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Strength characterisation of self cured concrete using AI tools

T. Udaya Banu [a], N.P. Rajamane [a], P.O. Awoyera [b], R. Gobinath [c]

[a] SRM Institute of Science and Technology, Chennai, India
[b] Department of Civil Engineering, Covenant University, Ota, Nigeria
[c] Department of Civil Engineering, S R Engineering College, Warangal, Telangana, India

A R T I C L E I N F O

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A B S T R A C T

Civil engineering experimentation process is termed to be a costly process when it involves destructive testing of materials to obtain their strength and durability. Testing of materials through destructive process is century old procedure, but recent decade science involves the prediction of strength and durability using alternative methods. One such method to predict the strength in nondestructive method is employment of Soft computing technologies, this process is gaining impetus in the recent decade due to its accuracy, reliability, and versatility. In this research, we had employed artificial intelligence tool to predict the compressive strength of concrete with available real time laboratory-based data. AI tools require a greater number of data to predict the results but in this work and attempt is made to predict using a smaller number of data with more accuracy. Compressive, flexure and tensile strength of concrete is predicted using ANN techniques (Levenberg-Marquardt (L-M) process and Bayesian regularization (B-R)). Two input parameters were only employed to check the real time accuracy with a model that has 12 input layers and 18 hidden layers incorporated. Model output shows regression values of 0.97428, 0.92865 and 0.96772, concerned with L-M algorithmic model and 0.96573, 0.95625 and 0.91787 for B-R based model. Also, its observed that while using L-M algorithm the best performance was obtained at 1.3287 at epoch 2 for compressive strength and 0.12417 is achieved at epoch 1 for tensile strength and 0.021578 at epoch 3 concerned with flexural strength. Also with B-R algorithm provided best performance of 2.1488 at epoch 4 for compressive strength, a value of 0.43468 at epoch 3 for flexural strength and 0.015279 for tensile strength reached at epoch 30. Thus we propose the usage of ANN even with less number of data using this method for predicting the values of compressive strength of concrete.

1. Introduction

Due to rapid urbanisation and the increased demand for commercial spaces construction industry is growing rapidly across the globe. This tremendous growth in the industry had put lot of pressure on the resource utilisation pattern that is used for construction. Concrete is the most widely used construction material which had undergone large amount of change in the ingredients used, method of preparation and also the admixtures employed to customise the concrete strength and durability. Researchers had studied the impact of using many materials including waste materials as concrete ingredients and admixtures (conventional and non-conventional). Bountiful research works clearly conveyed that properly utilising the waste materials is need of the hour and concrete provides a solution for the same [1–4]. This also avoid overloading the landfills which are normally used to dump those waste materials and reduce the cost of construction of landfills too. Also, recent research works had proved that this materials can be utilised either partially or fully replacing binder (cement) or fillers (aggregates) in any proportions, many materials were tried by several researchers that are proved to be viable supplementary materials.

Also, due to the shift that occurs from conventional to non-conventional cementitious materials usage of clay based materials is upcoming and gaining impetus in tandem with industrial waste materials like silica, ground granulated blast furnace slag, fly ash, bottom ash, pond ash, silica fume etc in concrete. Silica fume is an efficient industrial by-product that is very fine in nature and

E-mail address: paul.awoyera@covenantuniversity.edu.ng (P.O. Awoyera)

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has excellent pozzolanic nature that can be utilised to enhance the mechanical properties of concrete [5–9]. It has higher specific area, and other properties that makes it a viable admixture for enhancing concrete properties, but the workability of concrete will get decreased with the increased content of Silica fume. In this work we had added silica fume as an admixture in addition with a specific super plasticizer to increase workability and found that it increases the hardened concrete properties with increasing content of Silica fume [9–11]. Also recycled aggregates were used in this study for production of concrete, our target is to reduce wastage of materials through recycling the same. The major issue faced by several researchers is to reconduct the studies using different materials and testing the same for strength and durability which involves multiple attributes and parameters which controls the quality of concrete.

Some of the parameters that influence the production and quality of concrete includes nature and type of cement used, quality of aggregates (coarse and fine), properties of water used, water-cement ratio used, type of superplasticiser used, admixtures nature etc. Outcome of the concrete in terms of strength is defined by compressive and tensile strength of concrete which are two major properties agreed worldwide concerned with structural performance of any concrete [2,7,12,13]. Compressive and tensile strengths were obtained by crushing the concrete cylinders and cubes in compression testing machine after curing them for standard period (7, 14, 28, 56 days). Also, several non-destructive testing procedures were evolved in last few decades like Rebound hammer test, UPV test etc that gives the density, coherence and strength of concrete without crushing the sample. But the empirical solutions and equations available in various standards and codes are applicable only for conventional method of concrete testing and not suitable for NDT and other non-conventional testing process which adds more burden in evolving real time field strength of concrete produced. Conventionally concrete strength is predicted using maturity concept of concrete or by water-cement ratio rule yet newer avenues are emerging including modelling techniques which predict the strength by using the inter-relationship between the input parameters or influencing parameters.

To predict the strength of concrete many researchers had adopted techniques like mechanical modelling, statistical modelling, and analytical model, some also used Artificial neural networks which is an emerging concept [12,13]. Many researchers also used specifically designer statistical models including Multiple Linear Regression models (MLR), among this artificial neural network has numerous engineering applications and used to predict strength and durability nature of concrete. Artificial Neural Networks (ANN), also simply denoted as Neural Networks (NN) are modelling systems that is inspired by human brains biological neural networking system and imitate them exactly. In simple, an ANN is based on a collection of interconnected nodes or units which are termed as artificial neurons. They predictably model the neurons of the biological brain of a human being and in that each connection can receive a signal then process it and can also signal next neuron interconnected to it. The word "signal" is used in context of transformation in terms of real number and also the output of each neuron will be computed by using non-linear function of the sum of the related inputs. In ANN, the connections were called as edges, neurons and edges typically hold a weight that will be adjusted when the learning proceeds. The allocated weights either increases or decreased the signal strength at the connection, a threshold limit for the signal can also be fixed. Also, neurons are aggregated into different layers which may perform different transformations on their respective inputs. Generally, signal will travel from the first layer which is called as input layer towards the last layer called as output layer after traversing various layers multiple times. In this research, we had employed one such ANN based model to predict the compressive strength of self-cured concrete. We had employed a feed forward network in ANN to predict the compressive, tensile and flexural strength of concrete using experimental data as input values. Samples were casted in the laboratory, tested for the strength using various compositions of concrete and the results obtained was used in real time to predict.

