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Compressive Strength of Concrete containing Eggshell Powder as Partial Cement Replacement

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Abstract. The emission of carbon dioxide by cement manufacturing has caused a negative impact on society and environment such as the greenhouse effect. Disposal of eggshell has created a lot of environmental problems due to its reusability of material is low in many industries. Recent years, researchers have found the value of eggshell due to its high content of calcium carbonate. Consequently, it has encouraged the researchers to incorporate the eggshell as cement replacement for concrete production hence contributing to sustainable development of building materials. This experimental study is aimed to investigate the optimum percentage of eggshell as cement replacement for high strength concrete (HSC) and the effect on HSC were studied in terms of workability, compressive strength and rebound hammer test as well as ultrasonic pulse velocity (UPV). Four types of mix proportion of HSC were prepared namely 0% ESP, 5% ESP, 10% ESP and 15% ESP. Based on the experiment results, the workability of the fresh concrete mixtures decreases as the percentage of eggshell replacement increases. Mix containing 10% eggshell specimen achieved the highest compressive strength of 68.4 MPa at 28 days. Furthermore, the 10% eggshell specimen also achieved the highest value of rebound number of 42.1 and pulse velocity of 6.50km/s at 28 days. Correlation between actual compressive strength and UPV was more reliable and had accurate expression through regression analysis compared to rebound hammer test. Conclusively, the concrete containing 10% eggshell as partial cement replacement exhibits higher compressive strength than control concrete has the potential to be used as construction material.

1.0 Introduction

Concrete is one of the building materials that is commonly utilized as a construction material throughout the world. The gradual development in concrete research has led towards the production of high strength concrete (HSC) which is technically applicable for construction work where durability and strength is critical such as high-rise buildings [1]. A concrete with a specific characteristic of cube strength between

40 and 100 N/mm^2 could be known as HSC [2]. HSC showed better performance in compressive strength, durability and affordability compared to conventional concrete.
Cement is one the essential material used in the concrete production. Production of concrete in industry will cause social and environmental issues like emission of greenhouse gases and lead to global warming. Cement industry contributed up to 6% of the total global CO_2 emission [3]. Besides that, about 1.61 million tonnes of eggshell waste is produced annually that causes landfill problems and environment pollution [4]. Next, high demand of materials for concrete production has caused the depletion of good and quality natural resources such as limestone.
Concrete construction industry encourages introducing sustainable concrete by reusing waste materials as replacement of original material in concrete production. Eggshell has a very similar chemical component with limestone which has a high content of calcium oxide [5]. By utilizing of eggshell powder as cement replacement in concrete can help in reducing the use of cement in concrete production, conserving natural lime and utilizing waste material [6]. It also reduces the amount of global CO_2 emission by minimizing the consumption of cement in concrete production. Also, using eggshell waste in concrete production will reduce the waste landfill problems.
Currently, sustainable concrete is a widely studied topic in order to reduce the environmental impact and use of cement. The replacement of cement with waste products is a long-running study to reduce the reliance on cement while producing concrete with better strength and performance. However, the literature review on concrete containing eggshell is limited. Eggshell powder has been used as a cement replacement to produce green concrete. The use of eggshell powder as a cement replacement in the production of normal strength concrete has shown positive results. Therefore, this research attempts to fill the gaps of knowledge by studying the effect of eggshell as partial cement replacement in high strength concrete on the workability, compressive strength and correlation between compressive strength with non-destructive test.

2.0 Materials

2.1 Cement
The cement used in this study is localize Orang Kuat Ordinary Portland Cement (CEM I 42.5 N) manufactured by YTL Cement that conforming to BS EN Specification for Portland Cement (BS12/BS EN 197-1:2000 and ASTM C 150-95 Type I.

2.2 Aggregate
Coarse aggregate used in this study was crushed stone with a nominal size of 10mm. Meanw hile, the fine aggregate used was within the range of 75 µm to 4.76mm. In this study, the fine aggregate was dried in the oven at a temperature of 110 °C for 24 hours to remove its uncertain moisture. Then, aggregate was kept in dry condition and free from impurities and the aggregate used in this study was conforming to BS Specification for Aggregates for Concrete (BS EN 12620).

