Key Engineering Materials
ISSN: 1662-9795, Vol. 879, pp 34-48

Submitted: 2020-08-18
Revised: 2020-10-16
Accepted: 2020-11-03
Online: 2021-03-15

Properties of Concrete with Eggshell Powder and Tyre Rubber Crumb

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Keywords: eggshell; tyre rubber; concrete; properties.

Abstract. Solid waste management is one the leading problems in Malaysia. Rapid development and population growth have prompted researches to improve the recycling and reusing of waste material for sustainable development. Chicken eggshell is discarded in Malaysia as municipal waste, while waste tyre is a waste that is difficult to handle and often ends up in the landfill. This paper presents the properties of high performance concrete with eggshell powder and tyre rubber crumb as partial replacement of cement and sand. Grade 45 concrete was prepared with 5% tyre rubber crumb as sand replacement and up to 15% of eggshell powder as cement replacement. The mechanical strength of concrete was investigated for up to 90 days while durability properties were studied through water absorption and carbonation test. Results show that concrete with 5% eggshell powder is optimal for high mechanical properties, lower water absorption and low carbonation depth. X-Ray Diffraction of concrete shows increase of calcite compound which contributes to the gain of strength. Microstructure analysis with SEM and EDX provides insight of the improved performance, which is attributed to a denser C-H-S gels and finer pore structure.

1.0 Introduction

Malaysia produces about 23000 tons of solid waste per day, and number is expected to reach 30000 tons by the year 2020 [1]. Food waste and organic waste is the majority of the waste generated by Malaysian [2]. However, solid waste management is disorganized and most of the waste often ends up in the landfill [3]. Recycling rate and sustainable practices is also mediocre compared to others modern countries, and the government aims to increase the recycling rate to 20% in order to cater for the pace of its rapid development [2].

Eggshell waste is one of the wastes that is discarded in huge quantity. Malaysians are among the biggest egg eater in Asia. According to a report from International Egg Commission [4], the uptake in Malaysia has risen from about 320 eggs per person in 2011 to around 332 eggs in 2013. The Atlas of the Global Eggs Industry [4] also states that Malaysia is considered a country with high eggs consumption, production and export in the Southeast Asia region. In Malaysia's more than 36.5 million eggs are produced daily. Despite an extended poultry industry, eggshells are regarded as municipal waste in household and poultry industry so most of them ended up in the landfill [5]. Eggshell is non-hazardous, but it attracts worms and rats, which becomes a health problem to the public [6].

Apart from eggshell, waste tyre is another waste that plagues not just Malaysia but also many parts of the world. Around 1000 million waste tyres are generated annually and over 5000 million more are estimated to be discarded by 2030 [7]. Other than that, it is estimated that one waste tyre is discarded per person in developed areas, hence 1 billion waste tyres are disposed worldwide [8]. Waste tyre often ends up in the landfill due to various challenges of its disposal. Combustion of tyre is not advised as it is a fire hazard and the process releases highly harmful substance into the air [9]. The residue from combustion is also a pollutant that can damage the quality of soil and water [10].

Landfill can deal with waste with high organic content without the need of high technology [3], so it is widely practiced by developing countries with technological and financial constraints [1]. However, even when sent to landfill, waste tyres take up a lot of space and deplete capacity rapidly [11]. Vulcanized rubber also has low degradation, so waste tyres may break through landfill covers, outflow and cause pollution [12]. Hence, sending waste tyres to the landfill is not a proper solution as it causes environmental problems [13].

One solution to promote sustainability is to introduce new ideas of reusing said waste products. Eggshell has been proposed to be used as biodiesel catalyst, absorbent of heavy metals, fertilizer, medical items and animal feeds [14]. In the field of civil engineering, eggshell had also been tested as binder replacement, filler, and fine aggregate [15]. Eggshell primarily consists of multiple layers of calcium carbonate, $CaCO_3$ or about 5.5grams of the compound [16]. The overall chemical composition of eggshell is said to be similar to limestone [17]. Hence, eggshell has the potential to serve as a cement replacement in concrete [18]. In many cases, replacement of cement by eggshell powder increased the performance of concrete up to a certain proportion, and further increase beyond the optimal percentage caused a decrease in strength. In short, a curvilinear relation exists between percentage of cement replacement and strength of concrete. Bandhayva [19] performed a study on compressive strength ESC of up to 35MPa and concluded that the optimal strength was obtained at 10% eggshell replacement. Doh and Chin [20] obtained the same optimal percentage of 10% eggshell for concrete with strength 38MPa. The result agreed with other researches of similar studies [21-22]. Beyond the optimal percentage, addition of eggshell powder causes a higher water demand, which increases water-cement ration and hence reduces strength [19]. Other mechanical properties such as flexural strength [23-24] and split tensile strength [25] of ESC behave similarly with a curvilinear trend with respect to percentage of replacement.