2. Materials and methods

2.1. Materials

Throughout this study materials used were obtained through standard sampling procedure, binder used is Ordinary Portland cement with 53 grade which is stored and used as per standard codal provision. The specific gravity of cement is found to be 3.15 and the aggregates used in the study are obtained from local suppliers (crushed stone and river sand). Coarse aggregate is non flaky in nature and have a specific gravity of 2.62 obtained from basalt rock, the sand is passed through 4.75 mm IS sieve and has a specific gravity of 2.71. To increase the fluidity of concrete super plasticizer Conplast SP 430 was added at a rate of 5 ml/kg of cement. For self-curing implementation PEG 400 granules were used in this study which is obtained from local chemical shop in gel format and is used throughout the study. All the materials were stored in a dry condition and the water used in this study is free from hardness and passed through zeolite filters to remove hardness before mixing. Table 1 shows the materials proportion. For all testing Indian standard testing procedures were used (BIS standards).

2.2. Methods

Experimental results obtained is compared with the output from soft computing technique (ANN) to ascertain the accuracy of AI tools in predicting the strength characteristics of concrete. Artificial neural networks is a procedure or technique which comprises of certain dependent components (elements) which can provide solutions for complex engineering problems. We had employed ANN in this work and for generation of code MATLAB 2019b version is used with prebuilt code for L-M algorithm and B-R regularisation algorithm. Fig. 1 depicts the flow chart using in this study concerned with ANN implementation and the training of the neural network is done with more weights assigned for input parameters that deemed to be controlling the strength. Multiple training were done to increase the accuracy of the prediction using looping process by continuously varying the weights of the nodes assigned.

3. Results and discussion

3.1. Compressive strength

Considering strength and durability aspect of concrete in view, it is clearly evident that compressive strength of concrete plays vital role and holds more importance. In this research, main prediction is focusing on obtaining the compressive strength of concrete by using ANN. For the model development the input parameters were obtained from the laboratory compressive strength study after several curing days were supplied as input into the input layers of ANN. This work primarily focusses on predicting using limited data because compressive strength of concrete is a costly affair since it is obtained by crushing the concrete in laboratory. The total available data is split into three parts and in that 70% is used for training the model, 15% for testing the model and remain-

Table 1
Materials proportion.

Constituent	Cement (kg/m^3)	Water (liters)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	W/c ratio
Quantity	399	191.6	1127	673	0.48

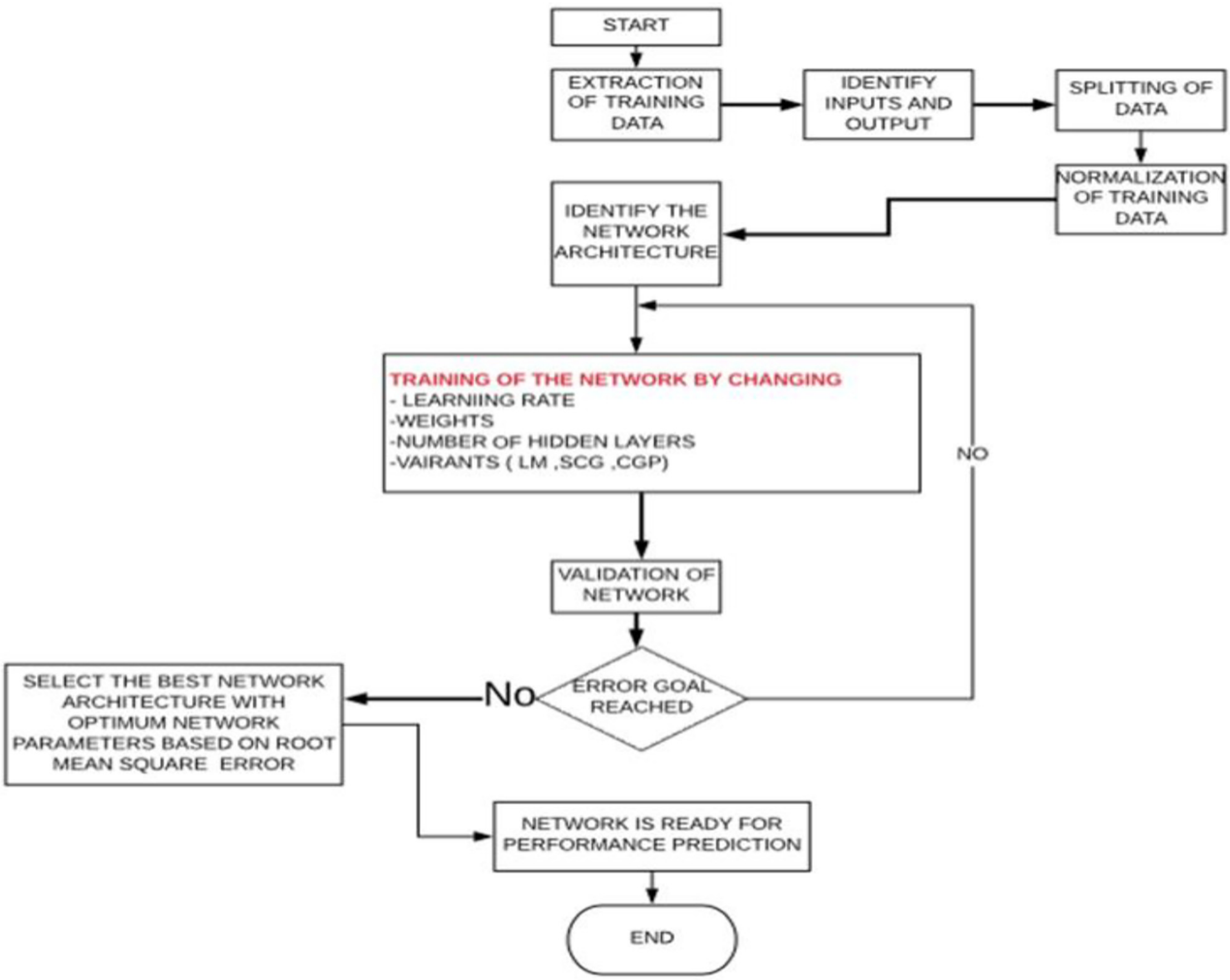

Fig. 1. Flowchart for using ANN in MATLAB.

