Development of Forecasting Model for Prediction of Compressive Strength of Foamed Concrete using Density with W/C ratio and S/C ratio by the Application of ANN

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Abstract. This Artificial neural network study presents the prediction model for a cellular foamed concrete. Foamed Concrete is a cementitious material that should consist of a minimum of 20% of foam, which is mechanically entrained using the mechanical generator of foam. Foamed Concrete possesses a cellular microstructure. By which they become a highly air-entrained system having unusual physical and mechanical properties. It is the perfect mixture of cement, water, sand (fine aggregate), and perforated foam. Published information related to the prediction of foamed concrete is limited, and rational guidelines to evaluate the compressive strength of the concrete are not widely available. This study aims to encourage the strength of foamed concrete economically and predict the strength in the compressive form of concrete. A dataset of 153 instances having an input parameter proportion of Density, W/C ratio, & S/C ratio have been taken to predict compressive strength to elevate and expand the precision and accuracy of the foamed concrete. The data has been trained with the help of ANN, in which we conduct a network analysis to forecast the compound's performance and stability. The deficiency of strength of foamed concrete is to be sorted out with the help of ANN, and the prominent and reliable equation for the compression power is generated. ANN helps to optimize the compressive strength at the time of physical casting of the concrete.

Keywords: Foamed Concrete, W/C ratio, S/C ratio, ANN, Compressive strength

1. Introduction

Conventional Cement Concrete is a broadly used substance, has immense segregation and deformable property compared to other materials. In the infrastructure industry, the use of concrete has been increased. Concrete is heavy due to the weight of coarse/fine aggregates, which adds majorly to its compressive strength. Hence, Foamed Concrete is used to make it less heavy than conventional concrete and attain significant compressive strength to make the structure reliable and effective. Foamed Concrete doesn't use a large volume of coarse aggregate; only fine aggregate and significantly lighter foamed material are used with cement and water. In a foamed mortar, 25% of preformed foam is added to make it light and durable [1–3]. The efficiency of Foamed Concrete remains the same
when tested for its compressive strength. The preformed foam is either a mixture of synthetic or protein-based. The addition of preformed foam into a control mix lowers the density of concrete and increases the yield strength. Mainly [4–6], there are two types of foam introduced in the foamed concrete:

i. Wet foam is generated by spraying an agent (usually synthetic agent) solution and the water content over a fine mesh. This procedure causes a severe pressure drop across the mesh allowing air to be sucked from the atmosphere to equal the pressure. This equalization method causes the solution to expand into it, and the best it can be termed as foam which gives a similar glimpse of the bubble bath foam. These bubbles are in a size of 2-5 m. it is not recommended to produce low-density concrete (below 1100kg/m3). Further, it is not recommended for pumping and pouring at a significant height or depth [7–9].

ii. The same process of wet foam is used to generate dry foam, but it is processed through a series of high-density mesh while forcing compressed air into a chamber of mixing simultaneously. It expands the chemical solution into a thick, tight foam, appeared as same as shaving foam. This type of dry foam has a bubble size of less than 1mm in dia. These foam types are most suitable to produce foamed concrete [10,11].

Foamed Concrete reduces the overall weight of the concrete and provides high workability, which aids in the economic construction of the concrete structure. With the appropriate design of foamed concrete, we can easily produce the concrete in a density ranging from 300 kg/m3 to 1600kg/m3. Another parameter mainly seen as the primary cause of the effect is the W/c ratio (water-cement ratio) & S/C ratio (sand-cement ratio) in the foamed concrete. It is usually seen that the sand proportion in the foamed concrete is increased to make the foamed concrete cheaper [12–14]. For a lower density foamed concrete, the proportion of sand is adequately maintained due to problems related to mixing segregation and the stability of the concrete. Simultaneously, we also have to look into a W/c ratio that is mainly responsible and has a significant role in attaining the appropriate strength when the final concrete settlement. The water content requirement depends upon the constituent we are using, and sometimes we also use the admixtures as per the requirement of the condition. Water content is also governed by the mix design's uniformity, stability, and most critical consistency. The previous research shows that the lower water content cause stiffed foamed concrete in the initial period and causes the bubble to break. The slurry could become more thing to carry the bubbles of form and cause the segregation of the sand and cement content from the slurry. The foaming agent will also not work as per the desire. The high water content also removes the foaming agent from the slurry, making it denser than desirable. The water-cement ratio recommended may vary between 0.4 to 1.25, or it is in a range of 6.5% to 14% of target density [15–17].

