Data Analytics and Modelling Of the Carbonation of the Recycled Aggregate Concrete

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Abstract— **In the current world scenario, the sites used for excavating natural aggregates are continuously getting depleted due to mining. Sustainable development is one of the main concerns for developing countries, especially in the field of building construction. While the mining sites of the aggregates are getting depleted, their prices of the aggregates are steadily increasing. Wastes generated from demolished structures are creating lots of pressure on land-filling. Recycling of the aggregates, which are generated from the demolished structures become the perfect solution for sustainable development. However, unlike natural aggregates, the structure of recycled aggregates is highly fractured. This affects the strength and durability properties of concrete made with recycled aggregates. Carbonation is one of the major durability concerns. The carbonation does not depend only on the recycled aggregate content. Concrete is a mixture of cement, water, aggregates, and additives. They all have a complex relationship with the mix proportion of the concrete. The main objective of this paper is to model the complex relationship of the mix proportion of the recycled aggregate concrete and the carbonation of the concrete. The data available for the durability properties of recycled aggregate concrete is often very limited. Thus, there is a need for multi-nation data analytics and problems like uniformity in the techniques of testing and results have to be sorted out. Linear models that are developed from the least square regression analysis are often ineffective in modeling the complex relationship of the carbonation of natural and recycled concrete. Machine learning algorithms are very effective in modeling such complex relationships with regards to the durability of recycled aggregate concrete. This paper aims to evaluate the effectiveness of the model generated from the linear regression and the artificial neural network and to evaluate the model in terms of accuracy and consistency.**

Index Terms— **Recycled Aggregate Concrete, Concrete Mix Design, The durability of the Concrete, Carbonation of the concrete, Multi-national Data Analytics, Artificial Neural Network, Linear Regression**

I. INTRODUCTION

One of the major challenges for the present Indian society is the protection of the environment. One of the ways to achieve this goal is by reducing the consumption of natural resources and increasing the recycling of waste materials. Inspite of the efforts of many researchers, their innovative techniques and Process management and upgradation, the demand of the increasing population will always require more and more consumption of the natural resources. This causes a major hinderance to the sustainable development because the avalability of the resources is often very limited.

In the construction industry, the cement and the aggregate, both requires the natural resources which are mined from the mining sites. The aggregate used in the construction are obtained by quarrying natural rocks. Concrete uses aggregates both as to increase the economy of the construction as well as to increase the strength of the concrete. Since the aggregate comprises of the bulk of the concrete, the depletion of the aggregate happens at a higher rate. Hence it is required to find the alternative of the aggregate, which is both economical as well as effective. Recycling of the aggregate is one such alternative. On one hand, it is used in place of natural aggregate thus reducing the consumption of natural aggregate and on the other hand, it solves the problem of lack of land available for land-filling by waste materials. Recycled aggregate based concrete uses broken bricks, construction and demolition waste in place of natural aggregates. They provide a cheap alternative to the consumption of natural aggregates. However, the recycled aggregates possess lower strength and durability properties.

Durability properties of the concrete are affected by the use of recycled aggregate based concrete because of the fractured structure of recycled aggregates. In this paper, changes will be compared in the carbonation of recycled aggregate based concrete and natural aggregate based concrete and there will be development of the models which can predict carbonation of the concrete using the mix proportion of the concrete.

Bazant [1] used linear regression for prediction model for creep and shrinkage of concrete. Mata [2] states that dam is exposed to seasonal variation and changes in the water level all across its lifetime and hence to model that using the properties like displacement measured form sensors, cracks, etc linear regression model is very useful. Parichatprecha [3] used Artificial Neural Network to model the strength of High Performance concrete. Ilker and Mustafaa [4] used the Artificial Neural network for prediction of properties of rubberized concrete. Lai and Serra [5] proposed a model for strength of concrete and the model was developed form the Artificial Neural Networks to predict the strength properties of concrete agglomerates.

II. CARBONATION OF THE CONCRETE

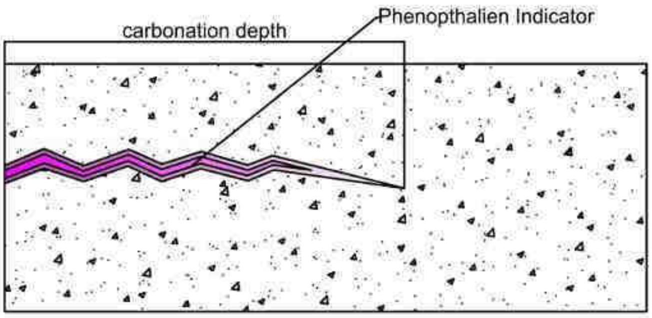
Carbonation is one of the major durability criteria of the concrete. Carbonation often occurs in the concrete because the calcium hydroxide present in the concrete is attacked by carbon dioxide of the air and converted to calcium carbonate. This reaction is endothermic in nature. The concrete will carbonate if CO_2 from air or from water enters the concrete ac- cording to:

$$Ca(OH)_2\ (s) + CO_2\ (g) \Rightarrow CaCO_3\ (s) + H_2O\ (l)$$

The rate of the carbonation process depends on the physical parameters like porosity, degree of hydration and moisture content of the concrete. The carbonation process requires the presence of water as the essential condition for the because CO_2 dissolves in the water forming H_2CO_3 (Carbonic Acid). When the concrete is dry, CO_2 cannot dissolve in the Water.

Also, when the concrete is too wet, CO_2 cannot enter the concrete to react with the concrete causing the carbonation.

Normally carbonation results in a decrease of the porosity of the concrete because it fills out the pores of the concrete and create the hindrance in the advancement of the carbonation reaction. Carbonation is harmful because the product of the carbonation which is calcium carbonate do not contribute to the strength of the concrete. It is also disadvantageous in reinforced concrete, as the pH of carbonated concrete drops to about 7; a value below the passivation threshold of steel and here the steel become susceptible to damage by corrosion.



Carbonation Testing in concrete

Carbonation of concrete is tested with the straightforward use of a chemical indicators. The most commonly used indicator is a solution of phenolphthalein in alcohol and water. When the phenolphthalein indicator is applied to the fresh strongly alkaline concrete, it will turn pink. If the alkalinity has been lost, the concrete will not turn pink. There should be a clear mark indicating the difference between pink and natural concrete color. The degree of carbonation can then be measured in millimeters, starting from surface. Normal ranges lie in between 1-3 mm.

The relationship of carbonation and cement content is quite interesting. When the Portland cement is used, then the amount of carbonation expected depends only on the degree of hydration. This is because of the amount of free lime and calcium hydroxide, which is the product of hydration of cement, determines the amount of alkalinity of the concrete and hence the extent of carbonation in concrete. The relationship between the carbonation and water is less prominent. Initial Water content do determine the amount of porosity, especially the number of capillary pores of the concrete and since the moisture and the carbon dioxide of the atmosphere requires the pores in concrete to make their way into the concrete, higher water cement ratio which renders the concrete more porous will have more carbonation. However, the carbonation decreases the porosity of the concrete and hence as the reaction proceeds, the propelling effect of porosity of the concrete will go on decreasing and this will reduce the rate of carbonation. The kind of water and its pH is also very important. Normally alkaline or neutral pH water is used but when the water is typically acidic, water will decrease the pH of the whole concrete.
The relationship between the carbonation and fine aggregates is also less prominent. Chemically fine aggregates are considered to be quite nonreactive and hence their size is only the factor which seems to affect the carbonation of concrete. Size ranging from 4.75mm to 2 mm may be expected to have more carbonation because the interstitial spaces will give the path for the carbon dioxide and water to seep in and react with the concrete. When the size of fine aggregates is lesser than 2 mm, they are expected to fill up the concrete and remove the voids in a better way, making the concrete highly compacted. The relationship between the carbonation and additives is prominent. Additives like plasticizers and air entraining agents reduces the water content requirement of concrete and hence reduces the porosity of the concrete. While plasticizers work by making a cushion of charged layer on the particles, air entraining agent have tiny air bubbles to produce such a cushion effect. This effect becomes prominent when the superplasticizers is used. Superplasticizers are useful in creating the self-compacting concrete. Self-compacting concretes have very less voids and very high degree of packing. Lesser will be the voids, more will be the resistant to attacks of carbon dioxide and moisture seeping into concrete.
The relationship between carbonation and coarse aggregates is prominent. Natural aggregates have less fractured structures than the recycled aggregates hence there is more carbonation occurring in recycled aggregates. Recycled aggregated have the fractured structures because they have been in use for quite some time. Under the load, with creep coming into play, the cracks which would have been very small initially will get widen eventually. These cracks and fractures create the path for the carbon dioxide and moisture from the atmosphere to penetrate and react with the concrete and cause the carbonation.

III. METHODOLOGY

1. Data Collection

The data has been collected the data from various research papers and following tables mentions the numbers of sample data points and the research paper from where the data has been collected.