2.3 Eggshell Powder
The eggshell waste was supplied by Egg Tech Manufacturing Sdn Bhd, Puncak Alam, Selangor. The eggshell was carefully rinsed and washed to eliminate the organic residue of the egg. Then, the eggshell was dried in the oven with temperature 105 °C for 24 hours. Clean eggshell was collected and ground by a grinding machine. The ground eggshell powder (ESP) was prepared by sieving through sieve size 150µm. Figure 1 shows the eggshell powder used in this study as a filler in the concrete mixing. The chemical composition of ESP and OPC is shown in Table 1.

Figure 1. Eggshell Powder

Table 1. Chemical composition of ESP and OPC

Element	OPC	ESP
Calcium Oxide (CaO)	60.1	52.10
Magnesium Oxide (MgO)	2.1	0.06
Silica Dioxide (SiO_2)	21.8	0.58
Alumina (Al_2O_3)	6.6	0.06
Ferric Oxide (Fe_2O_3)	4.1	0.02
Chloride (Cl)	-	-
Sulphur Trioxide (SO_3)	2.2	0.62
Potassium Oxide (K_2O)	0.4	0.25
Sodium Oxide (Na_2O)	0.4	0.15
Loss on Ignition (LOI)	2.4	45.42

2.4 Super plasticizer
Super plasticizer used in this study is Sika Viscocrete. It used to reduce the water content in concrete and maintain the workability performance.

2.5 Water
According to ASTM C1602 (2012), potable and non-potable water is permitted to be used as mixing water in concrete. In this study, water is used for concrete mixing and curing regime.

3.0 Methodology

3.1 Mix Design
In this study, the targeted strength of concrete is 60MPa at 28 days with a water/cement ratio of 0.32 and 1% super plasticizer. A basic control mix of concrete without eggshell powder (0%ESP) was designed as a control and four mix with different types of eggshell proportions by weight of cement namely as 5% ESP, 10% ESP and 15% ESP were prepared. The mix design proportion of this study was shown in Table 2.

Table 2. Mix design

Materials (kg/m^3)	0% ESP	5% ESP	10% ESP	15% ESP
w/c ratio	0.32	0.32	0.32	0.32
Cement	720	684	648	612
Coarse aggregate	915	915	915	915
Fine aggregate	610	610	610	610
Eggshell	0	36	72	108
Super plasticizer	7.20	7.20	7.20	7.20

3.2 Sample Preparation

A total of 24 cubes with dimensions of 100 mm x 100 mm x 100 mm were prepared and tested to determine the compressive strength for all mixtures. Each test result was obtained with the average reading for 3 cube specimens. The mould was coated with a thin layer of oil before fresh concrete was poured into the mould so that demoulding process would be easier. The mould will be filled in with 3 layers. Compaction is done by vibrating on a vibrating table for each layer to make sure the concrete is well compacted. After 24 hour the specimen was demoulded and cured in the water tank until the testing ages as shown in Figure 2.

Figure 2. Water curing

3.3 Slump Test

The slump test was performed according to BS 1881-102 to determine the workability of a concrete mix whether it can be mixed, transported, placed and compacted in position. The workability of the concrete will be based on its slump height and the type of slump that was observed.

3.4 Compression Strength Test

The compression strength test was conducted in this study by using a compression machine in accordance with BS 1881-116 to determine the compressive strength of the concrete cube at age 7 and 28 days. Equation 1 is used to obtain the concrete compressive strength.

$$f = P/A \qquad (1)$$

Where f is compressive strength (MPa); P is maximum load carried (N) and A is average cross-sectional area of the specimen (mm^2).

3.5 Rebound hammer

Rebound hammer test or a surface hardness test is known as a non-destructive test (NDT) that is performed according to BS-1881-Part-202 to determine the relative compressive strength and uniformity of concrete based on the hardness at or near its exposed surface. In the procedure of rebound hammer

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test, the plunger of rebound hammer is pressed on the surface of concrete, so that a spring-controlled mass with a constant energy is made to hit the concrete surface. At the same time, a spring-controlled mass rebound back. This extent of rebound on a graduated scale is measured for the surface hardness. This measured value is designated as Rebound Number or a Rebound Index. Low rebound number or rebound index means that the concrete has low compressive strength and low stiffness. Average of twelve readings should be taken for each point of testing for the rebound number on the concrete cube. The rebound number value will represent the concrete quality which references Table 3.