Likewise, tyre rubber crumb had been introduced in concrete to reduce the environmental impact poses by the waste. The introduction of rubber material in concrete can circumvents one of the greatest weakness of conventional concrete, which is its brittle nature [26]. Proper addition of rubber improves ductility, energy absorption and reduces concrete density, all of which is beneficial to the material. In short, it improves the durability of concrete to resist aggressive environment [27]. Rubberised concrete has been examined to be suitable for pavement and structure construction applications [28]. Lightweight concrete [29] and self-compacting concrete [30] can also be produced with the proper usage of rubber material. Waste tyre rubber which is ground to crumbs below 20mm size can be used as coarse aggregate [31], while fine rubber powder of micro size has been used as additive to cement [32]. However, using rubber of grind size below 4mm as fine aggregate replacement is the most common studies conducted [33-34]. Silva et al. [26] concluded that up to 15% tyre rubber can be used to replace sand in high performance concrete and still achieve the standard classification required for mechanical performance. Thomas and Gupta [10] conducted a similar study and concluded that up to 12.5% tyre rubber can be used on high performance concrete and still achieve the targeted strength despite the strength loss.

This objective of the present study is to investigate the mechanical properties and durability of concrete with eggshell powder and tyre crumb. While studies of eggshell concrete or rubberized concrete are present, it is a new approach to replace both cement and sand with waste materials. With eggshell expected to improve mechanical performance and rubber powder expected to reduce strength but improve durability, it is a novel study to investigate the pros and cons of concrete compared to control when both materials are being used at the same time. In this study, concrete was designed with 5% of sand replaced with tyre rubber and 0% to 15% of cement replaced by eggshell powder by weight. Various tests were conducted on the specimens, such as compressive strength test, flexural strength test, split tensile test, water absorption test and carbonation test. The effect of eggshell powder replacement on each tested parameter was thoroughly examined with correlations. Microstructure analysis of specimens was conducted via X-ray diffraction and Scanning Electron Microscope to study the effect of eggshell and rubber replacement on concrete.

2.0 Material and Properties

Ordinary Portland Cement from local manufacturer was used. The cement grade was 52.5N and it fulfilled the specification of MS EN 197-1: 2014. Table 1 showed the chemical composition and the physical properties of the cement powder.

Table 1. Chemical composition and physical properties of OPC

Tests		Units	Specification	Test
			Chemical Composition	
Sulfate Content (SO_3)		%	Not more than 3.5	2.1
Chloride (Cl^-)		%	Not more than 0.10	0.01
			Physical Properties	
Fineness (According to Blaine)		m^2/kg	-	440
Setting time : Initial		mins	Not less than 75	155
Soundness		mm	Not more than 10	0.8
Compressive Strength				
(Mortar Prism)	: 7 days	MPa	Not less than 16	24.0
	: 28days	MPa	$32.5 \leq x \leq 52.5$	35.2

Granite stone was the coarse aggregate of the concrete casted in this experiment. In the preparation of high performing cornet, the grading of coarse aggregate was extremely important as it contributes significantly to the filling, strength and durability of the concrete. In this research, the controlling of aggregate was done with the maximum size of 20mm. The aggregates selected were sieved through 20mm size before being placed in a mechanical shaker to identify the grading in detail. The result of sieve analysis was presented in Figure 1.

