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Utilisation of Eggshells Powder in Construction of Concrete

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Abstract: Many researchers research the potential use of any waste material used in construction material in this era. This statement is due to many countries are going to urbanisation because of population growth. In future, the construction industry will grow since Malaysia is one of the developing countries. During the construction of cement, carbon dioxide gas is released, and it causes environmental pollution and global warming. In order to reduce the impact of carbon dioxide gas in the environment, waste by-products are used as an admixture in this study, so environmental pollution and natural resources consumption can be reduced. Eggshell is generally thrown away as waste, but it contains calcium carbonate. This work has investigated the potential use of eggshell. The egg is one of the waste materials generated from the industry and contributes to the environmental and disposal problem due to the increase of eggshell continuously in recent years. In our research, the laboratory work was carried out into four proportions; 0%, 2%, 5% and 7% of eggshell that has been grind into fine powder. This research aims to investigate the properties of eggshell concrete and gathered from previous researchers and predict the strength of concrete based on laboratory data. A total of 12 cubes were cast and weighed to get the mass and density as preliminary data. Previous research that got density data is utilised to compare and predict the compressive strength. The analysis is done and forecast using Microsoft Excel using the trendline equation and R^2 value from the graph plotted. The prediction result showed eggshell powder in 5% additive in concrete has an excellent compressive strength compared to other proportions, which reduce the concrete's compressive strength. For recommendation, laboratory work should be conducted for at least seven days of compressive strength for more accurate prediction.

Keywords: Eggshells Powder, Construction Concrete, Compressive Strength, Strength Prediction

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1. Introduction

Throughout the world, concrete is one of the most critical parts of a construction project. This material has several different uses and is widely used to construct most buildings, pavements, sidewalks, and many others structures. In other words, concrete has been labelled as the backbone of the infrastructure development of a nation. Every project, especially the bigger one, requires a higher cost to cover all the construction costs, including workers, materials, and others. Many researchers come with good alternative ideas to reduce construction costs and save the budget by forming waste materials with processing and treatment that might replace potential building material used in many construction projects [1]. This suitable alternative has positive impacts on both earth and human.

Research has shown that recycled materials used in replacing some of the standard mixture components in concrete products can also produce a more sustainable building material. One common material that can be recycled and used in concrete applications is eggshell. The use of eggshell in construction materials can produce good strength characteristic concrete when mixed with others materials [2]. Most of the eggshell contains about 0.3% magnesium, phosphorous, and traces of sodium, zinc, potassium, iron, copper and manganese. The quality of eggshell usually affected by nutrient adequacy, flock health problem, breeding and environmental condition. Besides, the controlling rate of egg weight also contributes to a good quality of eggshell, and it does not depend on the high thickness eggshell means strong. The eggshell is used in micro size because the smaller the size, the stronger it will be. This statement is due to the unique characteristics of eggshell, which can operate as rigid particulate fillers of the concrete. This fact is also because of the shape and organisation of organic and inorganic component of the eggshell [3].

The eggshell powder is mainly composed of calcium compounds scientifically, which is very similar to cement. Researchers have shown that eggshell powder primarily contains lime, calcium, and protein. It can be used as an alternative raw material in construction to produce wall tile material, concrete, cement paste, etc. Eggshell also contributes to the construction industry in reducing construction costs and landfills, which gives good performance in concrete and durability properties [4]. Thus, eggshells can produce the new raw material for development in the construction industry as an additive in conventional concrete.

In our country, waste disposal is one issue that leads to an environmental problem and has dramatically increased in recent years. In this county, the most common waste disposal is compositing, open burning, incineration, and most eggshell waste deposited in landfills. Based on the news [1], Malaysians consume the highest chicken and egg compared to the other Asian, including Indonesian. The record shows that the Indonesian swallowed per capita egg was recorded as one egg per week, which is still low. For Malaysian, the per capita egg recorded at three-egg per day, which shows the big difference with Indonesian [1]. This statement is due to the high demand for local food that required egg as the main menu.

However, the large amount of waste production tends to increase the number of landfill sites and the number of landfill sites expected to increase due to growth in population, economy, and agriculture. Based on the research, dumping site in Malaysia has grown alarming. So identifying material from waste and using it in concrete production could be wise as Portland cement that costly, energy-intensive, and produces large amounts of carbon emissions. The disposal method such as landfill is not done appropriately and adversely affects the environment [2]. The dumps will fill continually if current trends of waste generation and handling. Therefore, efficient ways should identify by utilising waste to reduce waste disposal, such as by 3R practices; reduce, reuse, and recycle.