Table 3. Classification of concrete quality based on average rebound number

Average Rebound Number	Quality of Concrete
> 40	Very Good
30 – 40	Good
20 – 30	Fair
< 20	Poor and/or Delaminated

3.6 Ultrasonic Pulse Velocity
The scanning ultrasonic pulse velocity test is one of the NDT that performed according to BS 1881: Part 203 to determine the propagation velocity of longitudinal stress wave pulses through concrete by determining quality of concrete and detecting damage in structural components. Equation 2 shows the method to measure the time of travel of an ultrasonic pulse passing through the concrete. The quality of concrete also can be determined by referring to the standard in Table 4 by using the pulse velocity value.

$$V = \frac{\$}{\%} \qquad (2)$$

V = Pulse velocity (km/s)
L = Path length for vibration to travel between two transducers (mm)
t = Time taken for pulse go through concrete structure (µs)

Table 4. Classification of the quality of concrete based on pulse velocity

Pulse Velocity (km/second)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

4.0 Results and discussions

4.1 Influence of ESP on the workability of Concrete

In this study, the influence of ESP on the workability of concrete was determined by using slump test. The result of the slump test was tabulated in Table 5 and the relationship between slump test and concrete mixture is shown in Figure 3. It can be seen that the 0% ESP mix has the highest slump of 50 mm and mixture containing ESP fell under the acceptable range of 75±25 mm. Similar results were reported by Tan, Doh, & Chin [11], concrete containing ESP produce slump height of 73 mm within the acceptable range. Among the mixture of ESP, 15% ESP mix exhibits the lowest slump height of 45 mm. It is indicated that the slump height decreases as the percentage of eggshell replacement in concrete increases. This may be attributed to the high-water absorption of eggshell powder which consumes the water and restricts the flowability. The particle size of eggshell powder with finer grind will have larger surface water which will absorb more water and reduce the workability of concrete mix more adversely [12]. Nevertheless, the fresh concrete for all mixtures were classified as true slump as shown in Figure 4.

Table 5. Slump height of specimen

Concrete Mix	Slump Height (mm)	Slump Type
0% ESP	50	True Slump
5% ESP	48	True Slump
10% ESP	47	True Slump
15% ESP	45	True Slump