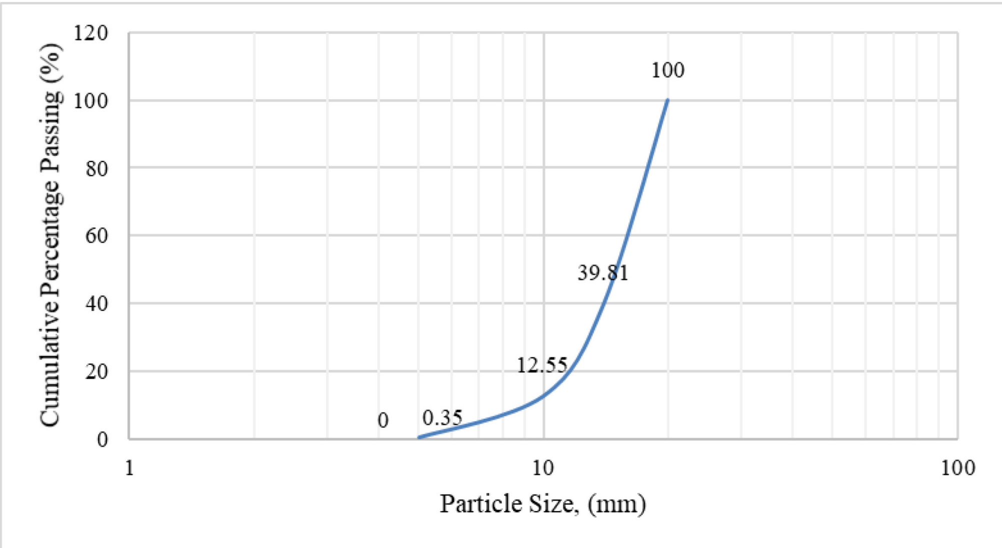

Fig. 1. Particle size distribution of coarse aggregate

River sand was used as the fine aggregate to produce mortar. Sieve analysis in accordance with BS EN 933-1-1997 [35] was carried out to identify the grading of the aggregate. Only aggregate that retained below sieve 4.75mm was used. The sieve shaker machine was consisted of several sizes which ranged from 4.75mm to 0.075mm. For this research, the sieves were arranged in descending order which from the size of 4.75mm at the top, followed by 3.35mm, 2.0mm, 1.18mm, 0.6mm, 0.425mm, 0.30mm, 0.212mm, 0.15mm and finally the pan at bottom. The 500g of sand was placed at the top of sieve and covered it with cover plate properly and ran the machine for 10 to 15 minutes. During the shaking process, the aggregate was passing through the sieve. If the aggregate size was bigger than the sieve it was retained. Figure 2 showed the result of the particle size analysis of fine aggregate.