The specific reason behind the strength of foamed concrete is the amount of sand used per cement content. Formed Concrete strength is obtained by the exothermic reaction in the presence of water content. The reason behind the density of foamed concrete is dependent on the amount of foam introduced.

So, this work aims to use the experimental test result data sets to develop the ANN (Artificial neural network) model to predict the compressive strength of foamed concrete. There are very few researchers in the past decades that have implemented the work on predicting the compressive strength of foamed concrete.

Some researchers concluded that the w/c ratio and the s/c ratio, and the curing age would be the main significant parameters to defend the compressive strength of Concrete. In this passing decade, ANN has become a role model in data implementation and prediction analysis. We can train and test the data with the help of ANN tools. The ANN has been used to predict compressive strength, bond strength, categorical curing strength, shear capacity, etc [18–20].
In recent years, it has been seen that the ANN has been extensively used for solving the most challenging problem related to numerical and analytical identification. The researchers proposed several results to show how efficient the ANN is for civil engineering work. So, in this analytical paper, we investigate the data through ANN, a generalized feed-forward multi-layer perceptron [21–23].

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In recent years, it has been seen that the ANN has been extensively used for solving the most challenging problem related to numerical and analytical identification. The researchers purposed several attachments in which they have shown how much the ANN can do efficient work in field of civil engineering.

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2. Modelling and interpretation technique

2.1. ANN (artificial neural network)

Neural network is based on the working of neurons of the human body. This method of network correlation is inspired and adapted by human brain behaviour. Despite knowing that the biological nervous system is different from the smart algorithm, but the aim and dedication of scientists and researchers have been shown the astounding and sophisticated result. By which the determination and analytical performance have been processed without any difficulty.

ANN can be trained to perform a particular function by adjusting the value of connection of an element. Performable data from the training source should be adopted for the target part. The network will be adjusted by comparing the target and the output values by the correlation performance. Neural networks are totally trained and fully adopted to solve the most challenging and complex functions in the various field, which are difficult to be done by the normal computer algorithm or by human intellectuality, see figure 1.
Before the interpretation of modelling data, the layer should be allotted based on the Training-testing ratio. ANN is the multi-layer network, which says that they used to feed forwarding to embody all the different layers. There are particular layers; first, the input layer was put in a predilection for the data interpretation to localize the data in the network. Second, the hidden layer is stationed between the input and output layer. The hidden layer is known to execute the nonlinear transformation of provided input from the data lexicon. At last, the output layer is prominently responsible and has the accountability of the algorithm to get the desired result. In today's world, performing the analysis more conveniently and done with the help of previously compiled data of an ANN has become a significant step.

In this ANN model, we are analyzing the data by using the regression analysis method. The task was based on purpose and selection. The first is to determine the input parameters or independent variables, mainly achieved by the correlation analysis between each non-dimensional parameter. After that, the regression method has been applied to the dataset. Regression analysis is a statistical activity in which a set of data is implemented to correlate the independent variable set (also termed as predictor) and the dependent variable set (also called outcome or response variable). We compute the utmost complex linear and nonlinear combination that most closely arranges the data as per specific mathematical criteria.

\[ \tau_b = (A + B \rho + C \beta + D \rho + E \gamma + F \delta + G) \sqrt{f'c} \]

Regression analysis is perfectly able to determine the relationship between the variables. The two types of variables are used in the analytical approach first is the dependent variable and the second is the independent variable. In the study, there should be two or more two independent variables. But the dependent value will always be depending on the associated data of the independent variable. The multiple linear regression analysis has been going to perfume in this data set to predict prominent equations which will be used further in the industry and the field of civil engineering to achieve a better compressive strength of foamed concrete in the final settlement days.

MLR and NT have been showing very astonishing results in the prediction of the dataset in various fields. Many researchers in the past have used the MLR and NT to perform analysis of the data set. To accomplish the MLR analysis in this study for computation of ideal expression. We are using prominent software in the field of statistical and analytical interpretation, NEURAL DESIGNER and MINITAB. The neural designer is the highly advanced software for the approach of ANN. Neural designers are highly competent software specially used for data mining or discovering complex relationships. It is mathematically ordered to perform like brain function that can be trained to perform tasks such as function regression, pattern recognition, time-series prediction, or auto-association. As of now, so many researchers working in machine learning and data science are using this software to focus on mathematical algorithms or programming techniques. MINITAB. MINITAB is intended mainly for the statistical approach and mathematical computing, consisting of a large algorithm section. MINITAB provide us a lively environment where we can efficiently work for innovation and research purpose. It gives a very desirable and effective result.