Author	No. of Sample	Author	No. of Sample
Anna et al. (1995)	4	Basheer et al. (2005)	10
Emmanuel etal (2009)	8	Qiang et al. (2013)	8
L. De and D. Van (1993)	6	Haquea et al. (2007)	4
Lulu et al. (2001)	20	Alexander et al. (2002)	3
Bary and Sellier (2004)	3	Song and Kwon (2007)	10
Kaid et al. (2009)	3	Song et al. (2006)	15
Saud (2008)	6	Basheer et al. (1996)	11
Linhua et al. (2004)	6	Alessandra et al. (2013)	4
Yagu et al. (2005)	4	Dias (2000)	23
Chatveera et al. (2011)	27	Haque et al. (2004)	10
In-Seok et al. (2007)	3	Kim et al. (2007)	10
Semiha et al. (2011)	6	Khana and Lynsdale (2002)	17
Khaiat and Haque (1998)	5	Songa and Velu (2006)	9
Mira et al. (2002)	9	Pipilikaki and Katsioti (2009)	3
Zhang and Li (2013)	5	Anna et al. (1993)	3
Vagelis (2000)	21	Haibing et al. (2012)	30
Kou and Poon (2012)	24	Chang and Chen (2006)	10
Castro and Brito (2013)	10	Tahir and Salih (2007)	12
Han et al. (2007)	4	Ewertson and Petersson (1993)	9
Anna et al. (2004)	5	Caijun et al. (2008)	3
Isgor and Ghani (2004)	17	Parrott (1992)	8

Data Collection for the Natural Aggregate Concrete

Parameter	Average	Variance	Maximum	Minimum
Cement	0.1563	0.0016	0.3251	0.1034
Water	0.0869	0.0004	0.1620	0.0606
Coarse Agg.	0.4511	0.0046	0.7331	0.3077
Fine Agg.	0.3048	0.0066	0.4615	0
Additives	0.0009	0.0000	0.0130	0
Carbonation (mm)	8.5112	12.1640	16.0000	1.9500

Statistical parameters of the Data for the Natural Aggregate concrete

Author	No. of Sample
Semiha et al. (2010)	4
Gameiro et al. (2014)	10
Pacheco et al. (2012)	12
Kou and Poon (2012)	18
Kiyoshi and Kohji (2007)	20
Sara and Brito (2013)	10
Vivian and Wang (2008)	9
Medina et al. (2012)	9
Roumiana and Frandois (2003)	4
Silva and Saikia (2013)	15
Jongsung and Park (2011)	12
Wonjun and Noguchi (2013)	12
Bravo and Brito (2012)	18
Valeria and Moriconi (2009)	12
Osborne (1999)	9
Zhu (2013)	6
Abdelgadir (2009)	14
Pedro et al. (2014)	6
Thomas et al. (2013)	20
Alexandre et al. (2014)	4
Salomon and Helene (2004)	16
Kou and Poon (2013)	11
Antnio et al. (2014)	10
Lovato (2012)	10
Evangelista and Brito (2010)	3
Lan et al. (2014)	4

Data Collection for the Recycled Aggregate Concrete

Parameter	Average	Variance	Maximum	Minimum
Cement	0.1638	0.0017	0.2559	0.0896
Water	0.0926	0.0004	0.1408	0.0579
Coarse Agg.	0.2923	0.0293	0.5018	0
Recycled Agg.	0.1502	0.0264	0.4292	0
Fine Agg.	0.3008	0.0071	0.4102	0.1514
Additive	0.0002	0.0000	0.0015	0
Carbonation(mm)	10.8071	55.0121	28.1000	0.7000

Statistical parameters of the Data for the Recycled Aggregate concrete

2. Data Modelling

Carbonation of concrete depends on the mix proportion of the concrete. It is the mix proportion which determines the end product which is made after mixing of the concrete. To model the relationship between the mix proportion and concrete durability properties is a very tough ask because this is a very complex relationship. In this paper, the Linear Regression Analysis technique and Artificial Neural Network Technique have been used for the data analysis and modelling of the carbonation of the concrete.

Abbreviation	Meaning
C	Cement Proportion
W	Water Proportion
G	Coarse Aggregate Proportion
S	Fine Aggregate Proportion
A	Admixture Proportion
R	Recycled Aggregate Proportion
Y	Carbonation

Linear Regression Analysis Technique

Linear regression Analysis technique is based on method of least square regression and uses the statistical data to arrive to the approximate solution. Linear regression is a simple approach which is used for modeling the relationship between and scalar dependent variable and one or more explanatory variables. When the relationship has been modeled, the values can be predicted of unknown data from the known values of data. Model developed from linear regression analysis are easier to fit than the model developed from other method of regression analysis.

PYTHON programming language has been used for coding.

Let's have X= (C, W, G, S, A) and Y= Carbonation of the Concrete.

