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The Compressive Strength & Water Absorption of Chicken Egg Shell Concrete

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Abstract

Concrete products are widely utilised in the building and construction. Ordinary Portland cement (OPC), one of the basic materials, is often costly and emits carbon dioxide during manufacture. As a consequence of the social and environmental challenges of sustainability and energy conservation, the cement industry is urging it to reduce and partially replace cement production with supplemental cementing ingredients. Hence, this research aimed to determine the strength and the water absorption of the concrete with chicken eggshell powder. Eggshells are rich in nutrients and can be used as a substitute for cement that contains the main cementing element, calcium aluminate (CaAl2O4). The eggshell will outperforms cement due to its high concentration of multifunctional nutrients. The degree of workability was measured through the use of a slump test, and the percentage of water absorption, compressive strength, and ideal ratio of chicken eggshell powder included in the concrete mix design were determined by testing the concrete cubes after 7 and 28 days of age. In this study, powdered chicken egg shell was utilized in place of cement, substituting 10%, 20%, and 25% of the original cement. A total of 36 concrete cubes conducted tests for water absorption and compressive strength. As a result, the slump test outcomes for a 10% cement replacement in the concrete mix was within the range of the concrete slump design in between 50 mm to 100 mm slump for medium workability, showing a true slump with a collapse height of 70 mm. This percentage also shows the lowest water absorption rate compared to other percentages which is 2.31%. For compressive strength test, the ideal percentage for cement replacement is 20% as this percentage shows the exact characteristic strength with the concrete M30 grade compared to other percentage that does not achieve the desired strength. This shown that the optimum amount for concrete mix design is 10% and 20% cement replacement with powdered chicken eggshell. If the replacement rate is larger than 20%, additional additives must be added to the concrete mix to achieve a better result.

1. Introduction

Concrete products are widely utilized in the building and construction sectors. Ordinary Portland cement (OPC), one of the basic materials, is often costly and emits carbon dioxide during manufacture. To generate 1 tan of cement, around 900 kg of carbon dioxide greenhouse gases are produced and the carbon dioxide mineralization process. As a consequence of the social and environmental challenges of sustainability and energy conservation, the cement industry is urging it to reduce and partially replace cement production with supplemental cementing ingredients [1].

Natural resources are progressively being depleted as a result of human activity; thus researchers are working to identify acceptable alternatives and additions to incorporate into concrete mix. The use of additives is a key part of producing excellent concrete with a high compressive strength. The presence and substitution of this new substance is aimed to ensure that the concrete that will be researched produces better concrete than the concrete that is now utilized in the industry. Naturally, the substance used to pick these additions and substitutes must have attributes similar to the material being replaced and added.

$CaCO_3$ (calcium carbonate) is an important chemical component of eggshells; it is required for the formation of binder gel (calcium-silicate-hydrate) in cementitious materials. As a consequence, it may be used as a powder alternative for cement/fine aggregate in construction products [2]. With all of the nutrients present in this eggshell, it is ideal for use as a replacement for cement containing 35 to 40% lime, 40 to 50% alumina, up to 15% iron oxides, and preferably less than 6% silica also the calcium aluminate ($CaAl_2O_4$) is the primary cementing ingredient. The eggshell will outperform cement due to its high concentration of multifunctional nutrients [3].

As a result, domestic waste such as chicken eggshells may be decreased while also improving the quality of concrete in Malaysia to better safeguard the environment. Both of these things can be beneficial to a variety of parties. This is a new alternatives for reducing the original concrete mix by finding acceptable and worthy elements to replace and add to the concrete mix. Furthermore, this is designed to generate concrete with maintainable strength, and if the inclusion of other materials enhances the structure, the original concrete's strength is improved.

1.1 Objectives

The purpose of this research is to create a stronger concrete mix that meets recognized requirements. The following are the objective of the study:

- To determine the strength of the concrete with eggshell powder
- To determine the water absorption of the concrete with eggshell powder

1.2 Problem Statement

Agricultural or culinary waste management such as egg shells is an essential and critical technique in global waste management. When there is an abundance of waste in the environment, it may become a significant issue for humans, animals, and vegetation [4]. The kind, quantity, and type of agricultural and culinary waste produced differ by nation especially in Malaysia. The search for an efficient method of appropriately managing the waste will benefit both the environment and human health.