In this study, we develop a Neural Network classification model to showcase all the standard elements. We perform the multiple linear regression in prediction modeling to target the desired output with a high prediction rate. The contour graph between the variables is plotted to show the relationship between the fluctuating output parameter (compressive strength) and input parameter (density, W/c ratio, S/c ratio).

2.2. Data interpretation and processing

The ANN model proposed in this study is used to predict the compressive strength of foamed concrete through a given data set. This is experimental data that we have shown and implemented in this study. There are a total of 153 instances of data set that mainly contained proportion of standard value used
to find the compressive strength of foamed concrete. In the analytical data performance, the dataset carried the prominent standard parameter used for foamed concrete prediction: density, water to cement ratio [W/c] ratio, and sand to cement [S/c] ratio. The sample of data set was constantly made up of ordinary Portland cement, water, sand, and the preformed foam (25%) and as per the standard following by IS code, the curing has been set up for 28 days after that foamed concrete has been tested, see figure 2.

| Density | w/c | s/c | Compressive strength |
|---------|-----|-----|---------------------|
| 2055.6  | 0.3 | 0   | 51.17794062499998  |
| 1969.59999999999997 | 0.3 | 0   | 46.50905312499994  |
| ...     | ... | ... | ...                |
| 1519.11 | 0.45| 2   | 11.48              |

Figure 2. Parameters and their instances

This table shows the data set obtained. Here the no. of columns is 4, and the no. of sample is 153. Here are the 153 instances in which density water-cement ratio and the sand-cement ratio will be in an input layer; we can say that these are the independent variable used to check the effect on compressive strength and used to obtain an ideal equation of foamed concrete strength, similarly the hidden layers the mathematical algorithms set up by the developer, as the name represents it is being hidden over the time, but the interpretation process will be in continuation at the backend of hidden layers. Similarly, the compressive strength is our output for which this study has purposed, see figure 3.

A graphical representation of the resulted deep structure is depicted next. It contains the following layers:
- Scaling layer with 3 neurons (yellow).
- LongShortTermMemory layer with 3 neurons (green).
- Perceptron layer with 1 neurons (blue).
- Unscaling layer with 1 neurons (red).
- Bounding layer with 1 neurons (purple).

Figure 3. Network diagram of parameters (Input and output)

Three different learning schemes are recommended for the implementation of the neural network prediction model. There is the ratio of training-to-testing data, which generally creates a difference
between the learning schemes. We considered the balanced 50:50 ratio and two offsets of 5 lower and 5 higher instances to train and test the data.

Various parameters are divided into mandatory and non-dimensional parameters as shown below.

1. Mandatory input parameters call raw data: like we always go through the standard design mix procedure given by the specific country code of general specification worldwide, weight per cubic meter is always calculated and used for the raw data. So, in this study, we are not approaching through the use of raw data.

2. Non-dimensional input parameters: These are the data that are not raw data for the mix design but carrying the standard parameter by which we can easily calculate and interpret the mix design. Density, W/c ratio, S/c ratio derived from the raw data (the non-dimensional parameters) will be used for the ANN analysis as the input layer.

3. Output parameter or dependent variable: the parameter we seek to achieve through this analytical study is that the 28-days compressive strength of Foamed concrete was termed the output parameter for ANN and the dependent variable for regression analysis.

The data must contain the variables for the higher prediction rate and to find the ideal equation through regression. Regression can give the best from the waste instances but the condition must be satisfied that the instances have the appropriate variable as good as variables are there in the data, the result will be as good.

So, the table -1 shows the difference between variables. The chart is showing the minimum and maximum values of the parameter. And also, the mean and the deviation of input parameters.

| Table 1 | Minimum and maximum values in instances |
|---------|----------------------------------------|
|         | Minimum | Maximum  | Mean   | Deviation |
| Density | 444     | 2009.48  | 1517.81| 445.701 |
| W/c     | 0.3     | 0.83333  | 0.42556| 0.12594 |
| S/c     | 0       | 4.29333  | 0.95488| 0.72290 |

In this chart, the minimum density, W/c ratio, S/c ratio are 444, 0.3, and 0, respectively. Similarly, the maximum imposed values for the same parameters are 2009, 0.833, 4.29, respectively.