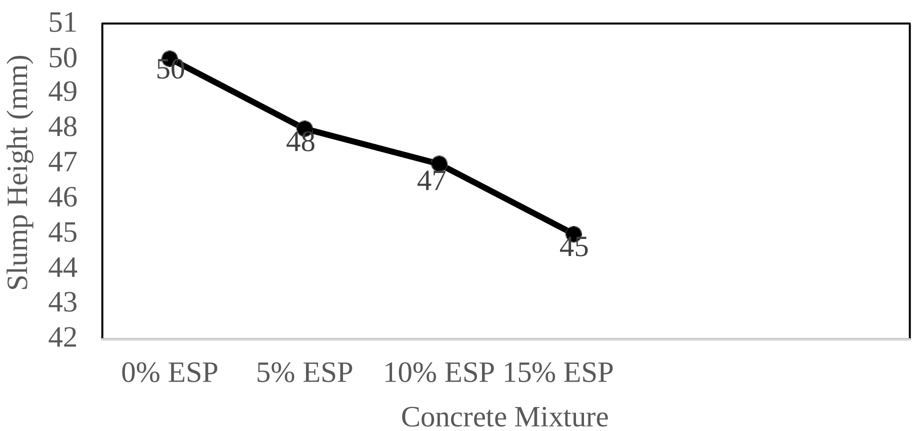

Figure 3. Relationship between slump height and concrete mixture

Figure 4. True slump

4.2 Influence of ESP on Compressive Strength of Concrete

The influence of ESP on compressive strength of concrete is shown in Figure 5. It can be seen that all mixtures achieved the desired strength of 60 MPa at 28 days and also exceed 70% of targeted strength at 7 days of water curing. Also, the compressive strength for all concrete mixes will continue to increase as the curing period becomes longer until it reaches maximum strength as water curing assists the cement hydration process to generate C-S-H gel. Furthermore, the 10% ESP mix produced the highest compressive strength of 68.4 MPa and followed by 5% ESP, 0% ESP and 15% ESP with 68.1 MPa, 67.1 MPa and 62.5 MPa respectively at 28 days. It was indicated that the compressive strength of concrete increases as the percentage of ESP replacement increases. However, further increase of ESP will decrease compressive strength at all curing ages. In this study, 15% ESP mix exhibits the lowest compressive strength at 7 and 28 days curing age compared to others. Therefore, it can be concluded that the optimum percentage of 10% ESP will enhance the compressive strength of the concrete. This result is similar reported by Jhatial [12] where optimum cement replacement of eggshell powder was 10% which achieved the maximum compressive strength and decrease in the compressive strength value when further increase in the percentage of the eggshell. According to Doh & Chin [13], the replacement of more than 10% ESP had greatly reduced the compressive strength of the concrete. This is due to eggshell possess as the filler function in concrete and behaviour of ESP concretes very close to limestone to replace concrete. Limestone reacts with the alumina pastes of cement to form a calcium mono-carboaluminate hydrate phase and contributes to strength change. At higher limestone replacement the pore sizes increases and consequently the strength of concrete decreases. This is due to the binding properties of the internal structure of the concrete had greatly reduced, thus the bonding of the cement and aggregate are weak [14][15].

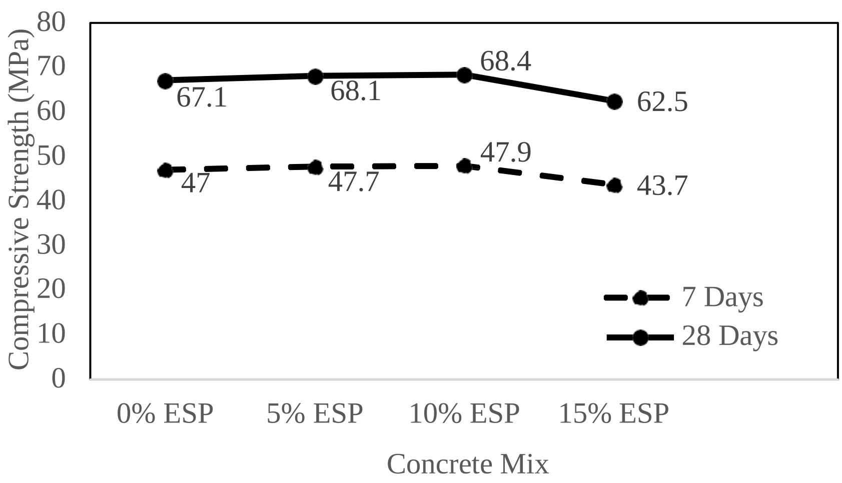

Figure 5. Compressive strength of concrete mixture

4.3 Influence of ESP on Rebound Hammer

The influence of ESP on rebound hammer tests is shown in Figure 6. The average rebound number presents the average of the surface hardness of concrete [16]. The results showed that rebound numbers increase as the percentage of eggshell powder replacement increases. The concrete containing 10% ESP specimen produces the highest rebound number at both 7 and 8 days of curing age followed by 5% ESP then 0% ESP. As the percentage of ESP further increases, the rebound number for 15% ESP decreases and is the lowest compared to other mixes in all curing age. According to Babu & Akhilchandran [17], the rebound number values depend on the surface hardness of concrete. The harder the surface of concrete, the higher the rebound number value is recorded. Based on the report of Yahya et al. [18], the concrete quality can be indicated based on rebound numbers achieved by the guideline table. For the concrete mix at 7 days curing age, all the concrete mixes have average rebound numbers which fall between the range of 20 to 30 and the quality of concrete can be considered as fair. For 28 days, the surface of concrete containing 10% ESP specimen is considered as a very good hard layer where the average rebound number was over 40, while concrete qualities of other ESP mixes that lie between 30 to 40 also have a good layer.

