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# Compressive strength prediction of environmentally friendly concrete using artificial neural networks

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## ABSTRACT

Solid waste in the form of construction debris is one of the major environmental concerns in the world. Over 20 million tons of construction waste materials are generated in Tehran each year. A large amount of these materials can be recycled and reused as recycled aggregate concrete (RAC) for general construction, pavement and a growing number of other works that drive the demand for RAC. This paper aims to predict RAC compressive strength by using Artificial Neural Network (ANN). The training and testing data for ANN model development were prepared using 139 existing sets of data derived from 14 published literature sources. The developed ANN model uses six input features namely water cement ratio, water absorption, fine aggregate, natural coarse aggregate, recycled coarse aggregate, water-total material ratio. The ANN is modelled in MATLAB and applied to predict the compressive strength of RAC given the foregoing input features. The results indicate that the ANN is an efficient model to be used as a tool in order to predict the compressive strength of RAC which is comprised of different types and sources of recycled aggregates.

## 1. Introduction

Considerations for sustainable development such as through environmental regulations and natural resources protection play a significant role in new requirements of the construction industry. The production of construction debris and demolition waste all over the world has been substantially increasing due to rehabilitation activities. In Tehran, the production of construction waste has been estimated to be as much as 20 million tons annually. Demolished materials are not used for any purpose and may adversely affect useful land spaces if dumped around cities. It is also a well-known fact that concrete is among the world's most common construction materials today where the annual global consumption of natural aggregate for concrete production is estimated at 8–12 billion tons [1]. Such aggregates are considered as essential components of concrete and potentially pose detrimental effects to the environment if associated debris is not managed responsibly. The sheer volume of produced construction waste will undoubtedly result in major environmental concerns.

In recent years, researchers have utilized different techniques to anticipate and evaluate various properties of recycled aggregate concrete (RAC). Methods that are based on the machine learning body of knowledge such as artificial neural networks (ANN) are increasingly gaining traction. However, ANN techniques are rarely adopted to predict performance of RAC and concretes in general due to their complex composition. Topcu and Saridemir (2008) [2] attempted to predict the compressive and splitting tensile strength of RAC that contains silica fume. Duan et al.[3], proposed an ANN model with 14 input features using 168 sets of data. Chopra et al. [4], performed a regression analysis to establish the relationship between recycled coarse aggregate (RCA) properties and the associated compressive strength based on 20 sets of data.

In studying the properties of RAC, Poon et al. [5] highlighted the effect of moisture levels in both natural and recycled that affect the strength of RAC.

Zega and Maio [6], exposed RCA to high temperatures in order to evaluate and compare the characteristics of concrete made of different natural aggregates. Lin et al. [7], outlined the optimal mixture for RAC and proposed a procedure to provide a better way for understanding the real engineering behavior of RAC. Domingo-Cabo et al. [8], worked on creep and shrinkage of RAC and presented an experimental program to assess the different characteristics of RAC while Gomez-Soberon (2002) [9], studied the porosity of RAC. Gonzalez-Fonteboa and Martínez-Abella [10], Yang et al. [11], Gonçalves et al. [12], Guti et al. [13], Kou and Poon [14] and Duan and Poon [15], worked on various properties of RAC particularly from resulting mechanical aspects such as compressive strength and presented several conclusions.

In 2016, Pour and Alam [16] investigated the influence of RAC on the strength of bonds between concrete and steel bars. By considering

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**Table 1**
Summary of existing models.

