research can be conducted by using various admixtures to increase workability and splitting tensile strength, which would result in sustainable concrete production.

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## Authors' contributions

Tanvir Ahmed contributed to investigation, data curation, formal analysis, establishing methodology, and was a major contributor in writing the manuscript. Ayesha Ferdous Mita contributed to investigation, and data curation, validated the resources and contributed to writing the manuscript by reviewing and editing. Sourav Ray conceptualized the research and its methodology, contributed in investigation, managing resources, supervised the project, and contributed to

writing the manuscript by reviewing and editing. Mohaiminul Haque contributed to investigation, supervision, and resource management. All authors read and approved the final manuscript.

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#### Availability of data and materials

All data and materials have been included in the manuscript.

#### Declarations

##### Competing interests

The authors declare that they have no competing interests.

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#### References

- Ray S, Haque M, Ahmed T, Nahin TT (2021) Comparison of artificial neural network (ANN) and response surface methodology (RSM) in predicting the compressive and splitting tensile strength of concrete prepared with glass waste and tin (Sn) can fiber. *J King Saud Univ - Eng Sci*. <https://doi.org/10.1016/j.jksues.2021.03.006>
- Bisht K, Ramana PV (2018) Sustainable production of concrete containing discarded beverage glass as fine aggregate. *Constr Build Mater* 177:116–124. <https://doi.org/10.1016/j.conbuildmat.2018.05.119>
- Jani Y, Hogland W (2014) Waste glass in the production of cement and concrete: A review. *Journal of Environmental Chemical Engineering*. Elsevier. <https://doi.org/10.1016/j.jece.2014.03.016>
- Mavroulidou M, Lawrence D (2019) Can waste foundry sand fully replace structural concrete sand? *J Mater Cycles Waste Manag* 21:594–605. <https://doi.org/10.1007/s10163-018-00821-1>
- Ray S, Haque M, Al Rakib K, Sakib MN, Rahman MM (2021) Experimental investigation and SVM-based prediction of compressive and tensile strength of ceramic waste aggregate concrete. *J King Saud Univ Eng Sci*
- Salahaddin SD, Haido JH, Wardeh G (2022) The behavior of UHPC containing recycled glass waste in place of cementitious materials: A comprehensive review. *Case Stud. Constr. Mater.* 17:e01494. <https://doi.org/10.1016/j.cscm.2022.e01494>
- Hogland W (1994) Remediation of an old landfill site: soil analysis, leachate quality and gas production. *Environ Sci Pollut Res Int Spec No 1*:49–54. <https://doi.org/10.1007/BF02987426>
- Taher SMS, Saadullah ST, Haido JH, Tayeh BA (2021) Behavior of geopolymer concrete deep beams containing waste aggregate of glass and limestone as a partial replacement of natural sand. *Case Stud. Constr. Mater.* 15:e00744. <https://doi.org/10.1016/j.cscm.2021.e00744>
- Ali MH, Dinkha YZ, Haido JH (2017) Mechanical properties and spalling at elevated temperature of high performance concrete made with reactive and waste inert powders. *Eng Sci Technol an Int J* 20:536–541. <https://doi.org/10.1016/j.jestch.2016.12.004>
- Oliveira LAP De (2008) Mechanical and durability properties of concrete with ground waste glass sand
- Wan Z, Chang Z, Xu Y, Šavija B (2023) Optimization of vascular structure of self-healing concrete using deep neural network (DNN). *Constr Build Mater.* 364. <https://doi.org/10.1016/j.conbuildmat.2022.129955>
- Ismail ZZ, AL-Hashmi EA (2009) Recycling of waste glass as a partial replacement for fine aggregate in concrete. *Waste Manag.* 29:655–659. <https://doi.org/10.1016/j.wasman.2008.08.012>
- Patnaik B, Bhojaraju C, Mousavi SS (2020) Experimental study on residual properties of thermally damaged steel fiber-reinforced concrete containing copper slag as fine aggregate. *J Mater Cycles Waste Manag* 22:801–815. <https://doi.org/10.1007/s10163-020-00972-0>
- Tan KH, Du H (2013) Use of waste glass as sand in mortar: Part i - Fresh, mechanical and durability properties. *Cem Concr Compos* 35:109–117. <https://doi.org/10.1016/j.cemconcomp.2012.08.028>
- Lee JS, Yoo HM, Park SW, Cho SJ, Seo YC (2016) Recycling of cathode ray tube panel glasses as aggregates of concrete blocks and clay bricks. *J Mater Cycles Waste Manag* 18:552–562. <https://doi.org/10.1007/s10163-015-0350-6>
- Sobolev K, Türker P, Soboleva S, Iscioglu G (2007) Utilization of waste glass in ECO-cement: strength properties and microstructural observations. *Waste Manag* 27:971–976. <https://doi.org/10.1016/j.wasman.2006.07.014>
- Mohajerani A, Vajna J, Cheung THH, Kurmus H, Arulrajah A, Horpibulsuk S (2017) Practical recycling applications of crushed waste glass in construction materials: a review. *Constr Build Mater* 156:443–467. <https://doi.org/10.1016/j.conbuildmat.2017.09.005>
- Afshinnia K, Rangaraju PR (2015) Influence of fineness of ground recycled glass on mitigation of alkali-silica reaction in mortars. *Constr Build Mater* 81:257–267. <https://doi.org/10.1016/j.conbuildmat.2015.02.041>
- Ahmed T, Ray S, Haque M, Nahin TT, Mita AF (2022) Optimization of properties of concrete prepared with waste glass aggregate and condensed milk can fiber using response surface methodology. *Cleaner Eng Technol* 100478
- Haque M, Ray S, Mita AF, Bhattacharjee S, Shams MJB (2021) Prediction and optimization of the fresh and hardened properties of concrete containing rice husk ash and glass fiber using response surface methodology. *Case Stud Constr Mater* e00505
- Lee G, Ling TC, Wong YL, Poon CS (2011) Effects of crushed glass cullet sizes, casting methods and pozzolanic materials on ASR of concrete blocks. *Constr Build Mater* 25:2611–2618. <https://doi.org/10.1016/j.conbuildmat.2010.12.008>

