Paper #XX

Data Analysis of Fly Ash Geopolymer Compressive Strength Using Machine Learning Method

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ABSTRACT

Geopolymer is an alternative material that is suitable to substitute Ordinary Portland Cement (OPC) to produce concrete. A mixture of geopolymer paste that binds coarse and fine aggregate and other unreacted materials together is called Geopolymer Concrete. Previous studies stated that alkaline activator molarity, water binder ratio, and type of activator played a significant role in the compressive strength of geopolymer concrete. Machine learning or artificial neural networks are particularly appropriate for modelling non-linear relationships, and they are characteristically used to accomplish pattern recognition and categorize objects or signals in vision, speech, and control systems. This research is to analyze compressive strength data sets of geopolymer concrete by using the machine learning method. The result comparison of compressive strength is divided into three parameters which are based on molarity, water binder ratio, and the type of activators in the ratio between sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The materials used for the preparation of geopolymer concrete in this study are fly ash as a binder, fine and coarse aggregates, water, sodium silicate sodium hydroxide, and (NaOH) (Na_2SiO_3) as activators. A total of 240 samples were cast and cured at 80 ^oC for 24 hours with 28 days age of maturity before it's have been tested for the compressive strength. This study confirms that the molarity, water binding ratio, and the type of activator pointedly affect the compressive strength of geopolymer concrete. The compressive strength was further analyzed by MATLAB to observe the neural network and clustering of the compressive strength data. It is found that there are 9 clusters discovered. The clustering of the compressive strength shows that there is a likeness of material usage in the creation of Geopolymer Concrete.

KEYWORDS

Geopolymer Concrete, Fly Ash, Sodium Hydroxide (NaOH), Sodium Silicate (Na_2SiO3), Artificial Neural Network, Machine Learning

1. Introduction

The demand for concrete is very high due to the increased development all around the world. When the concrete becomes the main element of construction, indirectly raises the higher demand for OPC. However, the production of OPC is responsible for carbon dioxide release that comes from the burning process of the limestone at a high temperature [1]. Geopolymer is used as a binder as an alternative to cement paste to produce concrete as it is believed to have a higher compression strength of 28 days when compared to conventional concrete with the same volumetric material proportions [2]. The microstructure of GPC is denser than normal cement concrete [3]. Besides, geopolymer concrete is gaining momentum as an innovation due to its potential in solving issues related to the environment [4]. Sodium hydroxide (NaOH) and potassium silicate or sodium silicate are the greatest common alkaline liquid used in geopolymerisation. The high concentration of NaOH solution surges the geopolymerization reaction [5]. The workability of GPC is subject to the ratio of Na_2SiO_3 to NaOH and the concentration of NaOH
The molarity of alkaline binder is believed to play a significant role in affecting the compressive strength of the Geopolymer concrete mixture [6]. Also, the different types of activators as a binder to the geopolymer concrete contribute to the compressive strengths of the geopolymer concrete. Other than that, the water binder ratio also influences the characteristics of geopolymer concrete in terms of workability and strength of the concrete. These days, artificial intelligence (AI)-based algorithms were broadly used to solve very complex problems in engineering [7]. An artificial neural network is a system designed similar to a brain of a human that learns by using interrelated neurons or nodes in a layered structure. ANN was accomplished to recognize shapes, categorize data, and estimate future events. As artificial neural networks concede modelling of nonlinear processes, it has turned into a very

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prevalent and convenient tool for solving many problems such as classification, clustering, pattern recognition, regression, dimension reduction, anomaly detection, structured prediction, decision making, and visualization and machine translation [8]. In the situation of classification and data breakdown, the Self-Organizing Map (SOM) method focuses on the neighbourhood structure between clusters. Topology preservation is the correspondence between this clustering and the input nearness [9]. The samples will be evaluated by the machine learning method to evaluate their clustering.

2. Methodology

2.1 Sample Preparation

In the mixing of the geopolymer concrete, the selection of materials is important to make sure the mixture fully complies with the standards and guidelines. The quality of the material is according to ASTM C618 class F classification to ensure the cube specimens give better results in structural response, strengths, and workability. Figure 1 shows the materials needed for the mixing of the geopolymer concrete.