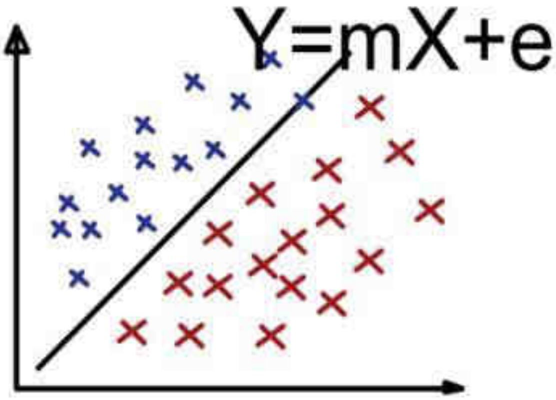
$$\sum Y = mX + e$$

$$For\ (\sum Y - (mX+e))^2\ to\ have\ the\ minimum\ value$$

$$\frac{d(\sum Y - (mX+e))^2}{dm} = 0\ and$$

$$\frac{d(\sum Y - (mX+e))^2}{de} = 0$$

Solving these two equations will give us the value for m and e.



Linear Regression Model

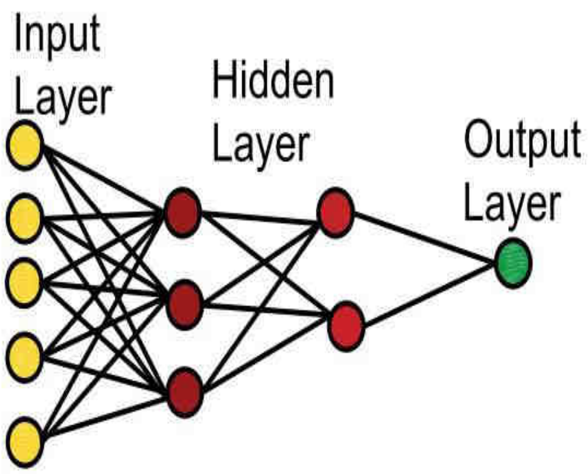
Artificial Neural Network

An artificial neuron network (ANN) is a computational model which is based on the structure and functions of our biological neural networks. Artificial neural networks are generally considered nonlinear statistical data modeling tools where the complex relationships between inputs and outputs is modeled. An artificial neuron is a computational model inspired by theworking of the natural neurons. Natural neurons receive signals through synapses located on the dendrites or membrane of each of the neuron. When the signals received are strong enough (surpass a certain threshold), the neuron is activated and emits a signal though the axon. This signal might be sent to another synapse, and might activate other neurons. Finally the signal which reaches the brain has got the information which relates to the input.

- Modelling is done by the use of PYTHON Programming language.
- Use of Numpy Library, Array Library and Matplotlibrary has been used.
- Randim number are used for creating the weights of the function
- For forward propocation and back propagation, the activation function used is Sigmoid function

$$f(x) = \frac{1}{1 + e^{-x}}$$

The three layers in the Artificial Neural Network are input, hidden and out layers. The network receives inputs by Dataset in the input layer, and the output of the network is gives the normalised output which has to be multiplied with the normalizing parameter.



Artificial Neural Network

IV. RESULTS

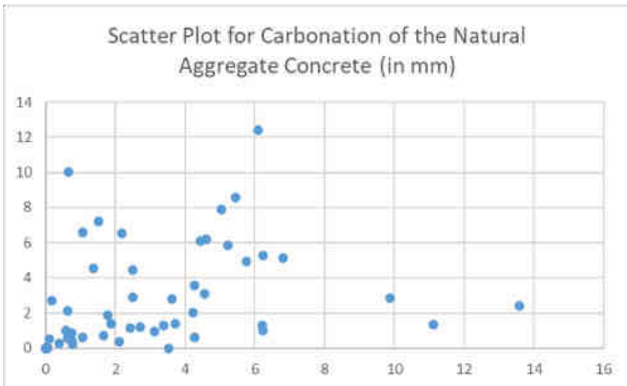
For the Natural aggregate concrete

Since the Data for the output has been normalized by dividing all the carbonation data by maximum carbonation=28 mm for the purpose of model generation, the output values need to be multiplied by a factor of 16.