1.1 Objective

The objective of this research are as follow;

- To investigate the properties of eggshell concrete and gathered from previous researchers.
- To predict the strength of concrete based on laboratory data.

1.2 Scope and Limitation of Work

The research scope of this study is to investigate the properties of eggshell powder concrete from laboratory work results and analyse data gathered from previous researchers. The properties that have been analysed and predict is compressive strength which use to determine the optimum ratio of eggshell powder when mixed with other materials to form a good concrete and get the significant compressive strength. The eggshell must grind until it turns into a fine powder before mixing the concrete cubes. The mass is weighed after one day of setting. The mass results are used to calculate the density of cubes with the known dimension of cubes. The prediction of our concrete cubes' compressive strength is compared to the previous study based on the densities.

1.3 Significant of Study

This study is significant for finding and investigating alternative ways to replace the construction materials with the eggshell powder partially. In this case, the methods used will help contribute and reduce the amount of eggshell waste and the cost of construction needed for every project. Besides, Malaysian is one of the biggest countries for egg consumers. Therefore, we can assume that this method is a solution to solve the problems and issues such as waste disposal. The prediction method used is significant because it helps to find the assumption results for compressive strength's data.

2. Materials and Methods

This part will clarify the method adopted by this research and mention every component involved in conducting the research: laboratory working, previous research studying, compressive strength predicting, and complying. This part also describes how the study can be carried out from the early stage and points out the issues addressed in more depth regarding the research method's execution to be interpreted. The technique in this part relates to the process of gathering data to carry out the prediction results. After collecting and processing the data obtained, the prediction technique will be used to gaining the results. Graph prediction and comparison techniques will use based on the data obtained from various sources using Microsoft Excel. The data will be compared with each other to prove the effectiveness as it is used.

2.1 Materials

2.1.1 Eggshell

Eggshell and eggshell powder contains calcium, zinc, iron, phosphorus, and magnesium. It is also known as a smooth surface that is desirable compared to rough eggshells that fracture more easily. The characteristics of the eggshell are similar to quarried limestone in terms of durability, water absorption and strength. That's why eggshell is be selected to replace quarried limestone. Besides, eggshell also has its grade, which is the best quality from commercial layers containing approximately 2.2 grams of calcium in calcium carbonate forms. Many factors affect quality, such as nutrient adequacy, flock health problem, environmental condition and breeding [2]. The rate of controlling egg weight is also essential to get a good quality of the eggshell. Most people assume that the thicker the eggshell is higher the strength, but sometimes it is not relevant because the thin one is usually more strong than the thick one. This fact is due to the shape and organisation of the organic and inorganic component of the shell [2].

2.1.2 Cement

Cement or some form of binding agent is required in practically all types of construction. In recent years, the cement market has been dominated by a single product, Ordinary Portland Cement (OPC). OPC is an expensive and sometimes scarce mineral in many nations, particularly Nigeria, which has severely hindered the construction of affordable housing. As a result, alternative cement offers an excellent technical alternative to OPC at a much lower cost. They can make a significant contribution to the availability of low-priced construction materials and, as a result, affordable housing [5].

2.1.3 Fine Aggregates

The effect of fineness, shape, and surface texture of fine particles on mechanical characteristics is frequently overlooked in traditional concretes, even though these features may increase water demand. The hydrated cement paste and the transition zone around the aggregate are relatively weak in this concrete. As a result, at the same degree of hydration, the water-cement ratio governs the mechanical properties of concrete [6]. The best fine aggregate grading is determined by the type of operation, the richness of the combination, and the maximum coarse aggregate size. A grade that approaches the maximum permitted percentage of passing each sieve is preferable for workability in leaner mixtures or when using small-size coarse particles [7].

2.1.4 Coarse Aggregates

Suppose that the proportion of fine aggregate to total aggregate creates concrete with good workability. In that case, the grading for a maximum size coarse aggregate can be changed over a modest range without a notable effect on the mixture's cement and water requirements. If the coarse-aggregate grade varies greatly, the mix proportions should be adjusted to make workable concrete. Because variances are difficult to predict, it is frequently more cost-effective to maintain uniformity in manufacturing and managing coarse aggregates than eliminating gradation variations [7].