Nevertheless, compressive strength of concrete by non-destructive can be interpreted by using regression analysis and the result was compared with compressive strength results collected from destructive tests to evaluate their prediction for concrete strength [19]. Figures 7 and Figure 8 showed the correlation between the compressive strength of concrete and rebound hammer using regression analysis for all the mixes at 7 days and 28 days of curing age. Based on Figures 7 and Figure 8, the rebound hammer presents the higher strength compared to actual compressive strength at both 7 days and 28 days of curing age. However, the R^2 exhibits good correlation with 0.807 at both 7 days and 28 days of curing age. According to Babu & Akhilchandran [17], as the rebound number values increase, the harder the surface of concrete and the compressive strength of concrete also increases. In this study, the actual compressive strength of concrete mix increases with the increase of percentage replacement of eggshell powder in concrete. Both actual compressive strength and rebound hammer showed that the concrete containing 10% ESP produced the highest compressive strength among others and further increase of ESP will decrease compressive strength at all curing ages like 15% ESP of concrete mix. The performance of compressive strength is said to be directly proportional to rebound hammer which gave regression coefficient, R^2 value of 0.807. The maximum percentage difference of compressive strength between destructive test and regression analysis was 2.29% and minimum of 0.59%. It was indicated that the estimated results are close with the actual results of compressive strength and the error is small. Based on previous research Shih et al. [20], result of rebound hammer test is the estimations of the concrete compressive strength which have an average of over 20% mean absolute percentage error when comparing to the actual compressive strength obtained by destructive tests. This happens because the rebound hammer is not very reliable and there are many factors that will affect the accuracy of the result. The condition of concrete surfaces influences the rebound number acquired during testing. Tests performed on a rough-surfaced concrete will commonly result in crushing of the surface paste, resulting in lower rebound number [21]. Low workability of eggshell concrete makes them hard to be placed and thus, not achieving a smooth concrete surface. However, the correlation between rebound number and actual compressive strength were strong and has an accurate expression. This means that the prediction of concrete compressive strength and quality from non-destructive techniques rebound hammer can be reliable [22].

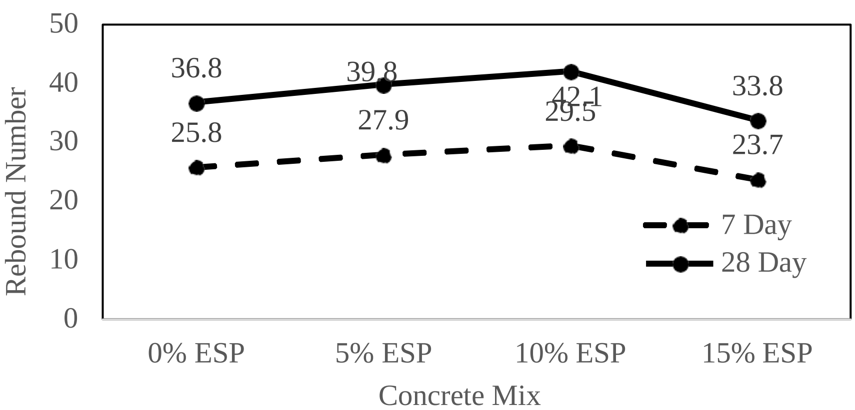

Figure 6. Rebound number

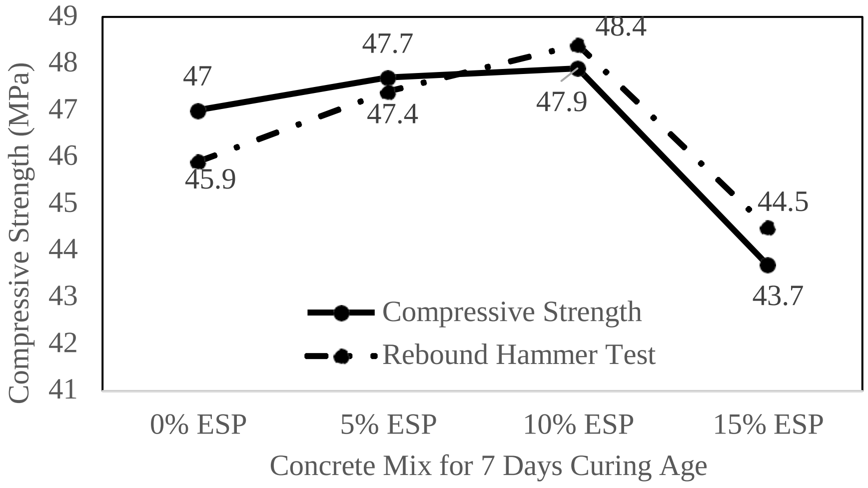

Figure 7. Correlation between actual compressive strength and rebound hammer at 7 days of curing age