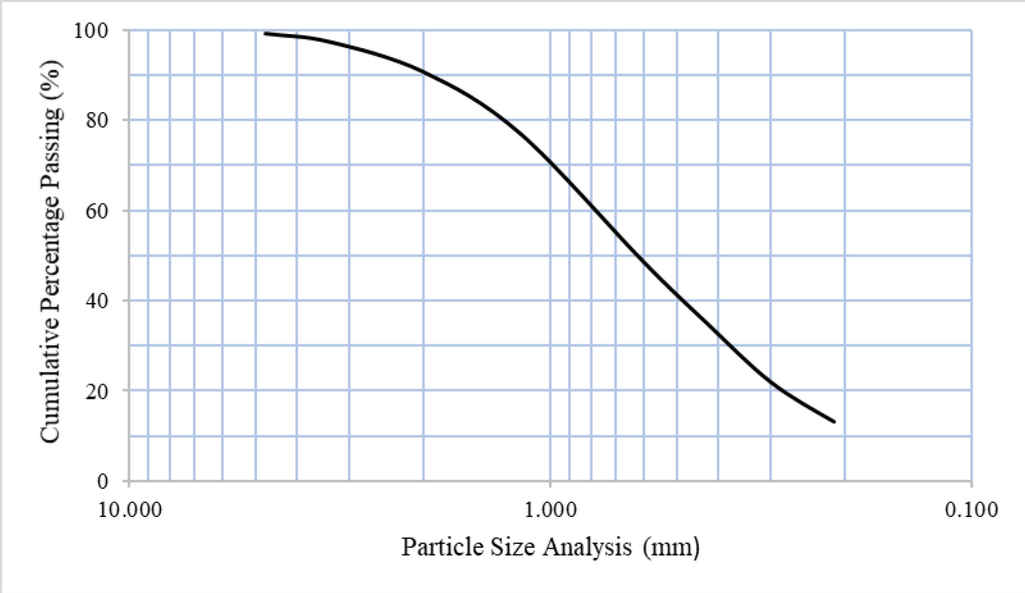

Fig. 2. Particle size distribution of fine aggregate

Eggshells which were collected from domestic sources. The eggshell was washed immediately after the collection or it would emit rotten smell. Then, it was dried under the sun for three days or until it was fully dry. The eggshells were crushed and grinded in the grinding machine into powder form and sieved through 150μm sieve for the usage of the study. The composition of eggshell is agreed to be 93.70% calcium carbonate ($CaCO_3$), 0.80% calcium phosphate ($Ca_3(PO_4)_2$), 1.30% magnesium carbonate ($MgCO_3$) and 4.20% organic matter based on high number of studies [19][36][37]. $CaCO_3$ is one of the main components of cement which is responsible for strength gain, so eggshell has the potential to serve as a cement replacement in concrete [18].

Tyre rubber crumb was used to replace 5% of the sand in the concrete mix. The tyre was in micro powder form passing the 180μm sieve. Pre-treatment was done with saturated sodium hydroxide aqueous solution. The tyre waste was soaked in the solution for 30 minutes at room temperature, washed with water, and then dried at ambient temperature for 24 hours before being used. Figure 3 showed the rubber crumb after treatment. Treatment through NaOH solution shows greatly improved properties of rubber compared to raw rubber [38]. The process enhances the ability of rubber to form stronger bond with cement [39].

Fig. 3. Treated tyre rubber crumb

3.0 Experimental Work

3.1 Mixing proportion, casting and curing

Table 2 showed the mix design used in the study. The mix was designed to achieve compressive strength of 45N/mm^2 at 28 days. The ratio of cement, coarse aggregate and fine aggregate was 1:2.16:1.4. Water-cement ratio of 0.35 was adopted for a medium workability of 75 ± 25mm slump and optimum strength. Pye Kwiset Plasticizing Accelerator was added as the water reducer in order to achieve the desired strength. The admixture was added to improve the setting time and increase the workability of concrete mix. The dosage used was 1.5% by weight of cement. Rubber crumb was introduced to replace 5% fine sand while the percentages of eggshell powder replacing cement were 0%, 5%, 10% and 15%. Casting of specimen was done by rotating drum mixer. All equipment was wet before mixing was conducted to reduce the loss of water through absorption and natural evaporation. 75% of the water was added into the drum while the remaining 25% was added along with superplasticizer after the mix was poured onto the tray. Manual mixing was done by shovel for another minute and slump test was conducted after superplasticizer had taken effect. Once the mix was thoroughly even and achieved the needed workability, it was cast into the mould. Filling was done in three layers and compaction was done by using a vibrating table to minimize void and trapped air. Curing of specimen was done by water immersion for 7 days and 28 days before subjected to mechanical and durability tests.

Table 2. Chemical composition and physical properties of OPC

Materials (kg/m^3)	**0%ESC**	**5%ESC**	**10%ESC**	**15%ESC**
Coarse aggregate	1050	1050	1050	1050
Fine aggregate	665	665	665	665
Cement	500	475	450	425
Water-cement ratio	0.35	0.35	0.35	0.35
Superplasticizer	7.5	7.5	7.5	7.5
Eggshell	0	25	50	75
Tyre Crumb	35	35	35	35

3.2 Compressive strength test

The compressive strength test was carried out according to the British Standard (BS 1881 : Part 116) [40]. Before carrying out the test, the surface of the compressive strength machine was wiped clean to be free from grits or any substances. The size of the concrete cube being prepared was 100mm x 100mm x 100mm. The specimens were put under loadings and the maximum loads were recorded. Other than that, the type of failure and the surface appearance of the cubes were observed as well. The testing of the cubes was taken at age of 7, 28, 56, and 90 days. There were three specimens for each age of the cubes to obtain the average data for more accurate results. The loading rate of the compression test machine was 1.00 kN/s and start load of 5.00 kN and stop load of 10%.

3.3 Flexural test

BS EN 12390-5:2019 [41] was the guideline used for flexural test. It was conducted on concrete beams of size 100mm × 100mm × 500. UTest machine was used to perform the flexural strength analysis for all the beam specimens. The loading rate of the UTest machine was 0.5kN/s. The specimens were tested until they failed, and the final force applied on the specimen was recorded.