22. Chen CH, Huang R, Wu JK, Yang CC (2006) Waste E-glass particles used in cementitious mixtures. *Cem Concr Res* 36:449–456. <https://doi.org/10.1016/j.cemconres.2005.12.010>
23. Degirmenci N, Yilmaz A, Andic O (2011) Utilization of waste glass as sand replacement in cement mortar. *Indian J Eng Mater Sci* 18:303–308
24. Turgut P, Yahlizade ES (2009) Research into concrete blocks with waste glass. *Int J Civ Environ Eng* 3:203–209
25. Batayneh M, Marie I, Asi I (2007) Use of selected waste materials in concrete mixes. *Waste Manag* 27:1870–1876. <https://doi.org/10.1016/j.wasman.2006.07.026>
26. Evangelista L, de Brito J (2007) Mechanical behaviour of concrete made with fine recycled concrete aggregates. *Cem Concr Compos* 29:397–401. <https://doi.org/10.1016/j.cemconcomp.2006.12.004>
27. Evangelista L, de Brito J (2010) Durability performance of concrete made with fine recycled concrete aggregates. *Cem Concr Compos* 32:9–14. <https://doi.org/10.1016/j.cemconcomp.2009.09.005>
28. Khatib JM (2005) Properties of concrete incorporating fine recycled aggregate. *Cem Concr Res* 35:763–769. <https://doi.org/10.1016/j.cemconres.2004.06.017>
29. Wang HY (2009) A study of the effects of LCD glass sand on the properties of concrete. *Waste Manag* 29:335–341. <https://doi.org/10.1016/j.wasman.2008.03.005>
30. Yildirim ST, Meyer C, Herfellner S (2015) Effects of internal curing on the strength, drying shrinkage and freeze–thaw resistance of concrete containing recycled concrete aggregates. *Constr Build Mater* 91:288–296. <https://doi.org/10.1016/j.conbuildmat.2015.05.045>
31. Adaway M, Wang Y (2015) Recycled glass as a partial replacement for fine aggregate in structural concrete -Effects on compressive strength. *Electron J Struct Eng* 14:116–122
32. Ali EE, Al-Tersawy SH (2012) Recycled glass as a partial replacement for fine aggregate in self compacting concrete. *Constr Build Mater* 35:785–791. <https://doi.org/10.1016/j.conbuildmat.2012.04.117>
33. Park SB, Lee BC, Kim JH (2004) Studies on mechanical properties of concrete containing waste glass aggregate. *Cem Concr Res* 34:2181–2189. <https://doi.org/10.1016/j.cemconres.2004.02.006>
34. Taha B, Nounu G (2009) Utilizing waste recycled glass as sand / cement replacement in concrete 709–721.
35. Haido JH, Zainalabdeen MA, Tayeh BA (2021) Experimental and numerical studies on flexural behavior of high strength concrete beams containing waste glass. *Adv Concr Constr*. 11:239–253. <https://doi.org/10.12989/ACC.2021.11.3.239>
36. Hamada H, Alattar A, Tayeh B, Yahaya F, Thomas B (2022) Effect of recycled waste glass on the properties of high-performance concrete: a critical review. *Case Stud. Constr. Mater*. 17:e01149. <https://doi.org/10.1016/j.cscm.2022.E01149>
37. Dong W, Li W, Tao Z (2021) A comprehensive review on performance of cementitious and geopolymeric concretes with recycled waste glass as powder, sand or cullet. *Resour. Conserv. Recycl*. 172:105664. <https://doi.org/10.1016/j.resconrec.2021.105664>
38. Gencel O, YavuzBayraktar O, Kaplan G, Arslan O, Nodehi M, Benli A, Gholampour A, Ozbakkaloglu T (2022) Light-weight foam concrete containing expanded perlite and glass sand: physico-mechanical, durability, and insulation properties. *Constr. Build. Mater*. 320:126187. <https://doi.org/10.1016/j.conbuildmat.2021.126187>