2.1.5 Water

Water is also one of the primary material used in concrete making. Generally, water is available easily on the site and lab, such as tap water, well water, municipal wastewater, etc. Increasing the amount of water in the mixtures will improve their workability. More water also increases the potential for segregation, settling coarse aggregate particles, increased bleeding, drying shrinkage and cracking, and decreasing the strength and durability. The quality of water plays an essential role because it will cause corrosion to the steel reinforcement. Besides, quality also affects by harmful substances such as oil, acid, salt, sugar, silt and organic matter [2].

2.2 Methods for Laboratory Work

2.2.1 Preparation of Materials Required from Raw Ingredient

Cement, sand and aggregate are the primary materials in the construction of concrete. However, in this study, it used other materials to replace some of these primary materials, which we used eggshell powder to replace cement partially. These essential materials are sourced from the Heavy Structural Engineering Technology Workshop and Concrete Technology Workshop in the UTHM Pagoh campus, and we also purchased eggshell powder in-store. As for the material ratio, 0%, 2%, 5%, and 7% of eggshell in fine powder form is used for the mixture. The cement to the sand ratio that we use is 1:2, which means 1 part of cement to 2 parts of sand for each percentage of mixture that we conduct. The water-cement ratio that we used in construction concrete is 0.4.

2.2.2 Method for Preparing Concrete Cube

The concrete that has been used in this laboratory work is based on British Standard EN 12390-2:2000 [11], part 2 of testing hardened concrete that entitles making and curing specimens for strength

tests. Usually, the concrete will be mixed using only hands for concrete in small quantities as our laboratory work. The primary tool used in manual concrete mixing is the scope. First of all, the mass measured cement, sand, and aggregate are placed on a tray. Next, the materials were mixed using a scope by flipping the mixture in one direction and repeated in the opposite direction three times for each order, and this inversion work was done in a dry state. After that, a puddle or crater is made in the middle of the mixture. Finally, water is poured into it, and the steps above are repeated for moist conditions.

The concrete cube test is one of the tests carried out on the concrete mix upon arrival at the construction site. The purpose is to determine the strength of concrete. First of all, concrete cubes are made using plastic moulds measuring 100 mm × 100 mm × 100 mm, and the concrete mix is put into a mould in three layers, and each layer is compacted with 30 strokes. The top surface of the concrete is levelled and labelled according to the date it was made. Lastly, the mould is protected from moisture for 24 hours. After the cube is opened, a curing process must be done. One of the curing methods is to soak in water for 7, 14 and 28 days. This process is done to prevent water evaporation from the cube before the compressive strength test is made. Each concrete must be labelled.

2.3 Prediction Method for Compressive Strength

2.3.1 Gathering and Analysing of Data from Laboratory Work

The mass of concrete cubes is weighed after the cube is opened out. **Table 1** showed the mass recorded results from laboratory work and density calculated for further prediction data.

2.3.2 Gathering and Analysing of Data from Previous Research

This research proposes making a prediction based on previously completed research data taken from official journal sources. The data obtained has performed use of eggshells in the construction concrete. Other than that, the completed and thorough in gaining the data is significant for prediction. Taken data are from the journal "Properties of concrete with eggshell powder as cement replacement" [8] and "Eggshell Powder: Potential Filler in Concrete" [9].

The data can be analysed in table form, and a few types of graphs can plot to show the result from the research. Graphs can plot from data are the percentage of eggshell powder against density, compressive strength against the portion of eggshell powder, and compressive strength against density as in **Figure 1**. **Figure 1** is more related and complete to this research, so it is used as the primary prediction data of this study.

2.3.3 Prediction of Compressive Strength

Based on the data obtained, a comparison will be carried out according to the same aspect from laboratory work and previous research from [8], compressive strength and density. It is due to each project may be used different types of material besides the eggshells in the construction concrete. By compare the nearly accurate project from the same aspect, a definite result could be obtained.

The prediction is carrying out by scaling a comparison graph that containing the complete data from previous research. As a result of the graph, the value of R^2 will be obtained and be analysed. A statistic provides information on a model's quality of fit. The R^2 coefficient of determination in regression is a statistical measure of how well the regression predictions resemble the actual data points. An R^2 shows that the regression predictions fit the data perfectly. On behalf of it, the linear trendline equation will be obtained as the nearer value of R^2 to 1, the better the trendline fits the data [10].

After all the prediction and comparison graph be obtained, the analysis could be conducted based on the R^2 value and linear trendline equation resulting in the graph of compressive strength against the percentage of eggshells powder for seven days and 28 days as shown in **Figure 3** and **Figure 4**.