ing 15% for validating the model. A value of 0.97264 and 0.97661 was obtained concerned with coefficient of regression values with training dataset for LM and BR algorithms respectively. Fig. 2 depicts the data that was obtained based on BR algorithm in which Epoch of data relies on Bayesian regularization algorithm. Also Fig. 4 depicts similar data obtained using LM algorithm, where the epoch of the data is based purely on LM algorithm as shown in Fig. 5. An overall compressive strength based regression value obtained was 0.97428 and 0.96573 respectively for LM and BR. Interestingly in this study it's found that these models used which has high regression values are predicting the concrete compressive strength with near accuracy correlating with experimental data. Also, the validation performance of the BR and LM algorithms were found to be 1.387 at epoch 2 and 2.1488 at epoch 4 respectively. In spite of the miniscule differences shown in the individual values of regression concerned with training, testing and also validation of both algorithms, it is found that LM algorithm gives better results with good overall regression. There exist small differences concerned with individual regression values pertaining to the training, testing and validation data for the both algorithms, yet we had received a good overall regression value for LM algorithm and its recommended for prediction (see Fig. 3).

3.2. Tensile strength

Concrete and components manufactured using it is strong in compression but it proved to be a weak material in absorbing tensile forces and hence it become mandatory to predict tensile strength to understand the life span of structural components. We had prepared multiple specimens of concrete in the designed proportions, cured it with internal curing agent and also added supplementary cementitious materials to enhance durability. All the specimens were cured for a period of 14 and 28 days before testing, they were wiped off clearly with dry cloth and tested in compression testing machine as per Indian code provisions. The obtained results were used as input parameters for ANN to create the LM and BR model using algorithms. Fig. 6 depicts the model output obtained using BR algorithm and the epoch of the same is based of Bayesian regularisation (Fig. 7). Fig. 8 conveys the output of LM algorithm-based data in which the epoch of the data is based

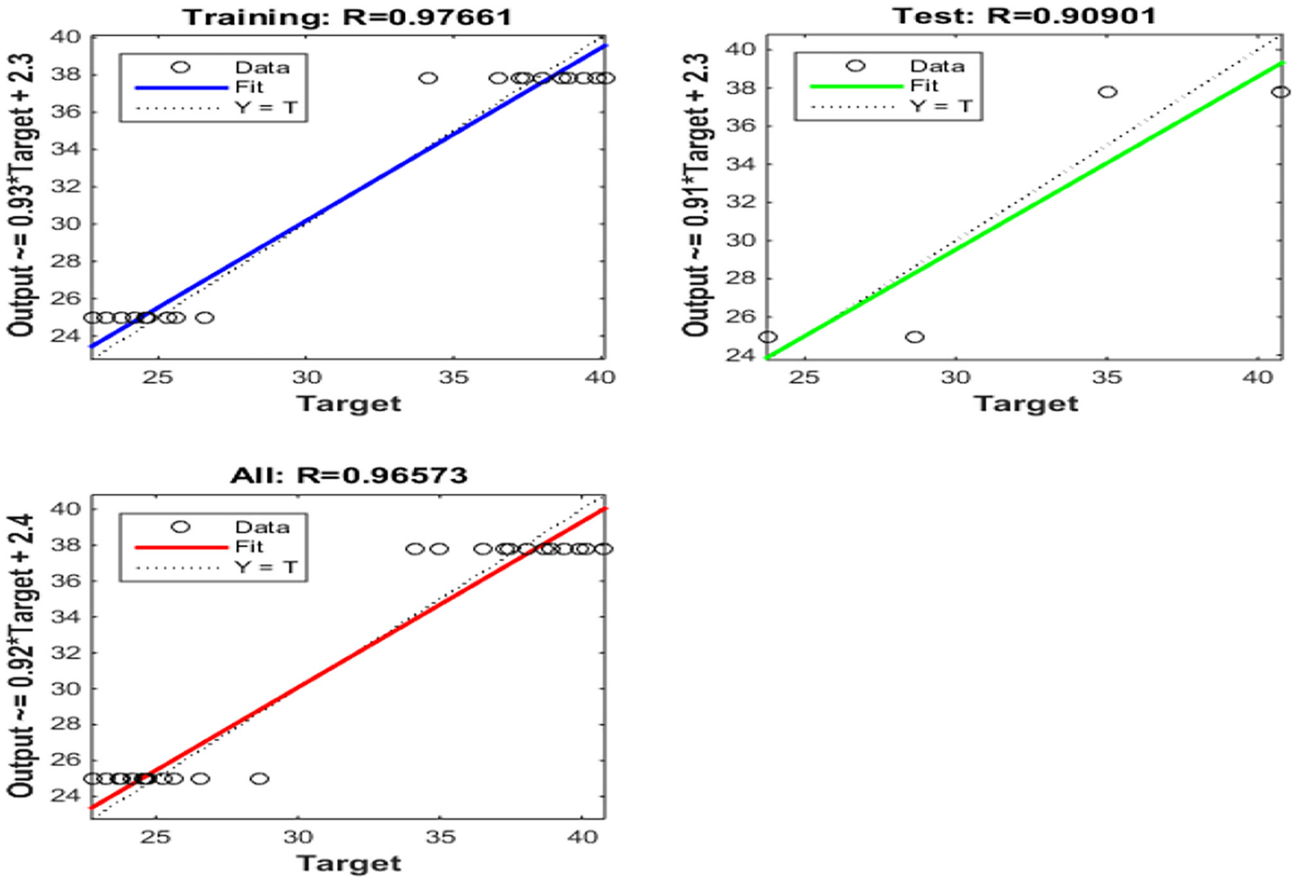

Fig. 2. Predicted and actual data based on Bayesian regularization algorithm.

