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Application of Artificial Neural Networking Technique for the Lifecycle Assessment of Recycled Aggregate Concrete

Amin Shakya[1], Lomash Bhattarai[1], Sagar Shahi[1], Suraj Kumar[1], Suguna Rao[2]

[1]*Student, Department of Civil Engineering, MS Ramaiah Institute of Technology, Karnataka, India*
[2]*Assistant Professor, Department of Civil Engineering, MS Ramaiah Institute of Technology, India*

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Abstract - *Construction industry is a major source of energy consumption and greenhouse emissions. With the natural resources required for the industry ever-limited and construction activities at its peak, a need for sustainable approach to the industry is deemed timely. Use of recycled aggregates provides an interesting solution in this context. An attempt has been made to understand the overall lifecycle of concrete with and without the recycled aggregates. Experimental study has been carried out with respect to different dosage of recycled aggregate. An Artificial Neural Network has been modelled based on literature to obtain the composition of a regular concrete mix with the same strength performance as per our experimental results. A comparative study of lifecycle behaviour has been done between the two results.*

Key Words: Recycled Aggregate, Artificial Neural Network, Lifecycle Assessment

1. INTRODUCTION

Climate change concerns and mineral depletion calls for greener means of construction. A lot of whose infrastructure was built post world war, slowly reaches a state where its old infrastructures need to be rehabilitated or replaced, emerging markets are sprouting globally along with their need for more robust infrastructure to continue this growth. [1] Use of alternate materials and in particular recycled aggregates is an interesting solution. It is important to understand the lifecycle implications of such alteration, an attempt at which has been made in this study. Such studies on concrete often require large resources and time. Application of artificial neural networking technique to aid this study and provide a reliable result has been explored.

1.1 Recycled Aggregates

The reuse of hardened concrete as aggregate is an interesting development. It can be crushed and reused as a partial replacement for natural aggregate in new concrete construction. The hardened aggregate can be obtained from the concrete structures which are to be demolished. Recycling or recovering of concrete material has two main advantages – it reduces the use of natural aggregates and the associated environmental costs, and it reduces the strain on cities in terms of the amount of landfill space required. [2]

Recycled aggregate is traditionally dumped as landfill. It has also been used as base layer in pavements, subgrade stabilization, in concrete kerbs, embankment fill, backfill material, in paving blocks, etc. The properties of concrete made with recycled aggregates is often inferior to that made with normal aggregate, principally because of their higher water absorption and low density characteristics.

1.2 Artificial Neural Network

The properties of concrete are highly nonlinear functions of its constituents. Various studies have shown that concrete's strength not only depends on water-cement ratio, but also on various other constituents (Oluokun, 1994). With no standard empirical relationship, soft computing tools have drawn the interest of many researchers. (Chaturvedi, 2008) Artificial Neural Networking (ANN), with its ideas of iterative learning and complex layers of relationships of several parameters at different weightages looks the most promising among the tools, and has been used in several studies particularly to model a concrete composition's compressive strength.

2. EXPERIMENTAL DESIGN

In this paper, we first model a ANN network for compressive strength of NCA concrete with the help of data from literature. The data used for modelling the network was then analysed, particularly for the maximum and minimum values of each parameter. A simple programming script was developed that created every possible combination of the parameters at regular interval within the maximum and minimum value range.

Experimental investigations were carried out for various percentage replacements of natural coarse aggregate by recycled coarse aggregate. 28 day strengths of each replacement mix was then determined.

For the strength determined by the experimental design, a statistical mean of the "every possible combination" strength value matrix described above was then computed. This gives us an equivalent concrete mix of NCA concrete to the experimental compositions of RCA concrete.
Unit values for each component for various lifecycle parameters were then fed into the compositions given by the method and the RCA composition to obtain a comparison between lifecycle performance of the two equivalent mixes.

2.1 Neural Network Design

Quality of cement, water-cement ratio, sand to cement ratio and natural aggregate to cement ratio were used as the input parameters and 28 day compressive strength was used as the output parameter. [3] A total of 62 sets of experimental data were collected from literature. 68% of the data was used in the training set, 16% of data used in the validation set and 16% was used as the testing set. 4-4-1 architecture neural network was selected in a feed-forward back propagation architecture. Levenberg-Marquardt training algorithm with hyperbolic tangent activation function, sum of squares as output error function and logistic output activation function was determined to be the optimum network setup.