39. Powezka A, Szulej J, Ogrodnik P (2020) Effect of high temperatures on the impact strength of concrete based on recycled aggregate made of heat-resistant cullet. *Mater*. 2020(13):465–465. <https://doi.org/10.3390/MA13020465>
40. Nedeljković M, Visser J, Šavija B, Valcke S, Schlangen E (2021) Use of fine recycled concrete aggregates in concrete: a critical review. *J. Build. Eng*. 38:102196. <https://doi.org/10.1016/j.jobbe.2021.102196>
41. Kumutha R, Vijai K (2010) Effect of steel fibers on the properties of concrete. *J Reinf Plast Compos* 29:531–538. <https://doi.org/10.1177/0731684408100258>
42. Mita AF, Ray S, Haque M, Saikat MH (2023) Prediction and optimization of properties of concrete containing crushed stone dust and nylon fiber using response surface methodology. *Heliyon*. 9(3):e14436. <https://doi.org/10.1016/j.heliyon.2023.e14436>
43. Ray S, Haque M, Ahmed T, Mita AF, Saikat MH, Alom MM (2022) Predicting the strength of concrete made with stone dust and nylon fiber using artificial neural network. *Heliyon* e09129
44. Gupta T, Siddique S, Sharma RK, Chaudhary S (2021) Investigating mechanical properties and durability of concrete containing recycled rubber ash and fibers. *J Mater Cycles Waste Manag* 23:1048–1057. <https://doi.org/10.1007/s10163-021-01192-w>
45. Ray S, Rahman MM, Haque M, Hasan MW, Alam MM (2021) Performance evaluation of SVM and GBM in predicting compressive and splitting tensile strength of concrete prepared with ceramic waste and nylon fiber. *J King Saud Univ Eng Sci*
46. Yoo D, Kang S, Lee J, Yoon Y (2013) Cement and Concrete Research Effect of shrinkage reducing admixture on tensile and flexural behaviors of UHPFRC considering fiber distribution characteristics. *Cem Concr Res* 54:180–190. <https://doi.org/10.1016/j.cemconres.2013.09.006>
47. Ilya J, CheowChea C (2017) Mechanical behaviour of fibre reinforced concrete using soft - Drink can. *IOP Conf Ser Mater Sci Eng* 271:1–6. <https://doi.org/10.1088/1757-899X/271/1/012079>
48. Wijatmiko I, Wibowo A, Nainggolan CR (2019) Strength characteristics of wasted soft drinks can as fiber reinforcement in lightweight concrete. *Int J GEOMATE* 17:31–36. <https://doi.org/10.21660/2019.60.4620>
49. Topçu IB, Saridemir M (2007) Prediction of properties of waste AAC aggregate concrete using artificial neural network. *Comput Mater Sci* 41:117–125. <https://doi.org/10.1016/j.commatsci.2007.03.010>
50. Ince R (2004) Prediction of fracture parameters of concrete by Artificial Neural Networks. *Eng Fract Mech* 71:2143–2159. <https://doi.org/10.1016/j.engfracmech.2003.12.004>
51. Kewalramani MA, Gupta R (2006) Concrete compressive strength prediction using ultrasonic pulse velocity through artificial neural networks. *Autom Constr* 15:374–379. <https://doi.org/10.1016/j.autcon.2005.07.003>
52. ASTM C 33 (2010) Concrete Aggregates 1 i, 1–11. <https://doi.org/10.1520/C0033>
53. Naderpour H, Rafean AH, Fakharian P (2018) Compressive strength prediction of environmentally friendly concrete using artificial neural networks. *J Build Eng* 16:213–219. <https://doi.org/10.1016/j.jobbe.2018.01.007>