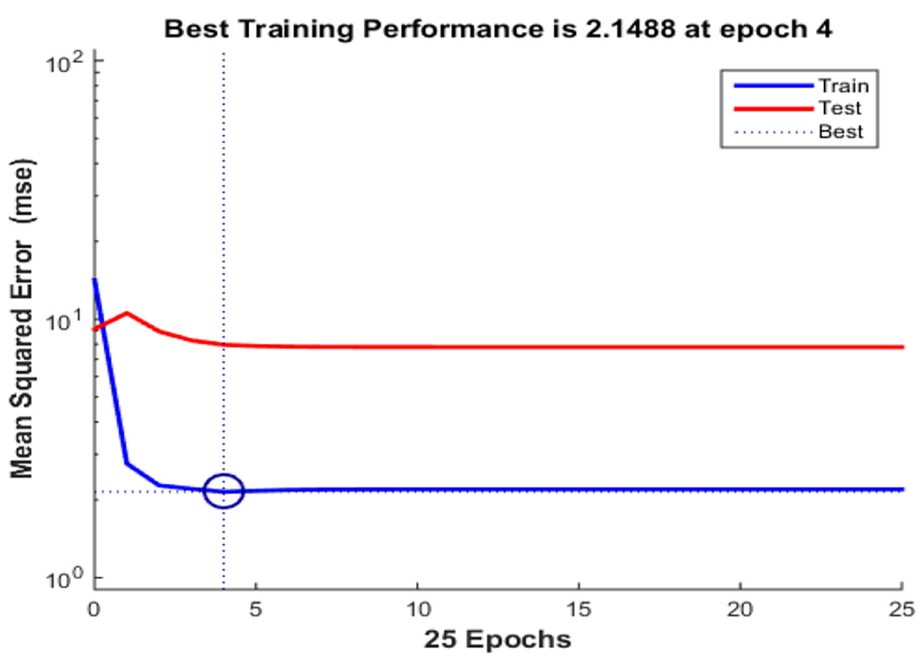

Fig. 3. Epoch of data based on Bayesian regularization algorithm.

upon LM algorithm (Fig. 9). A value of 0.96633 and 0.97078 was found respectively for LM and BR algorithms concerned with regression values for the training data input. The higher regression values (>95%) shows that the predicted and the experimental results are approximately nearer and the prediction accuracy is more reliable. It is also found that the overall co-efficient of regression is found to be 0.92865 and 0.95625 respectively for LM and BR and its also in the higher range depicting the accurate prediction.

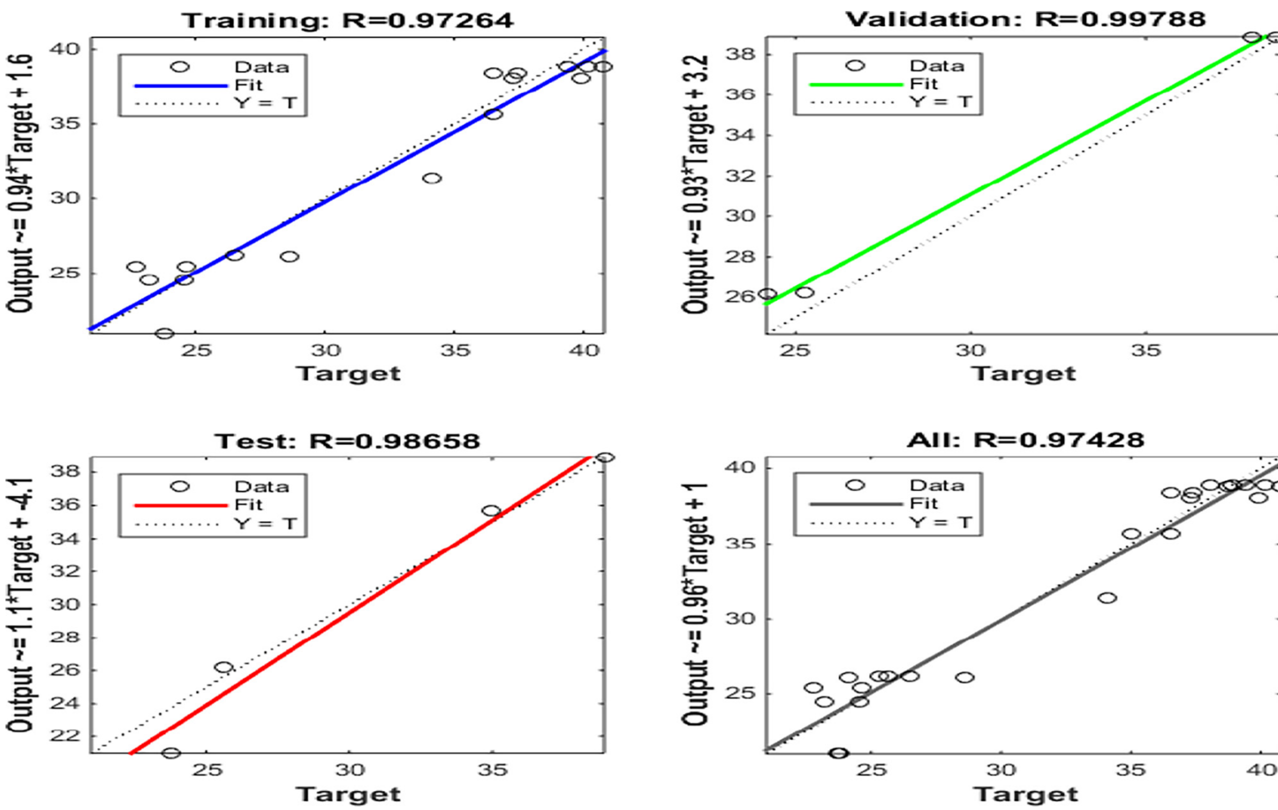

Fig. 4. Predicted and actual data based on levenberg–marquardt algorithm.

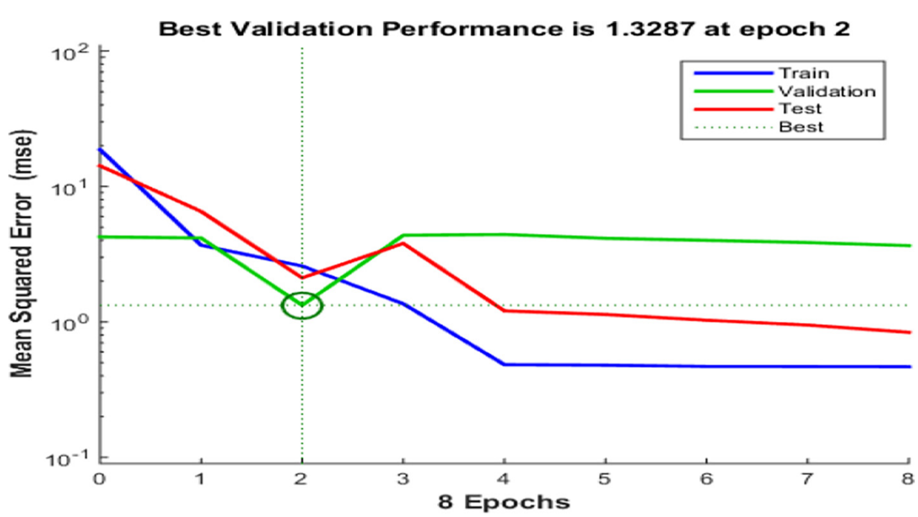

Fig. 5. Epoch of data based on levenberg–marquardt algorithm.