Linear Regression Model Carbonation (mm) for Generalized mix proportion is given by the following expression: -

Carbonation (in mm) =16*(0.1451 ∗ C − .0460 ∗ W + 0.7729∗ G− 0.0042 ∗ S + 0.1987 ∗ A)

The Correlation Coefficient was **0.55**



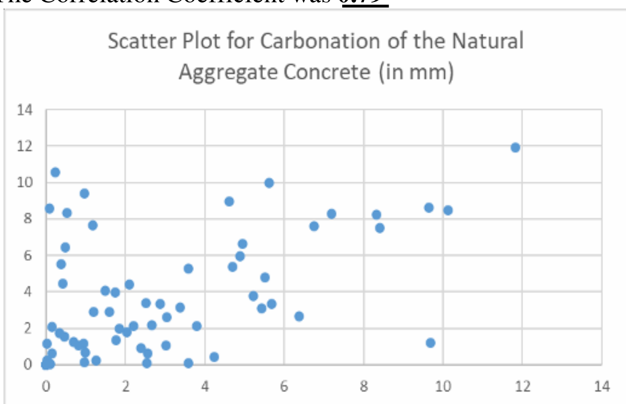
Artificial Neural Network Model The corrected weights in following form are resulted, this are the weights for layer 1 which is input; hence first index is zero.

W011	W021	W031	W041	W051
0.81	0.90	0.12	0.91	0.63

W012	W022	W032	W042	W052
0.27	0.54	0.95	0.96	0.15

The output from the Artificial Neural Network is to be multiplied by the factor 16 in order to attain the amount of carbonation (in mm)

The Correlation Coefficient was **0.79**



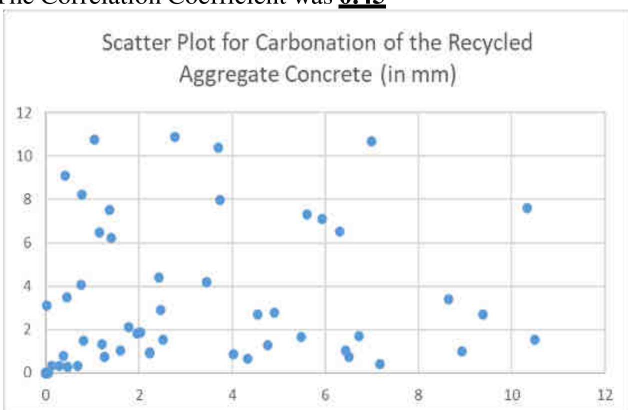
For the recycled aggregate concrete

Since the Data for the output has been normalized by dividing all the carbonation data by maximum carbonation=28 mm for the purpose of model generation, the output values need to be multiplied by a factor of 28.

Linear Regression Model Carbonation (in mm) for Generalized mix proportion is given by the expression

Carbonation (in mm) =28*(−2.5591 ∗ C + 2.5998 ∗ W+ 0.8282 ∗ G+ 0.5728 ∗ R − 0.5381 ∗ S + 0.1727 ∗ A)

The Correlation Coefficient was **0.45**



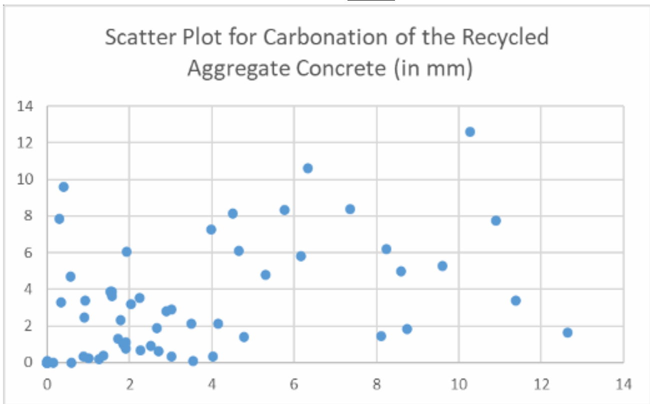
Artificial Neural Network Model The corrected weights in following form are resulted, this are the weights for layer 1 which is input; hence first index is zero.

W011	W021	W031	W041	W051	W061
0.48	0.32	0.54	0.95	0.36	0.02

W012	W022	W032	W042	W052	W062
0.39	0.51	0.58	0.50	0.73	0.72

The output from the Artificial Neural Network is to be multiplied by the factor 28 in order to attain the amount of carbonation (in mm)

The Correlation Coefficient was **0.65**



CONCLUSION

The data which has been collected, is full of variety, from all over the world. The data has been scaled to a common scale for the Data analysis. Some part of the data has been used as sample to develop the model and some part for the data to test the accuracy and effectiveness of the model. As the results are showing Artificial Neural network is far better than the linear regression analysis. The efficiency of the model is definitely going to increase with the more data collection. However, for some cases, data is abundant and for other cases there is scarcity of the data. Hence even for the similar carbonation properties, the model may have differences in the efficiency in the predictions

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