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# Modeling compressive strength of recycled aggregate concrete by Artificial Neural Network, Model Tree and Non-linear Regression

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**Abstract**

In the recent past Artificial Neural Networks (ANN) have emerged out as a promising technique for predicting compressive strength of concrete. In the present study back propagation was used to predict the 28 day compressive strength of recycled aggregate concrete (RAC) along with two other data driven techniques namely Model Tree (MT) and Non-linear Regression (NLR). Recycled aggregate is the current need of the hour owing to its environmental friendly aspect of re-use of the construction waste. The study observed that, prediction of 28 day compressive strength of RAC was done better by ANN than NLR and MT. The input parameters were cubic meter proportions of Cement, Natural fine aggregate, Natural coarse Aggregates, recycled aggregates, Admixture and Water (also called as raw data). The study also concluded that ANN performs better when non-dimensional parameters like Sand–Aggregate ratio, Water–total materials ratio, Aggregate–Cement ratio, Water–Cement ratio and Replacement ratio of natural aggregates by recycled aggregates, were used as additional input parameters. Study of each network developed using raw data and each non dimensional parameter facilitated in studying the impact of each parameter on the performance of the models developed using ANN, MT and NLR as well as performance of the ANN models developed with limited number of inputs. The results indicate that ANN learn from the examples and grasp the fundamental domain rules governing strength of concrete.


*Keywords:* Recycled aggregates; Recycled aggregate concrete; Artificial Neural Network; Model Tree; Non-linear Regression

## 1. Introduction

Scarcity of natural resources is a growing environmental concern and there is a need to reduce the impact of this scarcity and take a step toward conserving the environment. A possible solution to reduce this impact may be the use of C&D (Construction and demolition) waste as replacement to natural resources in concrete mixes. C&D waste, especially the concrete waste can be made to recycled aggregates (RA), which can be used in concrete as aggregates. RA is a material derived from waste concrete which is produced by a two stage crushing of demolished concrete followed by screening and removal of contaminants such as reinforcement, wood, plastics, etc. (Rao et al., 2010). When recycled aggregates are used in a

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concrete mix the concrete is termed as recycled aggregate concrete (RAC).

Several researches have studied the influence of RA on concrete properties such as compressive strength, tensile strength, etc. (Ajdukiewiez and Kliszczewicz, 2002; Hansen and Narud, 1983; Tsung et al., 2006; Ryu, 2002). RA is heterogeneous in nature as they contain attached mortar to the aggregates. This property of RA limits its use in concrete, as it decreases the compressive strength of RAC. Surrounding mortar on the aggregate tends to increase water absorption and reduce the density of RAC and becomes the governing criteria for the compressive strength of concrete with recycled aggregates (Ajdukiewiez and Kliszczewicz, 2002; Hansen and Narud, 1983; Tsung et al., 2006; Ryu, 2002). It was also observed that the workability of concrete made using RA is less as compared to workability of concrete made using normal aggregates may be due to more water absorption in the former (Yong and Teo, 2009). To add to it RA in concrete as a replacement to natural aggregates tends to reduce the compressive strength of concrete may be due to weaker bond between mortar and RCA. (Akbari et al., 2011). A similar study concluded that using different recycled aggregates RA replacement ratios, W/C ratios and RAs with different strengths and different moisture conditions, the strength of RAC was about 10–25% lower than that of natural aggregate concrete (NAC) and thus 100% replacement of RA tends to lower the strength of concrete (Ajdukiewiez and Kliszczewicz, 2002; Hansen and Narud, 1983; Tsung et al., 2006; Ryu, 2002) and therefore should be avoided. The study also concluded that the compressive or tensile strength loss of RAC prepared with low strength RA was more significant than that of concrete prepared with high strength RA, and the extent of the reduction was related to many parameters, such as the type of concrete used for making the RA (high, medium or low strength), replacement ratios, water–cement ratios and the moisture conditions of the RA (Ajdukiewiez and Kliszczewicz, 2002). Thus the diverse behavior of RA and RAC demands their extensive testing to have more insights into their behavior pattern. However extensive testing demands amounts of materials, time and cost. Thus to improve the studies and to reduce the cost and time required for testing, models based on experimental data predicting the compressive strength of RAC with an acceptable range of error may be encouraged. Many techniques such as Artificial Neural Networks, Regression analysis, etc. were used earlier to predict the compressive strength of RAC. The relationships among demolished concrete characteristics, properties of their RA and strength of their RAC were established using regression analysis (Vivian et al., 2008). ANN models were developed to predict the strength and slump of ready mixed concrete and high strength concrete, in which chemical admixtures and or mineral additives were used (Dias and Pooliyadda, 2001; I-Cheng, 2007). Particularly in the field of RAC, ANN was used to predict strength of recycled aggregate concrete (Adriana et al., 2013). Besides ANN other data driven techniques such as Linear Regression analysis and Model Trees (MT) were used to model compressive strength of concrete (Deepa et al., 2010). The study concluded that ANN facilitates a better correlation among inputs and output. However MT though showed a less correlation has an advantage of providing equations.

In the current study three techniques, Artificial Neural Networks (ANN), Model Tree (MT) and Non-linear Regression (NLR) are used with raw data and non-dimensional parameters as inputs and 28 day compressive strength of concrete as output. The major objective of the study can be stated as:

(i) To explore the possibility of predicting strength of concrete with limited number of inputs, i.e., by using raw data or mandatory parameters, using the techniques of ANN, MT and NLR.
(ii) To develop models for predicting compressive strength of RAC using raw data and non-dimensional parameters as input parameters, using each of the above said techniques and understand the performance and influence of each additional input parameter on output.

Basic concepts of ANN, MT and NLR are discussed in the next section followed by information about data adopted for the current study. The methodology for model development is then presented followed by results and discussion. The conclusions are presented at the end.

## 2. Modeling techniques

In the current study, prediction of recycled aggregate concrete strength is done using Artificial Neural Networks, Model Tree with M5 algorithm and Non-linear Regression. These approaches are described in brief below.

### 2.1. Artificial Neural Networks (ANN)

Artificial Neural Network (ANN) is a soft computing technique involving an input layer, one or more hidden layer (s) and an output layer. The hidden layer is connected to the other layers by weights, biases and transfer functions. An error function is determined by the difference between network output and the target. The error is propagated back and the weight and biases are adjusted using some optimization technique which minimizes the error. The entire process called training is repeated for number of epochs till the desired accuracy in output is achieved. Once the network is trained it can be used to validate against unseen data using trained weights and biases (Londhe et al., 2009). Readers are referred to Londhe et al. (2009) for details of ANN.