Mean squared error plots best obtained validation performance is at 0.1247 at epoch 1 and 0.015179 at epoch 30 concerned with LM and BR algorithms, respectively.

3.3. Flexural strength

Structural members like beam are subjected to bending loads during their lifecycle and they should have more flexural strength to withstand them, hence flexural strength of concrete is also an important property to be considered while designing. In this work focus is given to assess the flexural strength of concrete through laboratory studies using IS code provision through beam specimens of 1 m X 100mmX100mm and the data obtained is given as input for the ANN models. Various beam specimens were casted using internal curing agent and cured for a period of 14 and 28 days before testing. It is found that the values obtained through ANN model was very neared to the obtained experimental results. Data input is divided into three parts as 75% for training, 15% for testing and another 15% for validation of the results. Fig. 10 is showing the data that is obtained through BR algorithm output in which the epoch data is based on Bayesian regularisation algorithm as shown in Fig. 11. Also, Fig. 12 depicts the ANN output data obtained through LM algorithm in which the epoch of data is based on LM algorithm

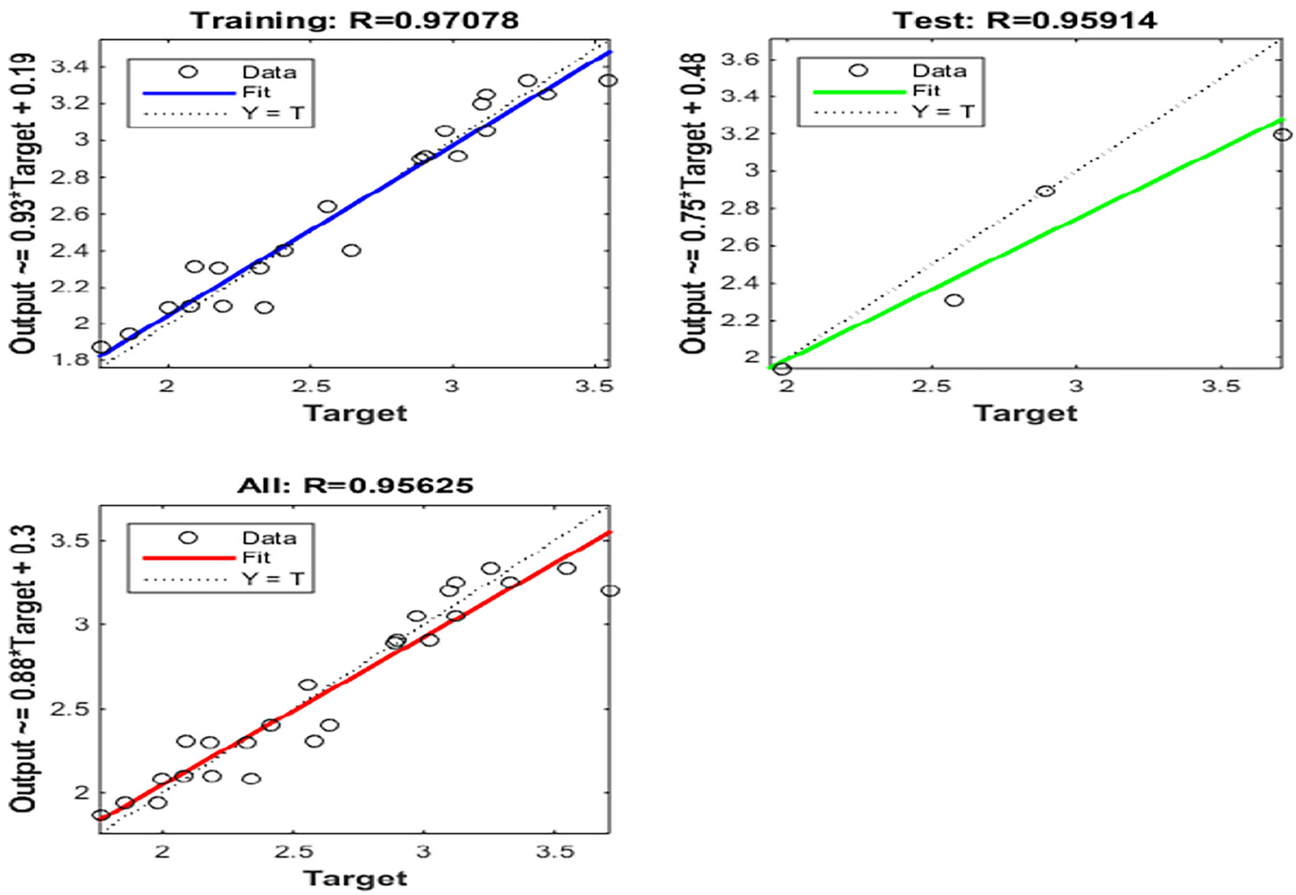

Fig. 6. Predicted and actual data based on B-R algorithm.

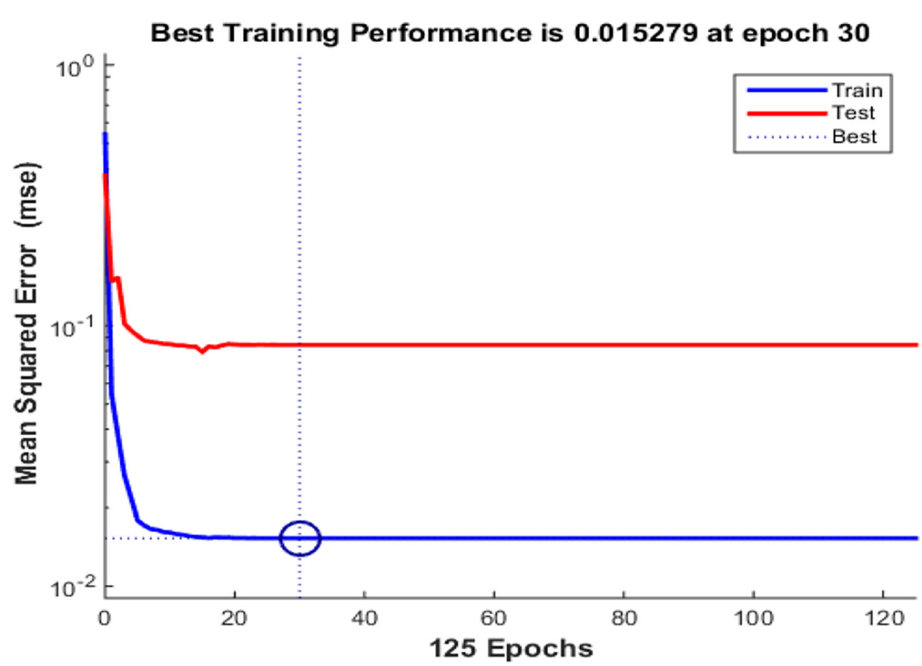

Fig. 7. Epoch of data based on B-R algorithm.