2.2.1. The directional output of data interpretation. It is imperative to see how the output varies as a single input function when all others are fixed in the data interpretation. We can easily observe a particular fitted line graph for each substance concerning compressive strength, see figure 4 and 5.

![Figure 4. Compressive strength-Density directional output](image-url)
So, in this study, we are purposing this data for NLR analysis, and we'll show what outcome we will get after the implementation of layers in the analytical analysis. The coefficient and variance for the output are also driven by the same relevant dependent and independent variable, see figure 6.

3. Result and discussion.

The data has been collected and processed for training, testing, and validating the model in this study. ANN and MLR have been used to generate the prediction model by interpreting the dimensional and non-dimensional parameters as our input and the 28 days foamed concrete compressive strength as the output. The 153 instances have been used to implementing and execution of the analytical study. The result is shown based on 153 foamed concrete data set. The minimum and maximum value have been discussed above.

NLR (Nonlinear regression) models were developed in the form of equation with coefficients for the parameter and constant. Performances of each model developed using the technique as mentioned above we compared. NLR technique in the study of ANN shows better output than the MT (model tree) technique used in the ANN, see table 2.
After all the certain procedures of training and testing of data. The residual graph was showing the statistical graph on the basis of four criteria,

1. Normal probability plot: it is said to be a graphical technique used to identify the substantive departure from normality. In normal probability, the value which were selected to make the resulting vs the sorted data are approximately distributed.
2. Histogram graph of frequency vs residual.
3. Versus fits and versus order.
All the graph shown in a figure 7 has drawn by the use of 153 instances of foamed concrete.

After implementing the regression analysis, we have got the value of the coefficients for compressive strength with respect to different parameters. The regression coefficient describes the size and the direction of the relationship between the independent variable (predictor) and the response/dependent variable. The coefficient is the number that will be used as the value multiplied in

| Term  | Coef  | SE Coef | T-value | P-value | VIF |
|-------|-------|---------|---------|---------|-----|
| Const  | -12.07 | 2.67    | -4.52   | 0.000   | 1.58 |
| Density | 0.03085 | 0.00108 | 28.49   | 0.000   | 1.40 |
| W/c   | -12.38 | 3.61    | -3.43   | 0.001   | 1.40 |
| S/c   | -6.249 | 0.578   | -10.82  | 0.000   | 1.19 |

Table 2. Coefficients value of compressive strength

Figure 7. Residual plot for compressive strength
the regression equation. Similarly, the SE coefficient is showing the standard error in the estimation of variability between coefficient estimates.

T-value in the chart measures the ratio between the coefficient and standard error. P-value is a probability that measures the evidence against the null hypothesis. Lower probabilities provide more substantial evidence against the null hypothesis, see figure 8.

| VIF   | Status of predictor |
|-------|---------------------|
| VIF = 1 | Not correlated     |
| 1 < VIF < 5 | Moderately correlated |
| VIF > 5  | Highly correlated   |

**Figure 8. VIP-status of predictor table**

VIF (variance inflation factor) table shows the collinearity and the inflation of variance of a coefficient due to the correlation among the predictor in the model, see figure 9.

**Figure 9. Pareto chart of the standardized effects**

ANN has an advantage by which we can get the relations between all the performed components, including input and output tuning with the technology. The Pareto chart is a quality chart of isolated data that helps recognize the most significant defect existences. Pareto chart also gives the value that mainly affects the compressive strength through the response of every instance used to predict which
ingredient is very prominent for compressive strength and which compound presence does not affect the compressive strength of concrete.

After all the proceeding of substantial data and the implementation and execution of processing data, we have generated the output of our compressive strength of foamed concrete in the face of the equation through multiple regression analysis. It will help to equate the data before implementing concrete in the industry by which we will get the desired amount of strength for foamed concrete.

**Regression Equation**

Compressive strength = -12.07 + 0.03085 Density - 12.38 w/c - 6.249 s/c

**Figure 10.** Regression equation for compressive strength of concrete

ANN has an advantage by getting the relations between all the performed components, including input and output tuning with the technology. The Pareto chart is a quality chart of isolated data that helps recognize the most significant defect existences. The Pareto chart also gives the value that mainly affects the compressive strength through every instance used to predict. That ingredient is very prominent for compressive strength and which compound presence does not affect the compressive strength of concrete, see figure 10.