This eggshell material may be used for a variety of purposes, including as a cement alternative. As a result, the concrete might become ecologically friendly. The egg's calcium content has the ability to function as a cement-like adhesive. Therefore, by reducing the amount of chicken eggshells disposed of as household garbage, the environment will be preserved and many stakeholders will profit.

1.3 Scope of Study

This study will solely involve compressive strength and water absorption tests. Each test will employ three concrete samples containing eggshell powder that have been curing for 7th and 28th day. This study only utilized chicken eggshell and no other species' shells. There are several classes of chicken egg shells that will be used, which are Grade A, Grade B, and Grade C as the only difference are the sizes. The usage of this eggshell in the concrete mix as cement replacement are 10%, 20% and 25% of the cement percentage in the concrete when the grade of concrete to be used is M30 with a ratio of cement : fine aggregate : course aggregate is 1:1:2 in the mix design, so the replacement of egg shell will be used as cement replacement materials.

1.4 Significance of Study

This study is important for identifying and examining potential alternatives for partially substituting eggshell powder for other construction materials. In this instance, the techniques employed will aid in reducing both the quantity of eggshell waste and the cost of construction required for each project. Besides, one of the largest consumers of eggs is Malaysia. Thus, presume that this approach is a solution to problems and worries like waste disposal. The prediction technique is important because it plays a role in determining the outcomes of the assumptions made for the data on compressive strength and the results of the water absorption test.

2. Materials and Methods

An overview and description of demonstration each action done to carry out the study methodically. It would include every aspect of the material used, the process, and the laboratory test that was conducted in order to conduct research to meet an objective. Planning is required for the methodology to enable smooth execution of projects.

2.1 Materials

Following the completion of the sieving process and the design of the concrete mix using the DOE Method, this study proceeded with the preparation of samples for laboratory testing.

2.1.1 Cement

Cement is among the most important components of concrete. Since composite cement was readily in the lab, it had been used in this study for concrete mixes containing 10%, 20%, and 25% cement replacement with powdered chicken egg shell (CES). In composite cements, a portion of the Portland cement clinker is substituted with industrial by-products like limestone, certain types of volcanic material (natural pozzolanas), pulverized fuel ash (pfa), and granulated blast furnace slag (gbs) [5].

2.1.2 Aggregate

To fill up the spaces in the concrete, fine aggregate (FA) was mixed in. The FA used in this study recommended using FA that, according to JKR standard, was retained on a 75 μm sieve after passing through a 5 mm sieve.

In general, stronger concrete needs more course aggregate (CA) to improve the bond between the aggregate and cement. The durability and reliability of concrete can be improved by adding more CA to the mixture. According to JKR standards, the size of CA varies, ranging from as tiny as 5 mm to as big as 20 mm.

Both aggregates will go through the same sieving process, the only difference is the size of the sieve set. FA uses sieve size of 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm and 0.15mm. Fineness modulus of finer aggregate is lower than fineness modulus of coarse aggregate. For CA, the sieve sizes are 80mm, 40mm, 20mm, 10mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm and 0.15mm.

The aggregate will be assembled in the sieve machine, a mechanical shaker, after being poured into the sieve set. After that, the aggregate sieved for 10 minutes. After 10 minutes, the sieve set was removed from the sieve machine, and a weighing equipment was used to determine the weight of desired aggregate size.

2.1.3 Water

The cement, aggregates, and powdered chicken egg shell will all be bound together by the action of water, which functions as a binder. The water utilized in this study was tap water from the UTHM Pagoh Campus that had been appropriately treated and provided by Syarikat Air Johor (SAJ). Using a measuring cylinder, the water was precisely measured and added to the concrete mixture.

2.1.4 Chicken Egg Shell (CES)

Following the collection process in Figure 1, the CES were rinsed with water to get rid of any dirt or egg slime. To make the crushing process easier, the CES's membrane was removed. Then, to dry the shells and get rid of the fishy smell, the cleaned CES will next be oven at 270°C for 10 minutes.

Fig. 1 *CES collected*

Subsequently, the dried CES will be transferred into a thick steel container that is part of the Cement Ball Mill equipment, and the container will be inserted into the machine. After closing the machine, the machine was set up to grind the CES into a powder that resembles cement for 5 minutes at 410 rpm. After 5 minutes, remove the machine's thick steel container and gently transfer the CES powder into the dry container.