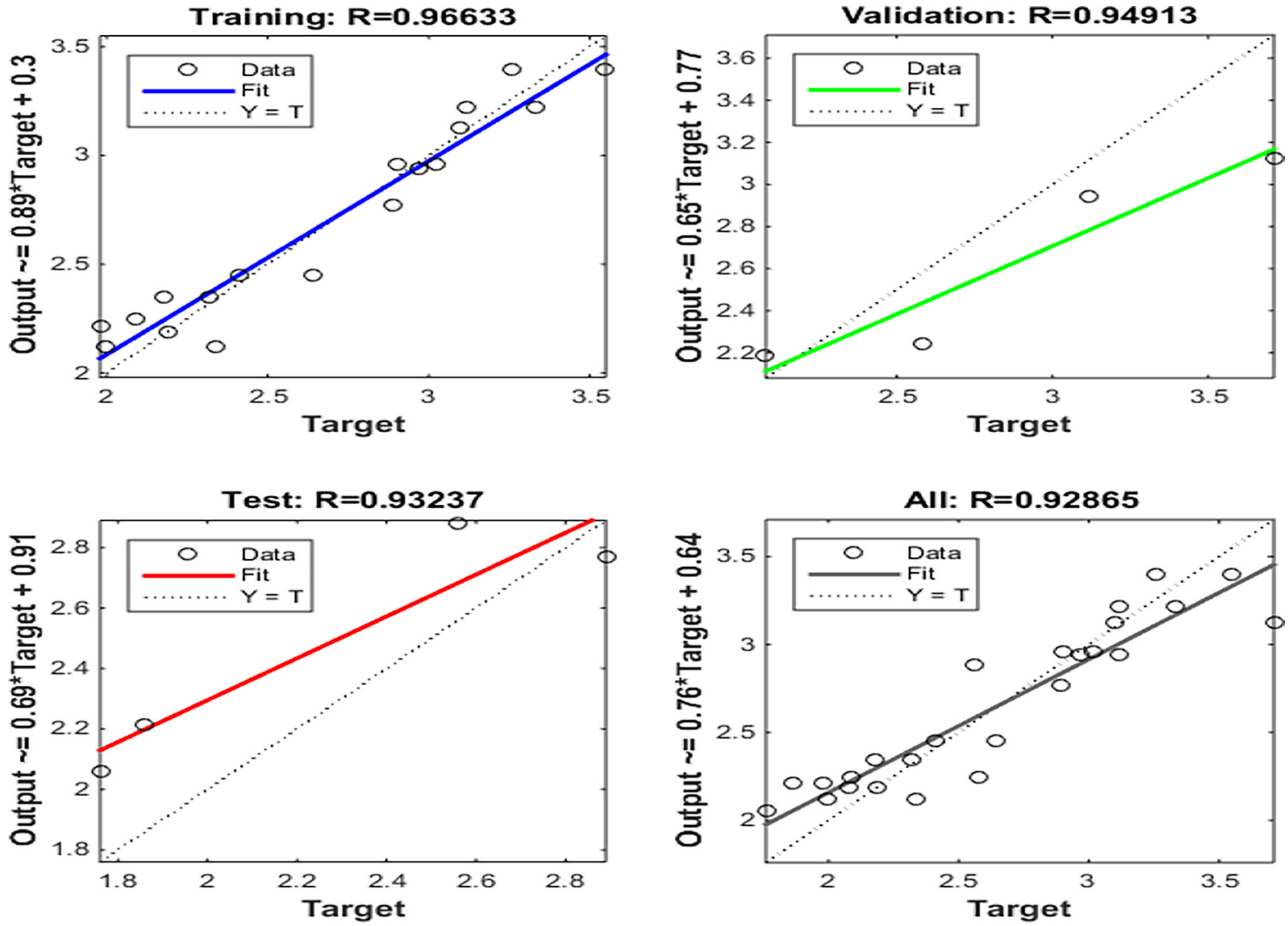

Fig. 8. Predicted and actual data based on levenberg–marquardt algorithm.

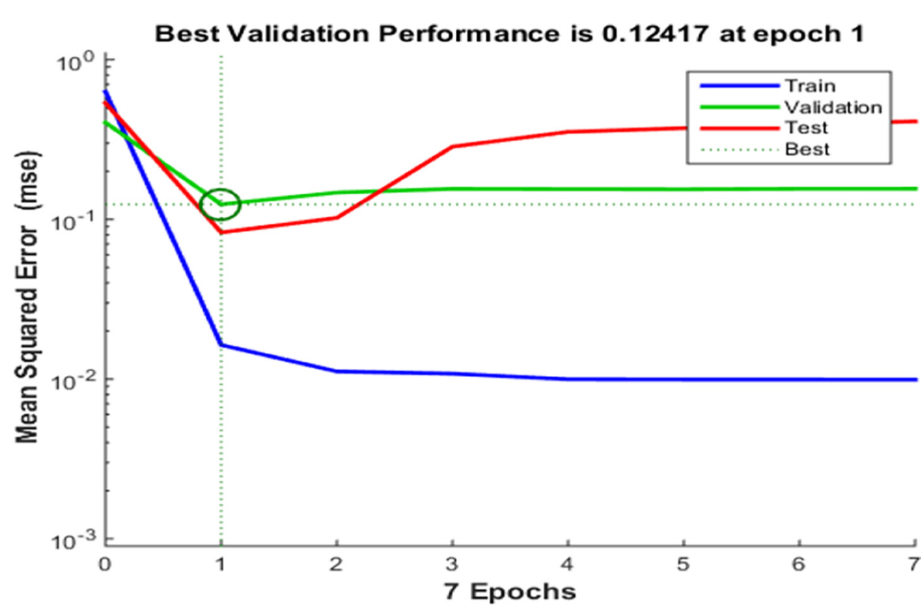

Fig. 9. Epoch of data based on L-M algorithm.