2.2 "Every Possible Combination" Matrix

Parameter analysis was conducted for a minimum and maximum parameter value. An appropriate step-length was assigned to each parameter and a small python programming code executed to obtain a "every possible combination" matrix.
This matrix was then fed into the neural network, which resulted in a strength prediction for each entry in the "every possible combination" matrix, the value pair thus referred to as the "Strength Matrix".

Table -1: Correlation Results for Different Training Algorithms

Correlation Results for Different Training Algorithms						
Training Algorithms	**Correlation**			**R-squared**		
	Training Set	**Validation Set**	**Test Set**	**Training Set**	**Validation Set**	**Test Set**
Quick Propagation	0.97	0.98	0.73	0.93	0.96	-0.24
Conjugate Gradient Descent	0.9	0.98	0.84	0.76	0.95	0.66
Quasi Newton	0.97	0.99	0.47	0.94	0.98	0.006
Limited Memory Quasi Newton	0.92	0.99	0.57	0.8	0.98	0.16
Levenberg – Marquardt	0.95	0.93	0.89	0.88	0.79	0.77
Online Back Propagation	0.91	0.87	0.9	0.8	0.63	0.79
Batch Back Propagation	0.87	0.85	0.88	-12.38	-15.38	-4.17

Table -2: Parameter Analysis and Choice of Step-length

Parameter	**Minimum Value**	**Maximum Value**	**Step Length**	**Number of Variations**
Water-Cement Ratio	0.3	0.6	0.05	6
Cement	320	650	5	66
CA/Cement	1.6	3.44	0.1	19
FA/Cement	0.39	2.59	0.1	22
Total Products: **165528**				

2.3 Experimental Investigation

28 day compressive strength values of recycled aggregates were experimentally observed for three samples each for each recycled aggregate replacement ratio. The resulting strength values were as follows:

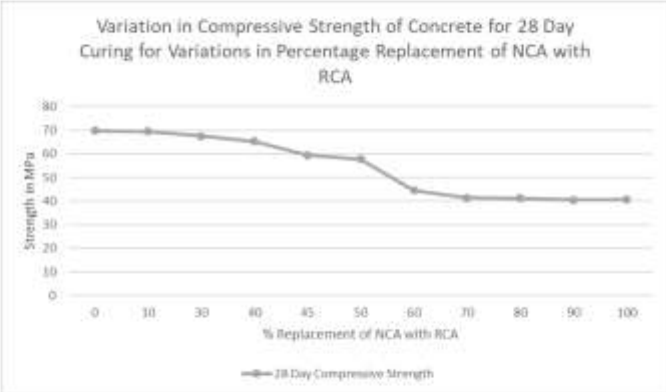

Chart -1: Variation in Compressive Strength of Concrete for 28 Day Curing for Vaiations in Percentage Replacement of NCA with RCA

The resulting strength values were then queried upon the strength matrix with an allowable variance of +/- 0.5 MPa for a selected W/C ratio. This results in an equivalent mix proportion for NAC for same strength as RAC of given proportion.

2.4 Lifecycle Study

For verification purposes, several lifecycle data were plotted for the two equivalent proportions – RAC and NAC. The lifecycle variation study includes embodied energy, fuel consumption, CO2 emission, particle emission, waste generation and mineral depletion. The basic values are shown in tables below: [4][5][6][7][8][11]

Table -3: Basic Values of LCA for materials used in concrete

S.N.	Item	Embodied Energy (MJ/Kg) [4][5][8][7][8]	Cost (Rs/Kg)	Transportation Fuel (l/tonne/Km) [4][5][6][7][8]	CO2 Emission (gm/Kg) [4][5][6][7][8]	Particulate Matter (gm/Kg) [4][5][6][7][8]
1	RCA	0.36	0.24	0.37	1.69	0.00179
2	NCA	0.47	0.4	0.37	1.34	0.00145
3	FA	0.15	0.57	0.29	2.2	4.44E-06
4	Cement	6.85	7.2	0.06	861.2	0.711

Table -4: Basic Values of LCA for RCA and NCA

SN	Item	Waste generation (Kg/m3): [4][5][6][8][11]	Mineral Depletion (Kg/m3): [4][5][6][8][11]
1	RCA	1000	1200
2	NCA	2500	2500

3. RESULTS AND DISCUSSIONS

3.1 Neural Network Design

The graph of target value vs output value for training, validation and test data are as follows.