All of these procedures were prepared by 10%, 20%, and 25% of the cement ratio in the concrete mix that was replaced with CES powder. Finally, the powder was sieved using a Sieve Machine equipped with a fine aggregate sieve set with sizes of 0.6mm, 0.3mm, and 0.15mm for the CES powder process. The purpose of this sieve is to guarantee that the CES powder and cement particle grain sizes are within the range of 7 to 200 μm (0.007 to 0.2 mm).

2.1.4.1 Benefit of Chicken Egg Shell (CES) as Cement Replacement

The following are the benefits using CES as the replacement component :

- By reducing the amount of solid waste that is dumped into the environment, the use of solid wastes, such as eggshells, will aid in the creation of a sustainable ecosystem.
- By lowering the creation of clinker, the use of eggshell powder in cement also contributes to a reduction in carbon dioxide emissions from cement mills.
- Calcite, a pure and more durable form of $CaCO_3$, is found in eggshells whereas limestone might include impurities such sand, clay, and other minerals.
- Investigation on the impact of eggshell ash on cement setting time, the amount of eggshell present has an impact on how quickly cement sets.
- An increase in eggshell ash content will, on average, boost the cement stabilised matrix's strength qualities by roughly 35%. That demonstrates how adding eggshell ash to concrete will boost its strength.

2.2 Methods for Laboratory Work

2.2.1 DOE Mix Design

In this DOE mix design techniques, it can determine the amount of concrete mixing components, including the ratio of cement, coarse aggregate, fine aggregate and water. The result of this calculation is based on a 100mm × 100mm × 100 mm mould expressed in unit kg/m^3.

2.2.2 Preparations for Raw Materials

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 Bengkel Teknologi Konkrit (2.F.1.001), Universiti Tun Hussein Onn Malaysia, Pagoh Campus, and the chicken egg shell (CES) waste was obtained from a Bahulu Factory located at Taman Bukit Serdang, Seri Kembangan, Selangor. As for the material ratio, 0%, 10%, 20%, and 25% of eggshell in fine powder form is used for the mixture.

2.2.3 Preparing for Concrete Cube

Concrete cube samples produced by pouring the concrete mixture into the cube shaped mould with dimension of 100mm×100 mm×100mm. The concrete cube mould has been applied grease in the inside of the mould so that the hardened concrete cube will easy to remove when it is dry. The hardened concrete cube were removed from the mould after 24 hours in room temperature using an air compressor.

Curing is primarily designed to minimize moisture loss from the concrete throughout the process to achieve strength, therefore keeping the concrete soaked at room temperature (27°C). The curing process happened in the laboratory's curing tank for 7 and 28 days age of concrete.

2.2.4 Slump Test

A concrete slump test assesses the consistency of a batch of concrete to predict its flow characteristics. In addition to ensuring batch uniformity the test searches for mixture faults, giving the tester a chance to correct the mixture before it is poured on site. By assessing the total slump of the concrete, it may be possible to figure out if the water-to-cement ratio is excessive and whether a mix will be easily workable.

The base placed on a smooth surface then the frustum filled with concrete mixture for three layers. Each layer was temped for 25 times with compacting steel rod. When the frustum completely filled, the top surface layered with the compacting steel rod. Next, the frustum carefully lifted vertically so that the concrete mixture can be collapsed. The slump measured by placing the frustum beside the slump in upside down position then the compacting steel rod was placed over the frustum. The difference in height of the frustum and the slump can be observed and measured with L-squared angle ruler.

2.2.5 Compressive Strength Test

Compressive strength is the capacity of a material or structure to support loads on its surface without cracking or deflecting. When a material is compressed, its size tends to decrease, and when it is stretched, its size elongates. For this test, the procedures follows the standard of ASTM C39 that based on the Universal Testing Machine (UTM).

The concrete cube sample were taken from the curing tank so the excess water was wipe off using wiping cloth. The base plate also must be clean from any undesired dirt. The concrete cube sample placed on the base plate of the machine centrally. The rapid approach button gently pressed by hand so that the plate touches the top surface of the concrete cube sample. Next, the load applied continuously until reached the load maximum and fails. The maximum load or any features of the fails on the concrete cube sample must be recorded.

2.2.6 Water Absorption Test

By measuring the rise in a specimen's mass as a function of time when just one surface of the specimen is exposed to water, this test method was used to estimate the rate at which concrete absorbs water. This test conducted using standard ASTM C1585 (Measurement of Rate of Absorption of Water) using curing tank and a set of time interval.