3. Results and Discussion

This part discusses how to utilise the mass of specimens with different percentages of eggshell powder used in the concrete mixture making from our laboratory work. First, from the known mass and volume of cubes, the density of the cube mixture can be calculated. Next, the data from other researchers are used to compare and predict our cube's compressive strength. Finally, Microsoft Excel is used to indicate based on their R^2 value and linear trendline equation.

3.1 Results of Mass and Density Used for Prediction

Table 1: Results of mass and density used for prediction

Percentage (%)	Mass (grams)			Density (kg/m^3)			Average density (kg/m^3)
	S1	S2	S3	S1	S2	S3	
0	2121	2125	2105	2121	2125	2105	2117
2	2098	2080	2107	2098	2080	2107	2095
5	2041	2089	2058	2041	2089	2058	2063
7	1925	1860	1887	1925	1860	1887	1891

Table 1 shows the value of mass obtained in grams and density calculated with different percentages of eggshell powder used in concrete making from our laboratory work. The cube's size that we used is 100 mm × 100 mm × 100 mm with a volume of 1,000,000 mm^3 or in an SI unit of 0.001 m^3. Density is mass per unit volume, so it can calculate by multiplying the mass obtained with 0.001 kg per grams and dividing by 0.001 m^3. It will get the density value in kg/m^3, which is the same as the mass value in grams, because the calculation's constant is cancels out mathematically. We can calculate the average cube's density and use that value to predict compressive strength further.

3.2 Data Analysis from Past Research and Preliminary Prediction of Compressive Strength

Analyse's data are from the journal "Properties of concrete with eggshell powder as cement replacement" written by Amarnath Yerramala [8] and "Eggshell Powder: Potential Filler in Concrete" written by Doh Shu Ing [9].

Figure 1 shows a graph of compressive strength against density that the results take from past research [8]. We get three equations from the linear trendline. The value of *y* indicates compressive strength, while the value of *x* indicates density.

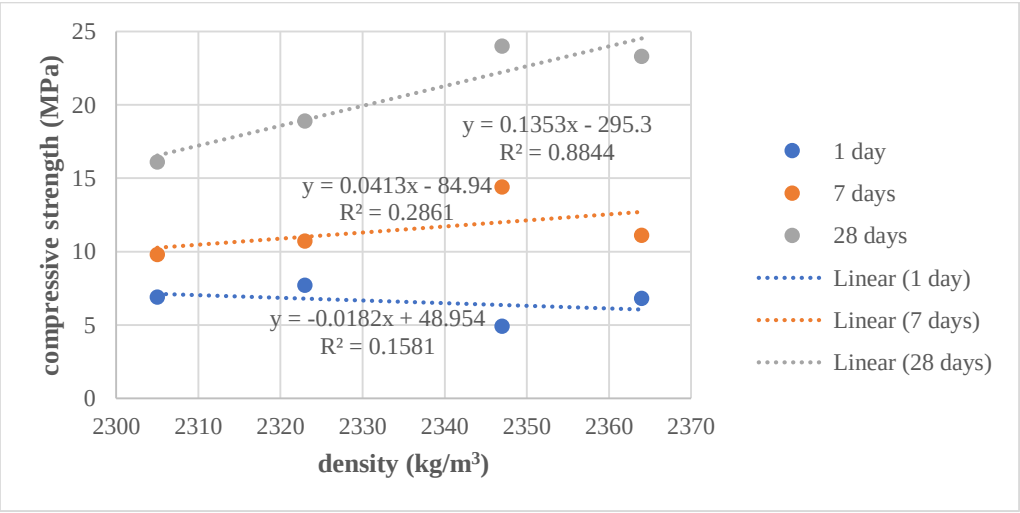

Figure 1: Graph of compressive strength against density (data from [8])

$$y = -0.00182x + 48.954 \quad \textbf{Eq. 1}$$

$$y = 0.0413x - 84.94 \quad \textbf{Eq. 2}$$

$$y = 0.1353x - 295.3 \quad \textbf{Eq. 3}$$

Eq. 1 shows the equation for 1-day compressive strength, Eq. 2 shows the equation for seven days compressive strength and Eq. 3 shows the equation for 28 days compressive strength. Therefore, the average density value from our laboratory work can be substituted in each equation, as shown in **Table 1**. The calculation results and the corresponding compressive strength and its percentage of eggshell powder from past research by different day curing of compressive strength are shown in **Table 2**.