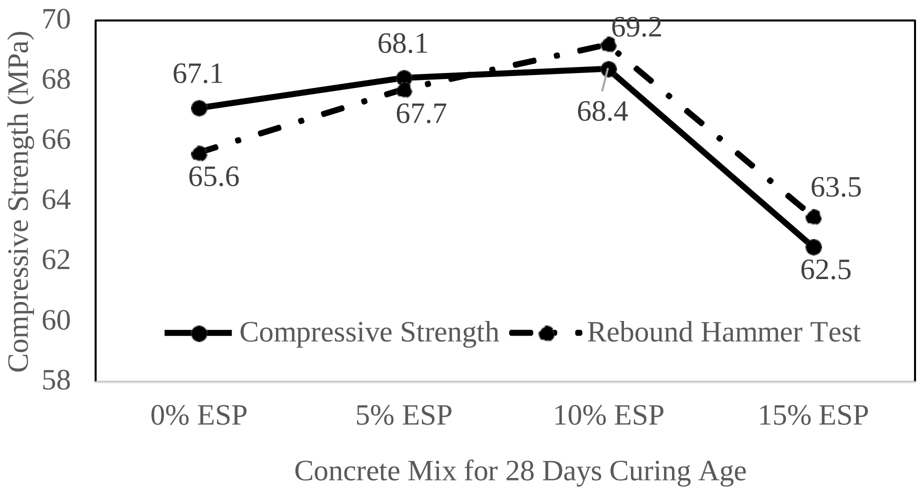

Figure 8. Correlation between actual compressive strength and rebound hammer at 28 days of curing age

4.4 Influence of ESP on Ultrasonic Pulse Velocity

In this study, the Ultrasonic Pulse Velocity (UPV) is a non-destructive test that is carried out to determine the homogeneity and integrity of concrete. The time taken by pulse ultrasonic to get through concrete structure was tested and measured. Figure 9 shows the result of average value of pulse velocity passing through each concrete mix i n direct transmission mode. It can be seen that the pulse velocity increases as the percentage of eggshell replacement increases at both 7 days and 28 days of curing age. The quality of concrete increases from day to day through the curing period of 28 days which makes it stronger and more durable concrete, thus the UPV will also increase. The 10% ESP concrete mix has the highest pulse velocity among other concrete mixes which are 4.55 km/s at 7 days and 6.50 km/s at 28 days. The pulse velocity decreases and has the lowest value when concrete mixes with 15% ESP which are 3.88 km/s at 7 days and 5.55 km/s at 28 days. According to the guidelines for quality assessment of concrete based on UPV test results [23], almost all concrete mixes at 7 days curing age have reached and over the longitudinal pulse of 4.50 km/s, this shows that all concrete has an excellent quality of concrete. Except for the 15% ESP concrete mix with 3.884 km/s which lies between a range of 3.50 km/s – 4.50 m/s, this represents the concrete quality is still good but slight porosity may exist in the structure. Then, all concrete mixes fell within the range of excellent beyond the 28 of curing day [24]. From Figure 9, graph line patterns of pulse velocity for 5% ESP and 10% ESP are almost linear and the value pulse velocity for both are close to each other. This can indicate that concrete quality will have the greatest quality at the range of 5% - 10% eggshell powder replacement. The UPV depends on the density of the material being tested. Higher pulse velocity indicates good quality and continuity of the material, while slower velocity may indicate concrete with many cracks or voids [25]. Thus, the 10% ESP concrete mix that has the highest pulse velocity representing the concrete will have the better quality compared to others due to its more uniform inside the concrete structure.

UPV test also has been commonly implemented to examine the mechanical properties of concrete. The strength of concrete has direct relation with the pulse velocity for well compacted concrete [26]. A correlation relationship is determined between compressive strength obtained from destructive test and prediction of concrete compressive strength through pulse velocity result by regression analysis to examine to measure their accuracy with respect to the experimental data. Figures 10 and Figure 11 present the correlation between the actual compressive strength of concrete and UPV using regression analysis for all the mixes at 7 days and 28 days of curing age. The higher the UPV will have a higher result of actual compressive strength. Based on pulse velocity result, the concrete containing 10% ESP specimen exhibits the highest pulse velocity and this indicates that the concrete will have the highest compressive strength compared to others due to its more uniform inside the concrete structure. The correlation coefficient obtained between actual compressive strength and UPV for 7 days and 28 days is nearly the same with R^2 value of 0.973. The closer the R^2 value to 1 represents that analysis result is more accurate and nearly exact to experimental result. Besides that, the predicted compressive strength through regression analysis has the maximum percentage difference of 0.90% compared to the exact result obtained from the destructive test and for the minimum percentage difference was 0.29%. This represents that the estimated results are close to the exact results of compressive strength and the error is very small which is less than 1%. The relationship between UPV and compressive strength has found exponential due to both UPV and compressive strength are low at early stages but increases as the curing period increases. However, the relationship between strength and pulse velocity is not unique and is affected by many factors such as aggregate type, size, and content; cement type and content [27].