The cured concrete cube were put into the industrial oven for 110°C and 24 hours to dry the moisture out. After 24 hours, the concrete cube were taken out from the oven and leave it to cooled down in room temperature for 24 hours. Next, each of the concrete cube sample was weighted and noted as the dry weight of the concrete cube. Then, the concrete cube sample were submerged in the curing tank for several interval of time which were 1, 5, 10, 20, 30 and 60 minutes using stopwatch. Each of the time interval, the concrete cube sample was weighted and noted it as wet weight of the concrete cube. All these weight were recorded and analyzed.

3. Results and Discussions

The data analysis and results from the laboratory tests are reported in this chapter. To ensure that the data was properly comprehended and elaborated, all collected data was presented using tables and graphs. These data were analysed and concluded in order to meet the goals of this bachelor's degree project. The test and analysis result were discussed in this chapter are based on slump test, compressive strength test and water absorption test.

A table and graphs are used to compare the results, which are then followed by discusses on each of the outcomes. The outcome for chicken egg shell (CES) concrete includes of comparing different CES ratios to its workability, compressive strength, and water absorption rate.

3.1 Workability

Slump tests were performed for each percentage of cement replacement to measure the degree of workability. To achieve the workability of fresh concrete, it was based on the standards of practise in BS EN 12350-2:2009 (Testing Fresh Concrete - Slump Test). The outcome was documented and is presented in Table 1.

Table 1 *Result of Slump Test*

Percentage of Cement Replacement (%)	Collapse Height (mm)	Type of Slump	Degree of Workability
0	55	True slump	Medium
10	70	True slump	Medium
20	65	True slump	Medium
25	60	True slump	Medium

According to Table 1's results from slump tests carried out with different percentage of chicken egg shell (CES) powder as replacement of cement, all proportions of the slump may be classified as true slump. Samples CES 0, CES 20, and CES 25 have low workability, ranging from 25 to 50 mm, while sample CES 0 has a medium degree of workability, ranging from 50 to 100 mm. The maximum slump of 55 mm shown by sample CES 0, while the minimum slump of 38 mm is shown by sample CES 25. All of the CES replacements had slumps that are within the 75±25 mm allowable slump range.

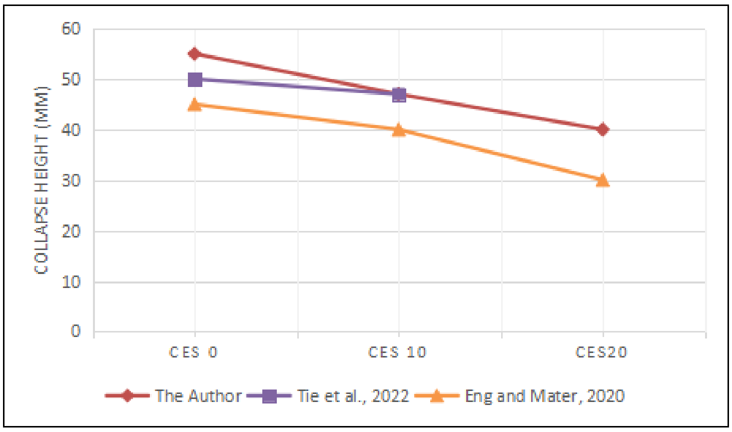

Fig. 2 *Line chart of result comparison for slump test with past researcher*

Based on the results of the slump test, it can be concluded that the slump height will decrease as the percentage replacement increases. Similar outcomes were reported by Eng and Mater [6] and Tie *et al.* [7]; in their research, which are illustrated in Figure 2, the concrete mixture that replace cement for CES resulted in slump height that was within an acceptable range. This might be justified by the CES powder's high-water absorption, which uses more water and affects flowability. The finer powdered CES powder particle size will have more surface area, allowing it to absorb more water and adversely affect the workability of the concrete mix.

3.2 Compressive Strength

The different percentages for cement replacement with chicken egg shell (CES) were used in concrete mixture to make a comparison in compressive strength of concrete sample to achieve the optimum percentage of CES. The compressive strength test were done based on ASTM C39 using Universal Testing Machine (UTM) for cube concrete. Figure 2 shows the data obtained for the test that done with concrete cube aged 7 and 28 days.