(Fig. 13). Regression values of 0.97558 and 0.90612 respectively was obtaine in training set with LM and BR algoriths concerned with flexural strength and an overall regression value of 0.96772 for LM algorithm and 0.91787 for BR algorithm is received. Comparably best validation performance is obtained in this studies which is obtained from the plot between mean squared error and epochs for training, testing and validation related to flexural strength. Best performance with LM algorithm is 0.021578 at an epoch 3 and with BR algorithm the best performance obtained is 0.43468 at an epoch 3.

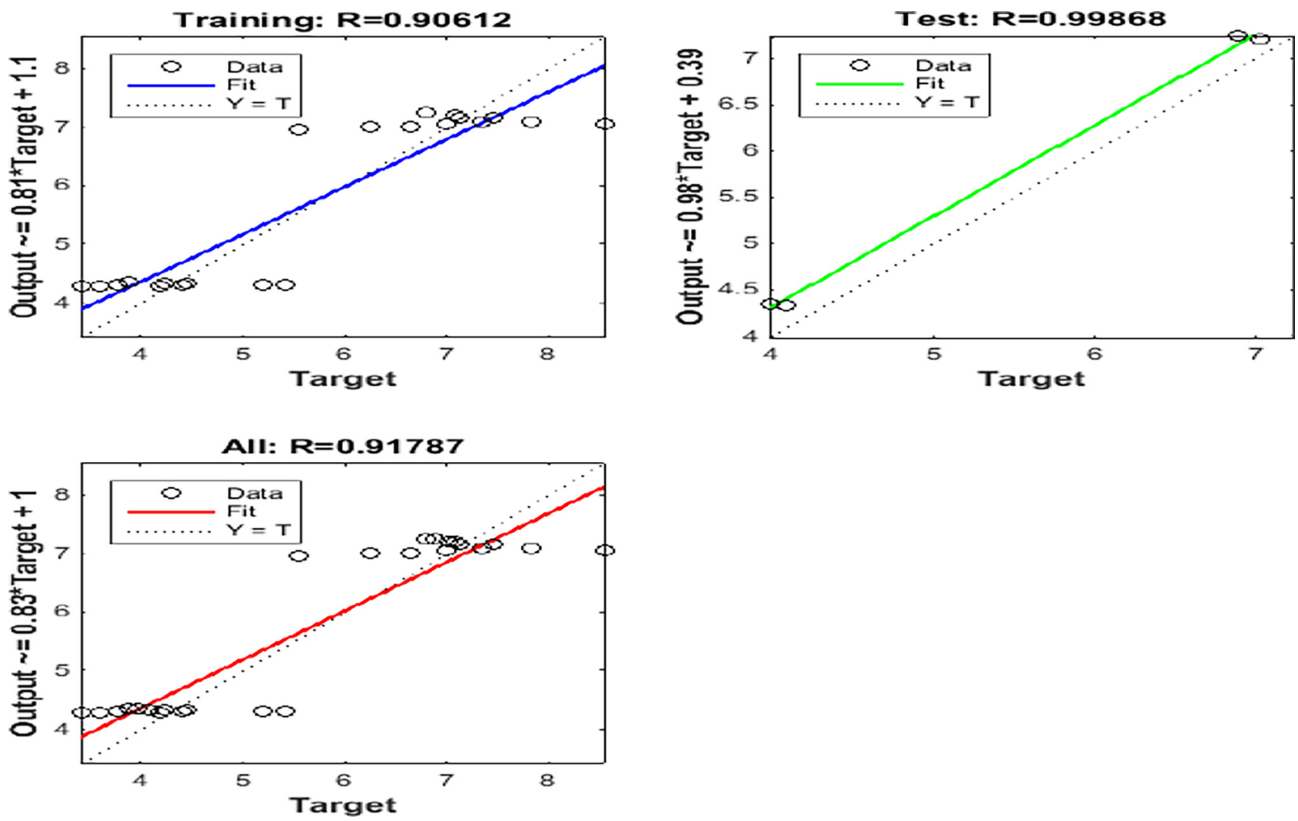

Fig. 10. Predicted and actual data based on B-R algorithm.

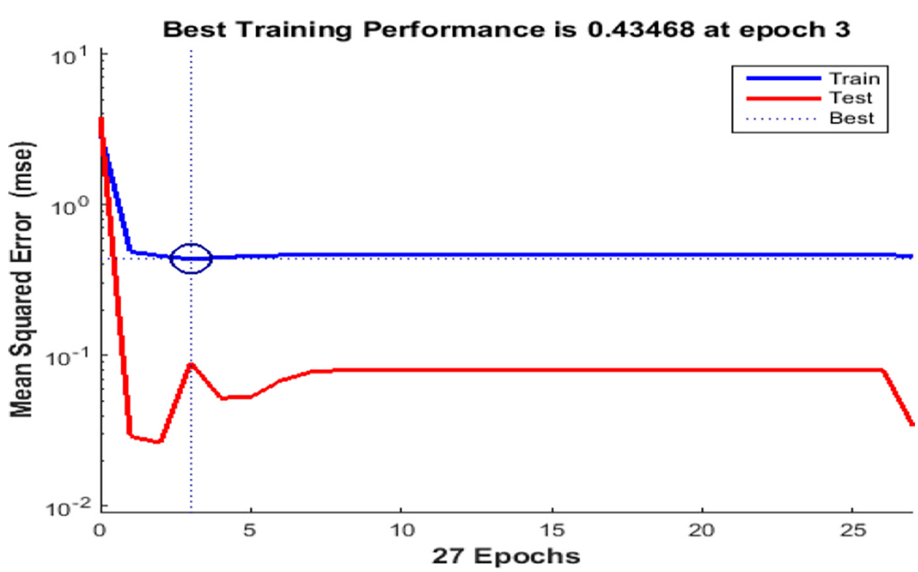

Fig. 11. Epoch of data based on B-R algorithm.

Thus using the LM and BR algorithms its possible to predict the strength values of concrete with near experimental results accuracy but the input parameters to be optimized properly before using it in model.