Table 2: Comparison of compressive strength between prediction and data from past researches [8] and [9] by the percentage of eggshell powder (*CS = compressive strength)

	Prediction			Data from [8]		Data from [9]	
	Density (kg/m^3)	Percentage (%)	CS (MPa)	Percentage (%)	CS (MPa)	Percentage (%)	CS (MPa)
1 day CS	2117	0	10.425	0	6.8	-	-
	2095	2	10.825	5	4.9	-	-
	2063	5	11.413	10	7.7	-	-
	1891	7	14.544	15	6.9	-	-
7 days CS	2117	0	2.492	0	11.1	0	21.22
	2095	2	1.584	5	14.4	5	17.48
	2063	5	0.248	10	10.7	10	18.38
	1891	7	-6.855	15	9.8	15	15.14
	-	-	-	-	-	20	17.20
28 days CS	2117	0	-8.870	0	23.3	0	27.20
	2095	2	-11.847	5	24.0	5	29.63
	2063	5	-16.221	10	18.9	10	42.82
	1891	7	-39.493	15	16.1	15	38.67

3.3 Further Prediction from Equation Involved

Compared to the value of prediction from **Table 2**, 1-day compressive strength values are more significant because it does not have any negative value. Therefore, we plot a graph of 7 days and 28 days compressive strength against 1-day compressive strength, as shown in **Figure 2**.

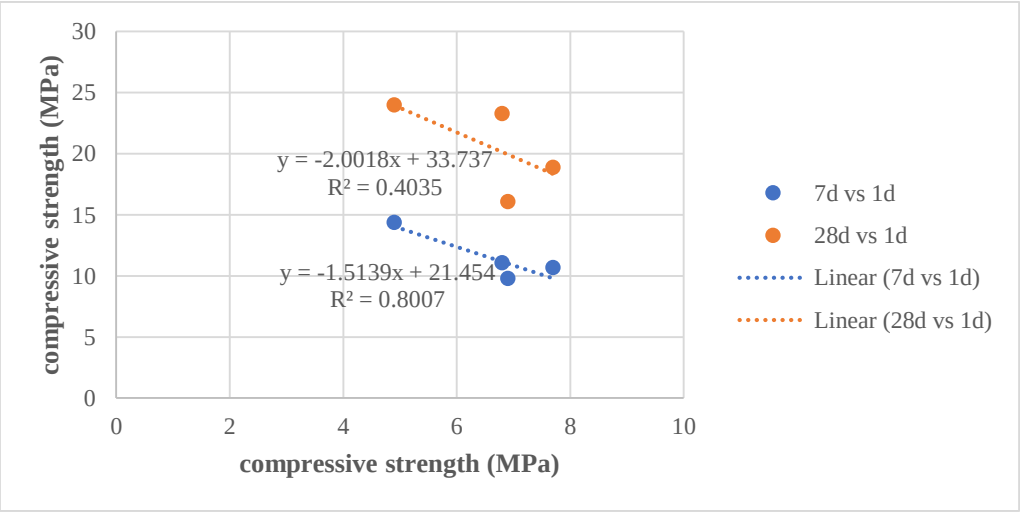

Figure 2: Comparison of compressive strength [8]

$$y = -1.5139x + 21.454 \quad \textbf{Eq. 4}$$

$$y = -2.0018x - 33.737 \quad \textbf{Eq. 5}$$

From **Figure 2**, two equations are obtained from the linear trendline, which is Eq. 4 is seven days, and Eq. 5 is 28 days compressive strength. Next, we substitute the prediction value of 1 day compressive strength as x value from **Table 2** into Eq. 4 for seven days compressive strength and Eq. 5 for 28 days compressive strength. The latest value of the compressive strength test shown in **Table 3**.

Table 3: Final prediction value of compressive strength

Percentage of eggshell powder (%)	Compressive strength (MPa)	
	7 days	28 days
0	5.672	12.869
2	5.066	12.068
5	4.175	10.890
7	-0.564	4.623

3.4 Comparison of Predicted Compressive Strength with Past Researches and Discussions

From **Table 3**, a graph of compressive strength against the percentage of eggshell powder for seven days as in **Figure 3** and 28 days as in **Figure 4** can plot to show the comparison between predicted compressive strength and past research [8] and [9].