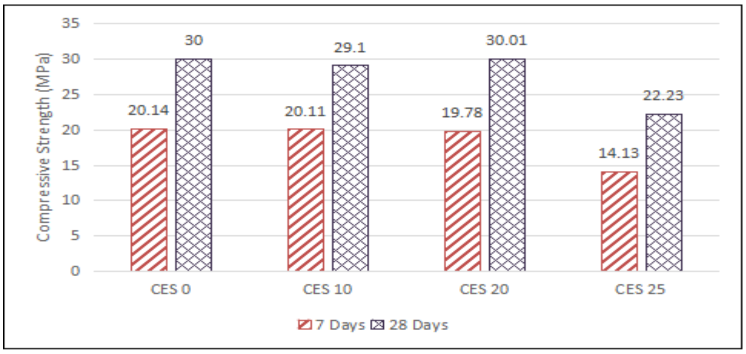

Fig. 3 *Bar chart of compressive strength test result*

Based on Figure 3, the targeted strength of compressive strength value for 7 days aged concrete is 20 MPa meanwhile for 28 days aged of concrete is 30 MPa. For 7 days aged concrete, sample CES 0 and CES 10 reached the targeted strength range of 20 MPa. Sample CES 25 did not meet the targeted strength with a compressive strength value of 14.13 MPa, whereas sample CES 20 did not reach the targeted strength slightly. On the other hand, for 28 days aged concrete, sample CES 0 and CES 20 reached the targeted strength of 30 MPa. Nonetheless, sample CES 10 just barely failed to achieve the targeted strength, while sample CES 25 failed to meet the targeted strength with the lowest compressive strength value for concrete that was cured for 28 days. Since sample CES 0 was a control sample and was not mixed with CES powder, which made the concrete stronger than the sample containing CES powder, only sample CES 0 achieved the desired strength for both the 7- and 28-day aged concrete. Furthermore, because sample CES 25 replaced the most amount of cement with CES, it failed to achieve any specified strength or compressive strength value for both 7 and 28 days of aged concrete. This indicates that as the amount of CES used to replace cement in the concrete mixture increases, the binding element present in the cement was reducing, which also caused the compressive strength value to decrease.

Based to the author's research, replacing 10% of the cement with CES did not result in the targeted strength of 30 MPa. Moreover, the results differed from the findings reported by Mohd Arif [8], who concluded that 10% of the cement was the optimal substitute for eggshell powder, achieving the targeted compressive strength and causing a decrease in the compressive strength value when the percentage of eggshell was increased. Doh & Chin (in Mohd Arif [8]) state that the concrete's compressive strength was significantly decreased when more than 10% CES was replaced. This is because CES concretes behave very similarly to limestone when used to replace concrete, and eggshells serve as a filler in concrete. A calcium monocarboaluminate hydrate phase is created when limestone combines with cement's alumina pastes, altering the material's strength. The strength of concrete reduces as the substitution of limestone increases because of the larger pore diameters.

3.3 Rate of Water Absorption

Water absorption test was conducted to determine rate of water absorption of the concrete that has chicken egg shell (CES) replacement with cement ratio with 10%, 20% and 25% replacement including the normal concrete. This test is completely based on procedure that stated in ASTM C1585. The result was recorded in Table 2 and shows each of the concrete cube sample's percentage of water absorption.

Table 2 *Data of Water Absorption Test*

Sample	Weight (kg)	Dried Oven Weight (kg)	Wet Weight (kg)	Percentage of Water Absorption (%)
CES 0	2.27	2.15	2.19	1.86
CES 10	2.20	2.16	2.21	2.31
CES 20	2.24	2.10	2.20	4.76
CES 25	2.27	2.13	2.28	7.04

*CES 0 - Cement replacement for 0% chicken egg shell powder.
*CES 10 - Cement replacement for 10% chicken egg shell powder.
*CES 20 - Cement replacement for 20% chicken egg shell powder.
*CES 25 - Cement replacement for 25% chicken egg shell powder.

As shown in Table 2, the percentage of water absorption were decreasing as the chicken egg shell (CES) as replacement of cement increased. The results show that, in comparison to concrete with sample CES 10, water absorption increased by 2.45% in sample CES 20 concrete, while the percentage of water absorption increased by 2.28% between samples CES 20 and CES 25. Sample CES 25, which replaced 25% of the cement with CES has a value of 7.04%, had the highest percentage of water absorption. It also differed by 5.18% from the control concrete, sample CES 0.

The research conducted by Khan *et al.* [9] shows the same result as the author and it is because of the filler effect and the mixture's CaO's chemical reaction are likely contributing elements. The concrete became denser and more compact due to the filler action of CES. Additionally, because of its porous nature, CES's ability to absorb more water has increased cement hydration and produced superior hydration concrete. Thus, it can be said that concrete that absorbs a lot of water is not recommended for usage since it might lead to corrosion.