Figure 1. Cube Specimens

For the purpose of this research, several parameters have been used in order to perform the strength of geopolymer concrete. Firstly, the molarity of the NaOH is 8M and 10M with a water binding ratio of 0.3 and 0.35. Second, is the ratio between NaOH and Na_2SiO_3 where the ratio takes 1:0.5 and 1:1 with a 0.3 water binding ratio. In order to demonstrate the mix proportion of the geopolymer concrete can be shown in Tables 1 and 2 respectively. The ratio of the mixture is 1:2:4 (fly ash: fine aggregates: coarse aggregates). There are 30 samples of cube specimens with sizes of 100mm x 100mm x 100mm for each parameter.

Table 1. Mix Proportion for Molarity and W/B ratio

Molarity	Fly Ash Content (kg)	Fine Aggregates (kg)	Coarse Aggregates (kg)	Alkaline Activator (NaOH) (g)	Water Binding ratio	Water Consumption (ml)	Maximum Size of Aggregates (mm)
8M	10	20	40	960	0.3	3000	20
8M	10	20	40	1120	0.35	3500	20
10M	10	20	40	1200	0.3	3000	20
10M	10	20	40	1400	0.35	3500	20

Table 2. Mix proportion for the type of activator

Ratio Between NaOH to Na_2SiO_3	Fly Ash Content (kg)	Fine Aggregates (kg)	Coarse Aggregates (kg)	Alkaline Activator (g)		Water Binding ratio	Water Consumption (ml)	Maximum Size of Aggregates (mm)
				8M / 10M of NaOH	Na_2SiO_3			

1:0.5	10	20	40	960	480	0.3	3000	20
1:1	10	20	40	960	960	0.3	3000	20
1:0.5	10	20	40	1200	600	0.3	3000	20
1:1	10	20	40	1200	1200	0.3	3000	20

2.2 Compressive Strength Test

After mixing geopolymer concrete, it is then compacted inside the cube mould and dried in the oven for 24 hours with a temperature of 80 C^{o}. Then, the mold cooled before demolding and cured at room temperature. The curing process for the geopolymer concrete is based on the normal temperature after drying in the oven. The cube specimens rest for 28 days before being compressed with a 0.5MPa/s loading rate to get their strengths according to ASTM C618, 2005.

2.2 Neural Network

MATLAB software was used to obtain the second objective of this study, which is to analyze the compressive strength of Geopolymer Concrete. The process of clustering is related to grouping data by similarity. In order to obtain that, the first step is to create the network with a single click on the software. Then, by using the self-organizing feature map (SOM), the neuron is organized in a grid form. The second step is to specify the map size, this corresponds to the number of rows and columns in the grid. For this study, the map size value to 30 x 8. The total number of neurons is equal to the number of points in the grid which is the map shows 9 neurons. Next in line is to analyze the result. The weight vector allied with each neuron moves to develop the center of input vectors. The neuron that is adjacent to each other should also move close to each other in the input space, consequently, it is visualized as a high-dimensional inputs space in the two dimensions of the topology network. The default topology of the SOM is in a hexagonal shape.

3. Result and Discussion

3.1 Compressive Strength

The average compressive strength of eight different mixtures of GPC and its clustering are shown in Figure 2. From the chart, it shows that the average strength of 1:1 10M NaOH to Na_2SiO_3 with 0.3w/b (24.516MPa) is higher compared to the other samples which are 1:05 10M NaOH to Na_2SiO_3 with 0.3w/b (16.614MPa), followed by 10M NaOH with 0.35 w/b (12.375MPa), next is 8M NaOH with 0.35w/b (12.047MPa). 10M NaOH with 0.35 w/b (9.920MPa), and 8M with 0.3w/b (7.908MPa), 1:1 8M NaOH to Na_2Si0_3 with 0.3w/b (4.67MPa) and lastly 1:0.5 8M NaOH to Na_2Si0_3 with 0.3w/b (3.123MPa). The strength of the GPC mixture is mostly influenced by the molarity of the alkaline binder in it. It can be proved from the result as the highest strength is the mixture with the highest molarity. Even with the differences between NaOH and Na_2SiO_3, a mixture with higher molarity is always on the top of the list. This is also meaning that the type of alkaline binder is influencing a little the strength but it is more to the molarity of the alkaline binder in it. After all, the addition Na_2SiO_3 did enhance the strength of Geopolymer Concrete. Consequently, it can be said that the higher the molarity, the highest its compressive strength. It can also be concluded that the strengths of the GPC mixture depend on the amount, type, and combination of the alkaline binder in it. Also, as the assumption proved by the data, the higher the water-binding ratio in geopolymer concrete, the lower its strength.