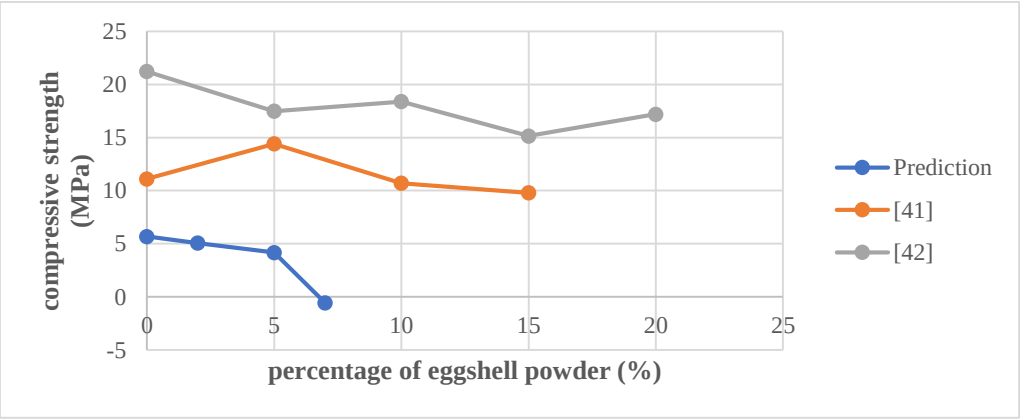

Figure 3: Graph of 7 days compressive strength against the percentage of eggshell powder [8] and [9]

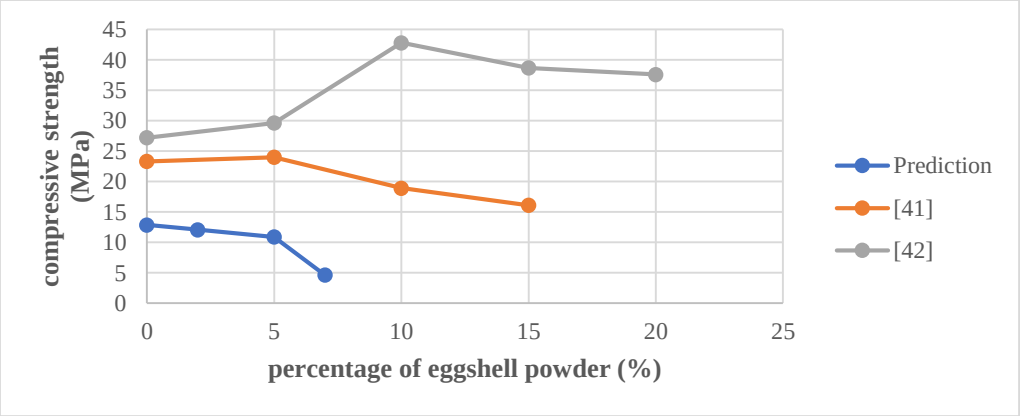

Figure 4: Graph of 28 days compressive strength against the percentage of eggshell powder [8] and [9]

It was a little bit high of data from [8] compared to [9]. Still, the prediction data is the lowest, as shown in **Figure 3** and **Figure 4**. It may be due to the different working of mixing concrete where the standard use for [8] is ASTM standard while [9] and this laboratory work use the British standard. It may also be due to the size of eggshell powder used in concrete construction as [8] uses 90 micrometres while [9] and this laboratory work uses 2.36 millimetres. It will make an impact on the density obtain between them. Furthermore, it also can notice that the predicted compressive strength value decreases sharply after 5% of eggshell powder used in concrete making. Therefore it can conclude that the optimum percentage of eggshell powder use in the concrete making is 5%.

4. Conclusion

In conclusion, the prediction method used to get the relevant results substantially affected accuracy and was generally more critical than other methods. The objectives of this study achieved where the prediction data was obtained based on the previous researches. Two previous research's journal is combined and compared to get more relevant results. Based on the prediction data, the most suitable percentage of eggshell powder was 5% compared to other portions because the compressive strength data predicted was 4.175 MPa for seven days and 10.890 MPa for 28 days. Eggshell powders can increase the strength of the concrete when mixed with other construction materials. Besides, the cost that needed to cover all the construction works and materials is relatively high. In addition, the increased consumption of eggs leads to an increase in eggshell waste which is highly harmful to the environment. The research for using eggshell as the materials in constructions is one of the solutions. The laboratory work should be conducted for at least seven days of compressive strength and record the results as a recommendation. The result obtained can be compared with other previous research's journal and helps to get a more accurate result for the prediction method.

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