3.4 Relationship of Result Between Compressive Strength Test and Water Absorption Test

Concrete containing 10%, 20% and 25% of chicken egg shell (CES) as replacement of cement has been taken through tests to measure its strength and percentage of water absorption using compressive strength and water absorption test, respectively. The test was conducted using concrete that was 7 and 28 days old; however, Figure 3 displays the outcome of the 28-day-old concrete.

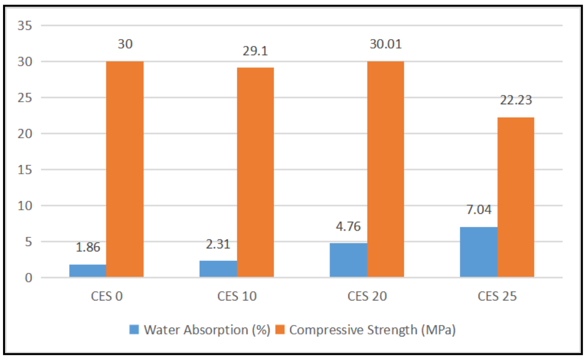

Fig. 3 *Bar graph of relationship between compressive strength test and water absorption test*

As shown in Figure 3, the results of the compressive strength test decreased from sample CES 0 to sample CES 10, then increased for sample CES 20, and finally decreased for sample CES 25 as the percentage of CES increased. In the meantime, as the proportion of CES increased, so did the results of the water absorption test. The water absorption of the control concrete (CES 0) was the lowest at 1.86%, and its compressive strength reached the characteristic strength of 30 MPa. This occurred as a result of the sample not having any CES powder, which prevented any material from disturbing the element in the concrete. Out of all the CES proportions, the results for both tests for sample CES 25 were the least satisfactory.

4. Conclusion

All tests done in following the guidelines provided by the standard to meet the objectives of this research. Three tests were performed: one for compressive strength, one for water absorption, and one for slump. The objectives of the research were achieved for the strength and percentage of water absorption of concrete that substituted cement with powdered chicken egg shell (CES). The optimum percentage of CES was determined based on 10%, 20% and 25% of cement replacement. The outcome of this research shown the different value of strength and water absorption based on the percentage of replacement compared with the control concrete contained 0% of CES. Table 5.1 shows the optimum percentage of CES as cement replacement in concrete mixture based on the test conducted.

Table 3 *The optimum percentage of CES as cement replacement in concrete mixture*

No.	Test	Value	Percentage of CES
1	Slump Test	47 mm (True Slump)	10%
2	Compressive Strength Test	30.01 MPa	20%
3	Water Absorption Test	2.31%	10%

Based on **Table 3**, the result can be summarized as follows :

- The slump test result shows that the collapse height of slump were decreasing as the percentage of CES as cement replacement increasing. Although the presence of CES in the concrete mixture makes the collapse height decreased and has low degree of workability but the slump was still within the allowable range of 75±25 mm. This shows that the workability of the concrete mixture contained CES were achieved. Given that the slump height value is close to the control concrete slump height, 10% of CES replacement is the optimum percentage for the concrete mixture.
- The compressive strength test result shows that the 20% of CES in 28 days aged concrete showed the highest compressive strength compared to the control concrete, 10% and 25% of CES concrete. This shows that the 20% of CES replacement in cement ratio achieved the objectives of the research for concrete strength. Given that the compressive strength value is exactly the same as the characteristic strength of 30 MPa, 20% of CES replacement is the optimum percentage for the concrete mixture.
- The water absorption test result shows that the percentage of water absorption were decreasing as the CES percentage increased. Control concrete has the lowest rate of water absorption compared to the concrete has CES replacement meanwhile 25% of CES concrete has the highest water absorption rate. Therefore, given that cement having the lowest water absorption value, the 10% of CES concrete has been considered to be an optimal percentage and achieved the objectives of this research.
- In summary, the ideal proportion of CES for each test varies; for example, 10% of CES is sufficient for the slump test, 20% for the compressive strength test, and 10% for the water absorption test. Based on this analysis, the author concluded that 10% CES replacement is the optimal percentage for this research, despite the compressive strength being only marginally different from the aimed characteristic strength (0.9 MPa difference value). This proportion also has the lowest water absorption. The rate at which water absorbs in concrete is a crucial factor in determining its overall quality.

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