4. Conclusions

In this research work an attempt is made to predict the strength characteristics of self-curing concrete using artificial intelligence tools (ANN). This method not only helps to predict the values accurately but also helps in evaluating the strength of structures without destructive testing of concrete. Artificial intelligence techniques were employed by several researchers, in this we had used Levenberg-Marquardt and Bayesian regularization algorithms. Model output shows regression values of 0.97428, 0.92865 and 0.96772, concerned with L-M algorithmic model and 0.96573, 0.95625 and 0.91787 for B-R based model. It is observed that while using L-M algorithm the best performance was obtained at 1.3287 at epoch 2 for compressive strength and 0.12417 is achieved at

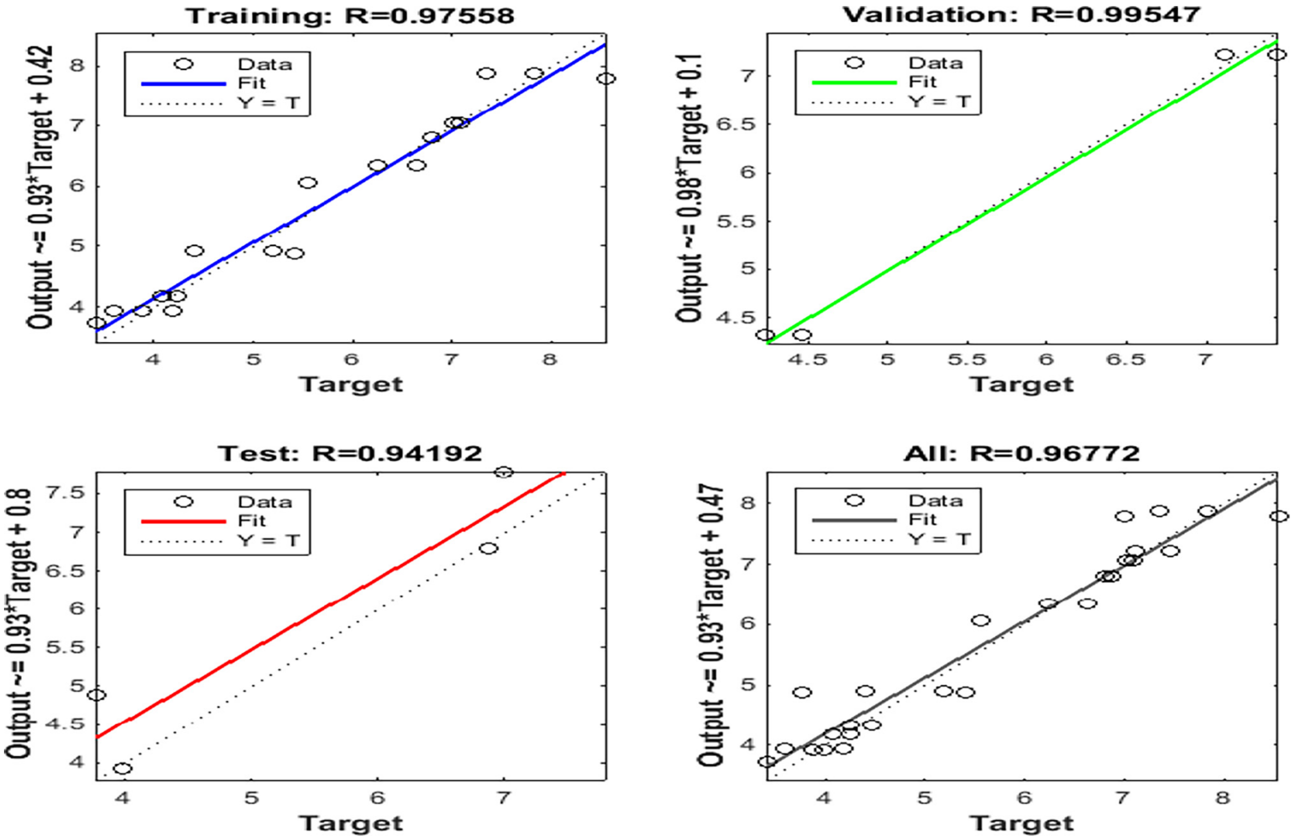

Fig. 12. Predicted and actual data based on L-M algorithm.

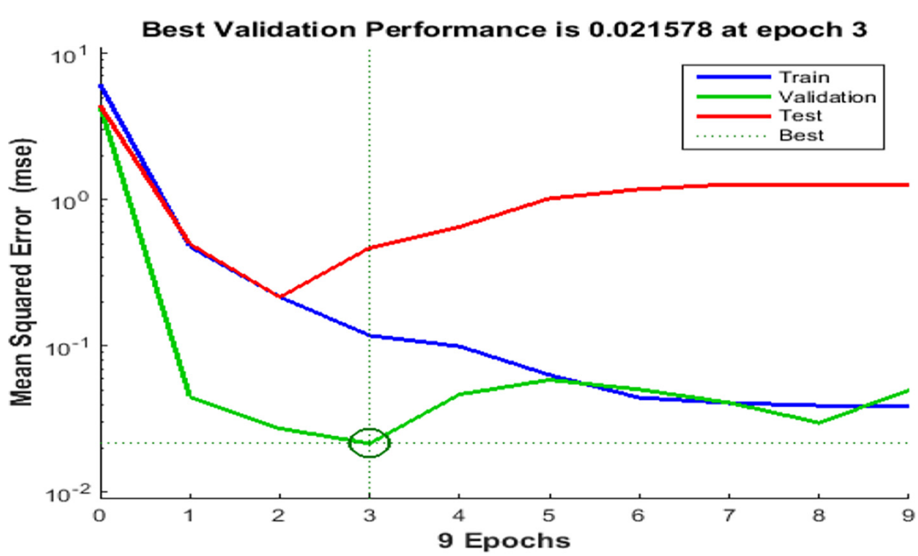

Fig. 13. Epoch of data based on B-R algorithm.

epoch 1 for tensile strength and 0.021578 at epoch 3 concerned with flexural strength. Also, with B-R algorithm provided best performance of 2.1488 at epoch 4 for compressive strength, a value of 0.43468 at epoch 3 for flexural strength and 0.015279 for tensile strength reached at epoch 30. It is found that Levenberg-Marquardt algorithm seems to be having more accuracy due to the nature of algorithm when compared with Bayesian regularization method. The results obtained are more reliable and shows that this method can be employed to predict concrete compressive strength for smaller sample size with more reliable results. Specifically, the algorithm works for all types of concrete inputs and hence recommended for the prediction of strength characteristics

CRediT authorship contribution statement

T. Udaya Banu: Methodology, Investigation, Writing - original draft. **N.P. Rajamane:** Investigation, Writing - original draft. **P.O.**

Awoyera: Writing - review & editing, Visualization. **R. Gobinath:** Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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