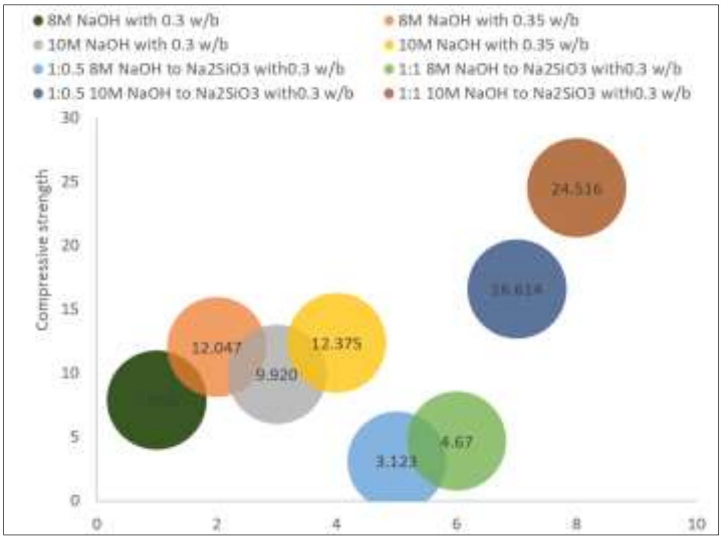

Figure 2. A cluster of Compressive Strength Range as A Function of Molarity, Water Binder Ratio, and Type of Activator

3.2 Neural Network

Figure 3 shows that most of the compressive strength is located in the same place proving that it is connected to each other. This is due to the mixture of the geopolymer concrete consisting of likely identical materials which contain NaOH and Na_2SiO_3 as the alkaline binder of GPC. This is the initial neuron network for the compressive strength to be clustered. While Figure 4 shows the whole intensity of similarities for every network connection in this study. There are eight (8) inputs have been formed based on the eight (8) types of parameters. The lighter colour of the structure connection shows the very good similarity of the neuron which means the compressive strength of each parameter of geopolymer concrete has similarity production that contributes to the value of compressive strength. This is could be the indication of likely similar material used in the mixture even with different amounts of the material itself. The darker colour of the neuron structure shows dissimilarity of the neuron.