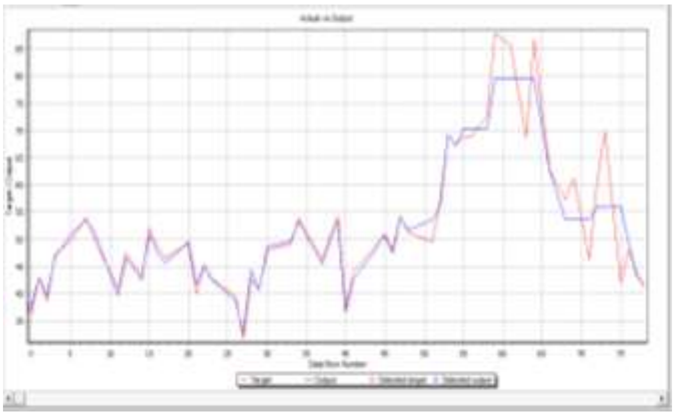

Chart -2: Target Vs Output for Training Data

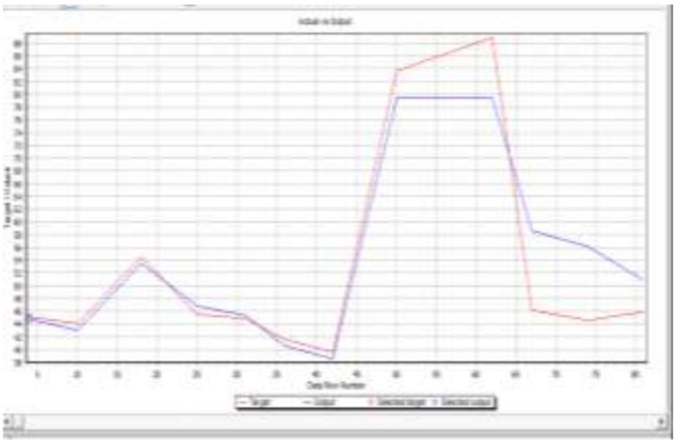

Chart -3: Target Vs Output for Validation Data

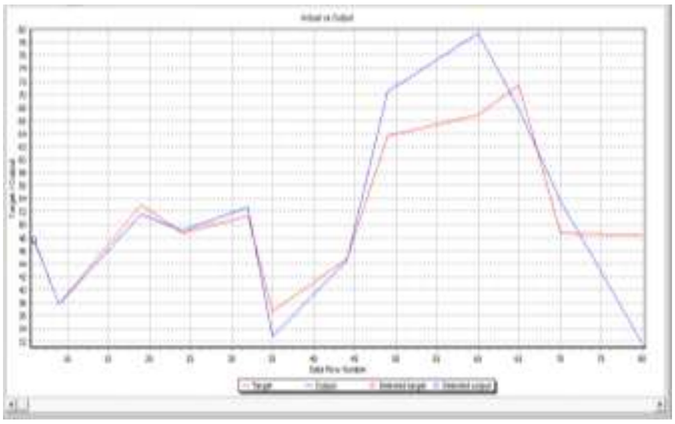

Chart -4: Target Vs Output for Test Data

It is obvious for output and target value to match in case of training data. The output and target curve for validation and test data are also showing reasonable similarity, which implies that the model has been properly trained to predict 28 days strength value. This fact can also be inferred by the correlation and r-squared values obtained which are 0.95, 0.93 and 0.89 (for training, validation and testing) & 0.88, 0.79 and 0.77 (for training, validation and testing) respectively.

3.2 Lifecycle Study

The results of lifecycle study are as follows:

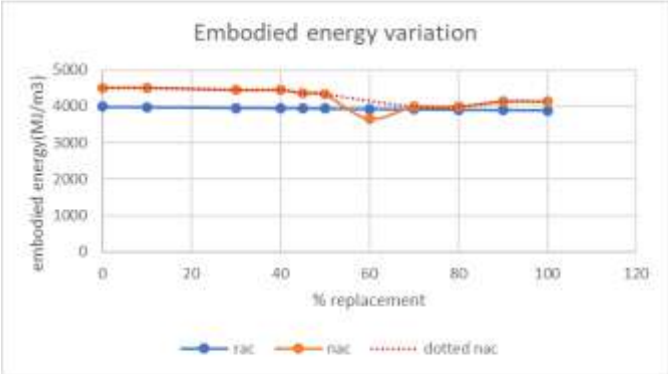

Chart -5: Embodied Energy Varaition with Percentage Replacement

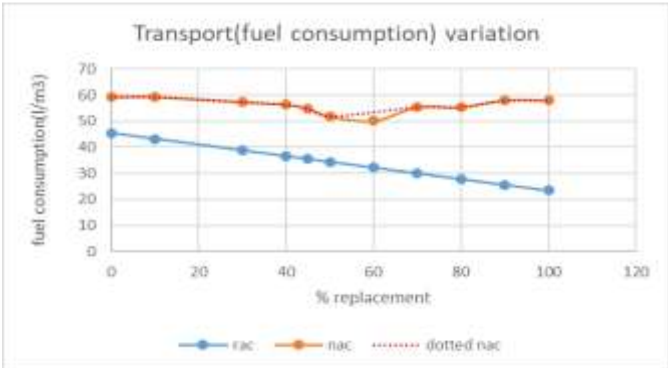

Chart -6: Transportation (Fuel Consumption) Varaition with Percentage Replacement