| Previous work | Sample size | Method | $R^2$ | Concrete type | Input variables |
|---|---|---|---|---|---|
| Yeh (1998) [17] | 727 | ANN | 0.914 | HPC | Cement; FA; BFS; water; superplasticizer; coarse and fine aggregates; curing age |
| | | Linear regression | 0.574 | | |
| Gupta et al. (2006) [18] | 864 | Neural-expert system | 0.5776 | HPC | Concrete mix grade; size and shape of specimen; curing technique and period; maximum temperature; relative humidity and velocity; period of strength |
| Zarandi et al. 2008 [19] | 458 | Fuzzy polynomial neural networks | 0.8209 | HPC | Coarse and fine aggregates; superplasticizer; coarse and fine aggregate; curing age |
| Yeh and Lien (2009) [20] | 1196 | Genetic operation trees | 0.8669 | HPC | Cement; FA; BFS; water; superplasticizer; coarse and fine aggregate; curing age |
| | | ANN | 0.9338 | | |
| Chou et al. (2011) [21] | 1030 | ANN | 0.9091 | HPC | Cement; FA; BFS; water; superplasticizer; coarse and fine aggregate; curing age |
| | | Multiple regression | 0.6112 | | |
| | | SVM | 0.8858 | | |
| | | Multiple additive regression trees | 0.9108 | | |
| | | Bagging regression trees | 0.8904 | | |
| Deepa et al. (2010) [22] | 300 | Multilayer perceptron (ANN) | 0.625 | HPC | Cement; FA; BFS; water; superplasticizer; coarse and fine aggregate; curing age |
| | | Linear regression | 0.491 | | |
| | | M5P model tree | 0.787 | | |
| Atici (2011) [23] | 135 | ANN | 0.9801 | Concrete contains BFS and FA | Cement; BFS; FA; ultrasonic; pulse velocity; rebound number; curing age |
| | | Multiple regression | 0.899 | | |
| Erdal et al. (2013) [24] | 1030 | ANN | 0.9088 | HPC | Cement; FA; BFS; water; superplasticizer; coarse and fine aggregate; curing age |
| | | Bagged ANN | 0.9278 | | |
| | | Gradient-boosted ANN | 0.927 | | |
| | | Wavelet bagged ANN | 0.9397 | | |
| | | Wavelet gradient-boosted ANN | 0.9528 | | |
| Omran et al. (2014) [25] | 144 | M5P model tree | 0.9476 | Concrete contains FA, Haydite LWA, and PLC | Cement type; curing age; water; cementitious material; FA; sand; pea gravel; Haydite LWA; Micro Air |
| | | M5-Rules | 0.9482 | | |
| | | REPTree | 0.9217 | | |
| | | Multilayer perceptron (ANN) | 0.97 | | |
| | | SMOreg (SVM) | 0.968 | | |
| | | Gaussian processes regression | 0.9843 | | |
| | | Additive regression | 0.9843 | | |
| | | Bagging | 0.9816 | | |

**Table 2**
Inputs and output.

| | |
|---|---|
| W/C | Water-cement ratio |
| Wm | Water absorption |
| FA | Fine aggregate |
| RCA | Recycled coarse aggregate |
| NCA | Natural coarse aggregate |
| W/T | Water-total material ratio |
| $f_{cu}$ | 28-day compressive strength |

144 push-out tests, they concluded that under constant mix proportions, an increase in the bar size and the embedment length to bar diameter ratio would lead to a reduction in the bond strength.

Table 1 provides a structured review of some of the primary works on compressive strength prediction. It can be observed that relatively fewer works have been done on compressive strength prediction of RAC wherein most previous studies were particularly centric about high-performance concrete (HPC) containing blast furnace slag (BFS), flay ash (FA) and superplasticizer.

The database utilized in this study, was populated from existing tests documented in the literature on RAC to investigate the relationship between various variables on the resulting compressive strength. Correspondingly, a new model based on ANN is developed and presented herein.

## 2. Recycled aggregate

The inherent characteristics of recycled aggregate (RA) are often inferior when compared to natural aggregate (NA), due to presence attached mortar and old cement paste. This includes 20–30% of the volume of recycled concrete, and is generally relatable to the original properties of the parent concrete from which it is extracted from.

The salient points below briefly highlight the benefits of using RA over NA:

- Lower bulk
- Higher water absorption
- Inferior strength

**Table 3**
Statistical properties of experimental data.

| Input nodes | $W_m(\%)$ | $\frac{W}{C}$ | $FA\ (kg/m^3)$ | $RCA\ (kg/m^3)$ | $NCA\ (kg/m^3)$ | $\frac{W}{T}$ | $f_{cu}$ (MPa) |
|---|---|---|---|---|---|---|---|
| Mean | 8.73 | 0.53 | 714.71 | 589.04 | 411.56 | 0.09 | 40.42 |
| Minimum | 0.4 | 0.34 | 325 | 0 | 0 | 0.04 | 9.74 |
| Maximum | 28.58 | 0.86 | 1398 | 1219 | 1301 | 0.21 | 80.5 |
| Standard deviation | 5.88 | 0.09 | 192.51 | 382.42 | 421.17 | 0.03 | 13.24 |
| Coefficient of variation | 0.67 | 0.19 | 0.27 | 0.65 | 1.02 | 0.38 | 0.33 |