Important formulae used to calculate the mix design:
The density can be expressed as
\[ p = \frac{m}{V} = \frac{1}{v} \]

Density = C+W+S
Water content = W/c × C
Sand content = S/c × C

Where:
• \( p \) = density \([\text{kg} / \text{m}^3], [\text{slugs} / \text{ft}^3]\)
• \( m \) = mass \([\text{kg}], [\text{slugs}]\)
• \( V \) = volume \([\text{m}^3], [\text{ft}^3]\)
• \( v \) = specific volume \([\text{m}^3] / [\text{kg}], [\text{ft}^3] / [\text{slug}]\)
• Conversion: 1 kg / m\(^3\) = 0.624 lb. / ft\(^3\)

After all the proceeding of substantial data and the implementation and execution of processing data through multiple regression analysis, we have generated the output of our compressive strength of foamed concrete in the form of the equation. It will help to predict the compressive strength of foamed concrete, see figure 11.

**Model Summary**

|     | S   | R-sq | R-sq(adj) | R-sq(pred) |
|-----|-----|------|-----------|------------|
|     | 4.78613 | 89.58% | 89.38% | 89.20% |
The regression equation generated by using 153 instances of different parameter for computing compressive strength of foamed concrete seems to be 89.20–90% accurate. It means the equation generated will become prominent for the computation of compressive strength for foamed concrete.

3.1. Contouring of different parameters

Contouring is a unique technique to show a three-dimensional change or view in two dimensions. It is a simplifying technique to represent spatial data. All types of activities (data preparation& execution, selecting contour intervals, interpolating, and gridding) is performed by the contouring. The dataset of 153 instances of different parameters of foamed concrete has been used to plot the contour. It is an implementing and observing process. We can see the change in the targeted parameter (can say dependent variable) by specific changes in the independent variable value. So, we have plotted a contour of compressive strength on behalf of density, W/c ratio, S/c ratio. This contour graph plotted by the color-ranging layers will show the compressive strength range in the different regions of W/c ratio and S/c ratio. We can see that at every point of graph the value of W/c ratio and S/c ratio are fluctuating and by the help of the table of compressive strength shown in figure 12 we can easily target the compressive strength. For e.g., the compressive strength ranging between 40-50Mpa will be plotted with the dark green colour by which we can easily check the value by observing the graph. Like 40-50Mpa will be achieved when the w/c ratio will be between 0.38 to 0.42 and S/C ratio will be between 0 to 0.1.

Similarly, the surface plot with used to display contour, which creates the three matrices hyphenation. The contour and the reliability of the contour will remain the same. It is a three-dimensional data set. It clearly defines the functional relationship between the X, Y, & Z parameters, see figure 12.

Thus, the prediction models for the ideal composition of foamed concrete and plotting of contour for the correlation of different parameters were developed.

4. Conclusion

This paper has presented the research conducting for developing a predictive model through ANN for the prediction of compressive strength of foamed concrete. Particularly, this paper has represented the nonlinear correlation between the input activation at the layer used for the predictive model. The ANN architecture has been taken into a step to develop the model, which will have high accuracy and low complexity to solve the problem related to compressive strength. It will be efficient and less time-consuming too. The studied carried out to predict the 28 days compressive strength by using 153 instances dataset of foamed concrete carrying the standard dimensionless parameters W/c ratio & S/c
ratio with the density of foamed concrete. Multiple linear regression (MLR) technique has been used to developing the predictive model and generate a prominent equation for the compressive strength of concrete. All the statistical graph method has been used to plot the contour between the parameter, which will help later to assure beforehand of compressive strength. substances.

1. A neural network trained and tested with the raw data of 153 instances carrying the proportion of dimensionless parameters. All the input parameters are used to create the architecture of ANN to predict/compute the prominent equation.
2. Directional output of data, Pareto chart, a residual plot for compressive strength, Prediction equation, Prediction rate of model, contouring graphs for compressive strength of foamed concrete all has been clearly shown and described in this study.
3. ANN will help predict the output with minimum no. of instance, which will help grow our infrastructure industry and make it more sustainable by using the ANN (Artificial neural network).
4. The prediction trend through ANN has been flying in the clouds because of their efficient output and reliable prediction. It is dominating the field of engineering also. Every engineering field is now adopting ANN to carry forward their relevant achievement and make it better, as our civil engineering is doing the same.
5. ANN model dominates over the other technique used for prediction technique in the term of accuracy and reliability.

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