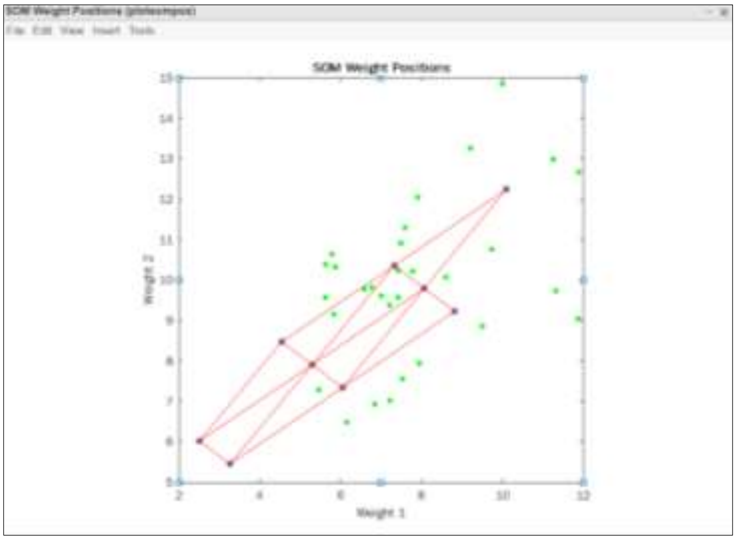

Figure 3. Neuron Network of Geopolymer Concrete compressive strength

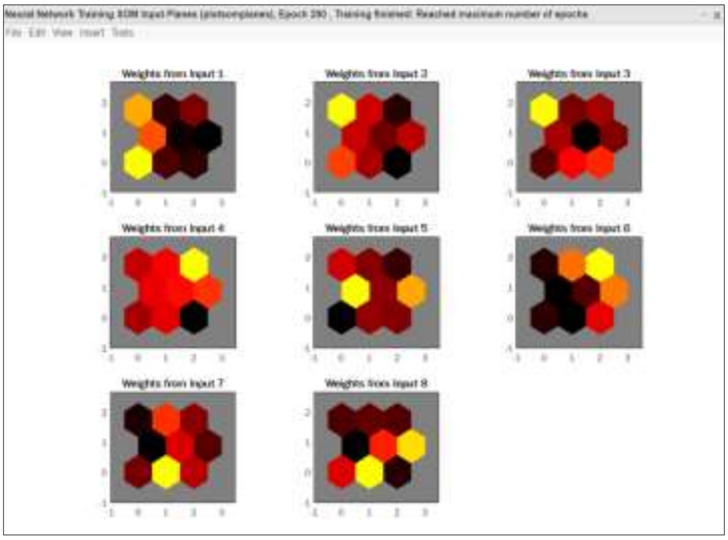

Figure 4. Neural Network Input

From Table 3 below, it can be presumed that most of the neurons have similarities to each other which can contribute to a cluster. The colours represent the input parameters of the geopolymer mixes. The same colour means similarities to each other in terms of compressive strength. It also shows the relationship between input and similarities between each mix.Based on the result of the compressive strength, the neuron classified and connected to each other. It clarified that the most similar input layer is input layer 2 which is 8M NaOH with 0.35 w/b where it has a strong relationship to the 5-input layer which is input layers 3, 4, 5, 6, and 8. It shows a very good relationship to the neuron and has similarities to each other.

Table 3. Neuron Similarity and Dissimilarity

Input	1	2	3	4	5	6	7	8
1								
2								
3								
4								
5								
6								
7								
8								

Input 1	8M NaOH with 0.3 w/b
Input 2	8M NaOH with 0.35 w/b
Input 3	10M NaOH with 0.3 w/b
Input 4	10M NaOH with 0.35 w/b
Input 5	1:0.5 8M NaOH to Na_2SiO_3 with0.3 w/b
Input 6	1:1 8M NaOH to Na_2SiO_3 with0.3 w/b
Input 7	1:0.5 10M NaOH to Na_2SiO_3 with0.3 w/b
Input 8	1:1 10M NaOH to Na_2SiO_3 with0.3 w/b

4. Conclusion

The result comparison of compressive strength is divided into three categories, there are based on molarity, water binder ratio, and the ratio between Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3). As expected, the concrete strength for a mixture with higher molarity of alkaline mixture which is 10M is higher than the mixture with 8M. The evaluation of geopolymer concrete strength based on the water binder ratio also verifies the hypothesis that a mixture with a higher binder ratio not only improves the workability of the geopolymer concrete but also enhances the strength of GPC. The result similarly shows that the highest strength geopolymer concrete is the mixture with a 1:1:10M NaOH to Na_2SiO_3 ratio (1:05), 0.3w/b which is 24.516MPa stress applied for 28days of Geopolymer Concrete age compared to the lowest strength 8M NaOH to Na_2SiO_3 ratio (1:0.5), 0.3w/b with only 3.123MPa stress applied. It can be said that the analysis shows that the ratio of NaOH/Na_2SiO_3 significantly affects the compressive strength of geopolymer concrete. This study also basically applied the result of geopolymer concrete strength on MATLAB to produce Neural Network. The aim is to analyze the data portrayed in Self Organizing Map to evaluate its cluster. There are 9 clusters discovered. The clustering of the compressive strength shows the likeness of material usage in the production of geopolymer concrete.

5. Recommendations

It is recommended to further study this analysis as it could be the innovation of concrete technology to be in line with the Sustainable Development Goals (SDGs). It is advisable to prepare and tested the geopolymer concrete strength for 3, 7, 14, 28, and 60 days to consider the strength and durability of geopolymer concrete over time to determine the types of structure is the most suitable to use geopolymer concrete to prove the hypothesis that the strength of geopolymer concrete is higher at the early stage. The high early compressive strength can be suitable for emergency construction and repair works. It is also recommended to further study the application of Artificial Neural Networks (ANN) to predict the compressive strength of geopolymer concrete.

6. Acknowledgements

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