From the regression analysis result, it showed that the UPV test has higher accuracy to predict the compressive strength with respect to the exact experimental data from the destructive test. Regression analysis of UPV test results have higher regression coefficient, R^2 value of 0.973 which is closer to 1 and also smaller maximum percentage difference of 0.90%. According to Turgut [28], using UPV tests on high strength concretes is more reliable due to high strength concretes are more uniform than the normal strength concretes, so it decreases the error of estimating the concrete strength through UPV test. Thus, the correlation between compressive strength and UPV are more dependable and can be used to find the approximate value of concrete strength by regression analysis.

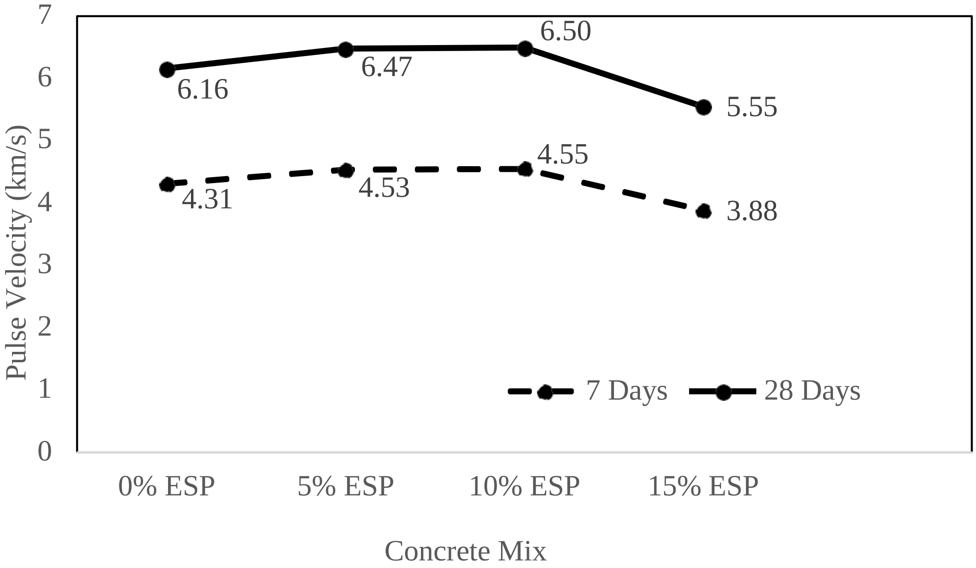

Figure 9. Average pulse velocity

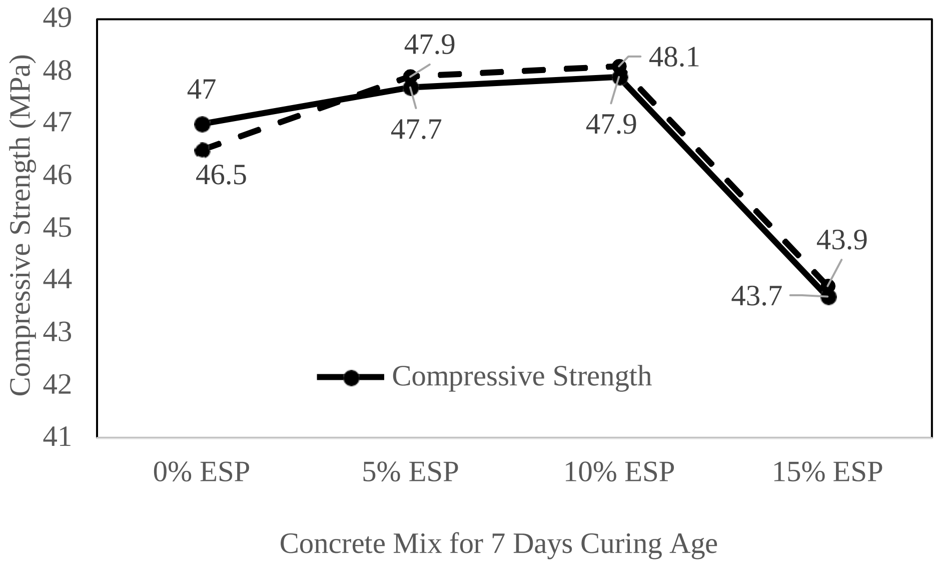

Figure 10. Correlation between actual compressive strength and UPV test at 7 days of curing age