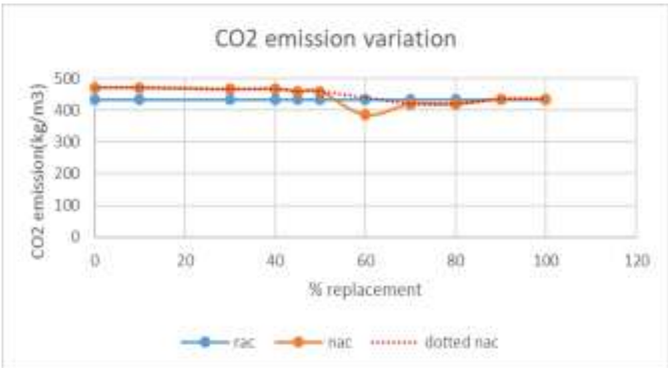

Chart -7: CO_2 Emission Varaition with Percentage Replacement

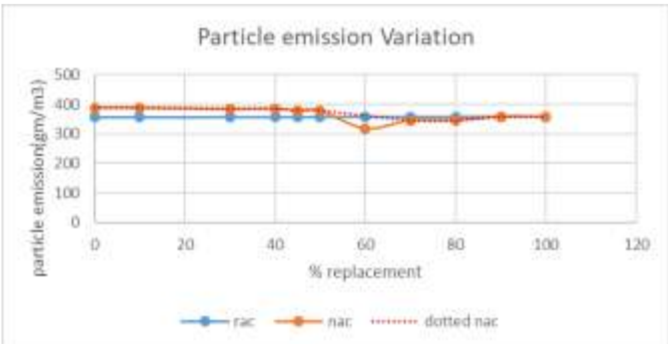

Chart -8: Particle Emission Varaition with Percentage Replacement

Chart -9: Waste Generation Varaition with Percentage Replacement

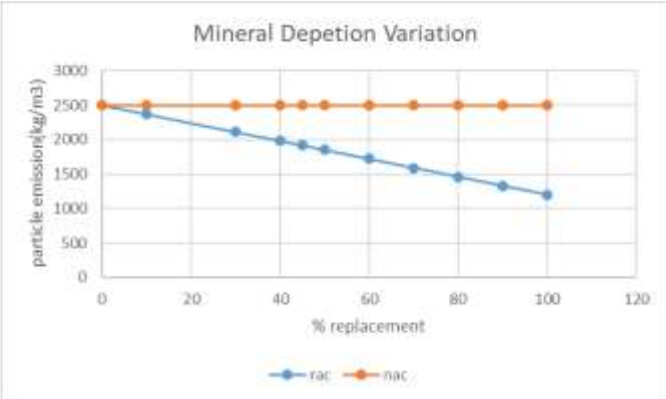

Chart -10: Mineral Depletion Varaition with Percentage Replacement

The results show better lifecycle performance of RAC than NAC, suggesting more prevalent usage of Recycled Aggregates for construction purposes for a more ecofriendly construction practice. Further the graph shows a continuous smooth curve, providing a weak validation of the method imposed. A consistent dip can be observed for the data for 60% replacement.

4. CONCLUSIONS

It is highly advisable we move our construction practices to more environment-friendly ways. Use of recycled aggregate is a promising move in this direction. More studies and improved regulating guidelines are a must if it is to take a role in mainstream construction industry. Further concrete being a system of physical and chemical bonds should have a fairly good predictive value. Application of prediction tools such as the Artificial Neural Network highly improves the rate at which such systems can be studied.

The study shows a viable method to obtain a breakdown of material composition of concrete which can then be used to proceed further studies. The lifecycle study shows a weak validation of the material composition breakdown process. Further studies and a more rigorous experimental design is necessary to establish this technique, which if established, could provide researchers an extremely useful tool in their study of RAC concrete or studies related to concrete in general.

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