54. Alshihri MM, Azmy AM, El-Bisy MS (2009) Neural networks for predicting compressive strength of structural light weight concrete. *Constr Build Mater* 23:2214–2219. <https://doi.org/10.1016/j.conbuildmat.2008.12.003>
55. Gupta T, Patel KA, Siddique S, Sharma RK, Chaudhary S (2019) Prediction of mechanical properties of rubberised concrete exposed to elevated temperature using ANN. *Meas. J. Int. Meas. Confed.* 147:106870. <https://doi.org/10.1016/j.measurement.2019.106870>
56. Getahun MA, Shitote SM, AbieroGariy ZC (2018) Artificial neural network based modelling approach for strength prediction of concrete incorporating agricultural and construction wastes. *Constr Build Mater* 190:517–525. <https://doi.org/10.1016/j.conbuildmat.2018.09.097>
57. Shojaeefard MH, Akbari M, Tahani M, Farhani F (2013) Sensitivity analysis of the artificial neural network outputs in friction stir lap joining of aluminum to brass. *Adv Mater Sci Eng.* <https://doi.org/10.1155/2013/574914>
58. De Castro S, De Brito J (2013) Evaluation of the durability of concrete made with crushed glass aggregates. *J Clean Prod* 41:7–14. <https://doi.org/10.1016/j.jclepro.2012.09.021>
59. Taha B, Nounu G (2008) Properties of concrete contains mixed colour waste recycled glass as sand and cement replacement. *Constr Build Mater* 22:713–720. <https://doi.org/10.1016/j.conbuildmat.2007.01.019>
60. Topçu IB, Canbaz M (2004) Properties of concrete containing waste glass. *Cem Concr Res* 34:267–274. <https://doi.org/10.1016/j.cemconres.2003.07.003>
61. Al-Awabdeh FW, Al-Kheetan MJ, Jweihan YS, Al-Hamaiedeh H, Ghaffar SH (2022) Comprehensive investigation of recycled waste glass in concrete using silane treatment for performance improvement. *Results Eng.* 16:100790. <https://doi.org/10.1016/j.rineng.2022.100790>
62. Duan ZH, Kou SC, Poon CS (2013) Prediction of compressive strength of recycled aggregate concrete using artificial neural networks. *Constr Build Mater* 40:1200–1206. <https://doi.org/10.1016/j.conbuildmat.2012.04.063>
63. Schober P, Schwarte LA (2018) Correlation coefficients: appropriate use and interpretation. *Anesth Analg* 126:1763–1768. <https://doi.org/10.1213/ANE.0000000000002864>
64. Nazerian M, Kamyabb M, Shamsianb M, Dahmardehb M, Kooshaa M (2018) Comparison of response surface methodology (RSM) and artificial neural networks (ANN) towards efficient optimization of flexural properties of gypsum-bonded fiberboards. *Cerne* 24:35–47. <https://doi.org/10.1590/01047760201824012484>
65. Parichatprecha R, Nimityongskul P (2009) Analysis of durability of high performance concrete using artificial neural networks. *Constr Build Mater* 23:910–917. <https://doi.org/10.1016/j.conbuildmat.2008.04.015>

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