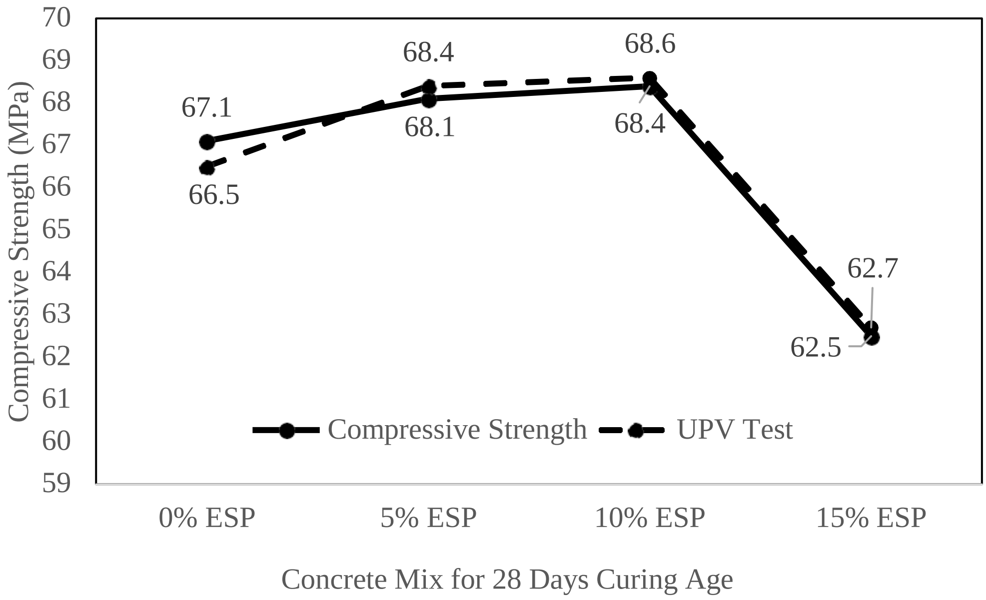

Figure 11. Correlation between actual compressive strength and UPV test at 28 days of curing age

5.0 Conclusion

Based on the experimental results, it can be concluded as follows;

i. The increment of percentage replacement of eggshell powder in the concrete mix, result in lower workability of concrete. The workability of concrete is directly affected by the higher water absorption of eggshell powder, the replacement of eggshell in concrete will decrease concrete workability.

ii. The incorporation of eggshell powder in concrete greatly influences the compressive strength. The partial replacement of cement with eggshell as filler in concrete mix will increase the concrete strength. Concrete containing 10% eggshell powder exhibits the highest compressive strength of 68.4 MPa. While further increasing eggshell powder in cement replacement up to 15% ESP will result in decrease in compressive strength.

iii. The rebound number value was dependent on the surface hardness of concrete. Rebound value increased with respect to the increase of percentage of eggshell in concrete mix until 15% replacement. Rebound number indicated that the 10% ESP concrete mix has a good hard layer while all the other concrete mixes have achieved a good layer of concrete. The rebound number was correlated with the actual compressive strength of concrete with the R^2 value of 0.807 and maximum percentage error that small which are 2.29% through regression analysis. In general, the rebound number will increase when the compressive strength of concrete increases.

iv. The ultrasonic pulse velocity of all concrete mix increased with respect to curing period and increased percentage of eggshell in concrete mix. The eggshell concrete generally has excellent quality. It was noted that the quality of the concrete is declining as the percentage of eggshell in the concrete mix further increases to 15% due to higher porosity and lower homogeneity. The velocity pulse was correlated with the compressive strength of concrete with the R^2 value of 0.973 and maximum percentage error that is very small which are

v. 0.90%. Thus, the higher the pulse velocity represents the concrete has better uniformity and higher compressive strength.

vi. Correlation between actual compressive strength and ultrasonic pulse velocity (UPV) was more reliable and had accurate expression through regression analysis compared to rebound hammer test. UPV tests on high strength concretes are more reliable due to high strength concretes are more uniform than the less strength concretes.

vii. The optimum cement replacement of eggshell powder was 10%, which achieved the maximum compressive strength. Further increase in cement replacement resulted in a decrease in compressive strength.

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