3.4 Split tensile test

Split tensile test was performed based on ASTM C496 [41]. The size of the cylindrical samples was 100mm diameter and 200mm height. MATEST machine was used to conduct the splitting tensile strength. The cylinder was inserted into the machine lying down, and load was applied through a long piece of steel across the center of the cylinder. Load was applied until the specimens cracked and split, and the final force applied was recorded.

3.5 Water absorption

Water absorption and penetration both relates to the pore structure of concrete which contributes to the long term strength of the material. The characterization of pores structure in concrete can be determined using the water absorption testing in accordance with BS 1881: Part 122 (2011) [41]. In this research, the concrete cubes of (100 x 100 x 100) mm were selected to examine the rate of water absorption. After 28 days curing, the concrete cubes were dried inside oven 72 h ± 2h. After the drying process, the specimens were cooled in sealed container for 24 h ± 0.5. immediately after the cooling process, the specimens were weighed, and the mass was recorded. The specimens were then fully immersed in water at which there was 25 mm ± 5 mm of water. The specimens were then shaken to remove water from the concrete surface. The cube was then dried up using cloth as fast as possible until all water on the mortar surface was completely removed. The concrete specimens were weighed, and the mass was recorded. All the data were recorded, and the degree of absorption was calculated.

3.6 Carbonation test

Carbonation test was performed on the cross section of split 90 days beam specimen in order to determine the depth of carbonation which may contribute to the corrosion of reinforcement bars. 1% phenolphthalein indicator solution was sprayed on the cross section of split concrete surface. The uncarbonated region was indicated by pink colour due to the indicator while the carbonated region would be colourless. Measurements of carbonation depth was conducted by measuring the depth of the colourless region from the corner of the square surface.

4.0 Result and Discussion

4.1 Compressive strength

Table 3 presents the result of compressive strength tests performed on eggshell concrete specimens. For all specimen, sand was replaced with a constant 5% rubber crumb while cement was replaced with varying percentages of eggshell powder. The control specimen (0% ESC) achieved a 44.20 N/mm^2 at 28days, which is slightly below the targeted 45 N/mm^2. At 5% eggshell powder replacement, concrete specimen showed the highest strength of all specimens, which was 47.07 N/mm^2 at 28 days. The improvement of strength was attributed to the supplement of calcium hydroxide (CaO) from the eggshell powder, which improved the hydration process of concrete. However, further increase of percentages of replacement caused concrete to loss strength and falls lower than the control specimen, which were 39.78 N/mm^2 and 37.77 N/mm^2 at 10% and 15% eggshell respectively. This pattern adhered to the curvilinear trend of many researches on eggshell concrete [22-25] although the optimal content fell on a lower percentage of 5% instead of 10% according to other studies. The strength of the control was also slightly lower than the targeted 45MPa at 28 days because of the replacement of fine sand with tyre rubber crumb, as various researches had concluded that the addition of rubber negatively affects the mechanical properties of concrete [7]. However, the reduction had been controlled and minimized through proper handling and treatment of rubber crumb [39]. The improved strength of 5% ESC can be associated with eggshell having high content of calcium carbonate and serving as a great filler material to improve the pore structure of concrete [20]. In conclusion, 5% ESC was the optimum design for compressive strength.

Table 3. Compressive strength test result

Specimen	Compressive Strength			
	7 days	28 days	56 days	90
0% ESC	37.09	44.20	48.69	52.30
5% ESC	38.61	47.07	50.58	51.93
10% ESC	34.53	39.78	44.05	48.61
15% ESC	26.52	37.77	41.26	42.83

4.2 Strength activity index

Figure 4 showed the strength activity index for the compressive strength of eggshell concrete. According to ASTM C311-18, strength activity index is used to determine the strength development of concrete compared to control when fly ash or nature pozzolan is used. The method can be adopted to study the strength of cementitious product with other material replacement. Moreover, it is believed that eggshell powder is able to improve the hydration of cement and formation of C-H-S due to its high content of calcium hydroxide [42]. The strength activity index for 5% ESC was greater than control and was the highest at 28 days after curing. 10% ESC showed acceptable result at around

90% throughout the period. At 15% ESC however, the index was only 72% at 7 days and significantly lower than the rest of the specimens. This may indicate that excessive among of eggshell powder affected the strength gain of concrete because it absorbed water which was needed for development of strength. Based on the result, the effect of eggshell powder was most positive at 5% cement replacement.

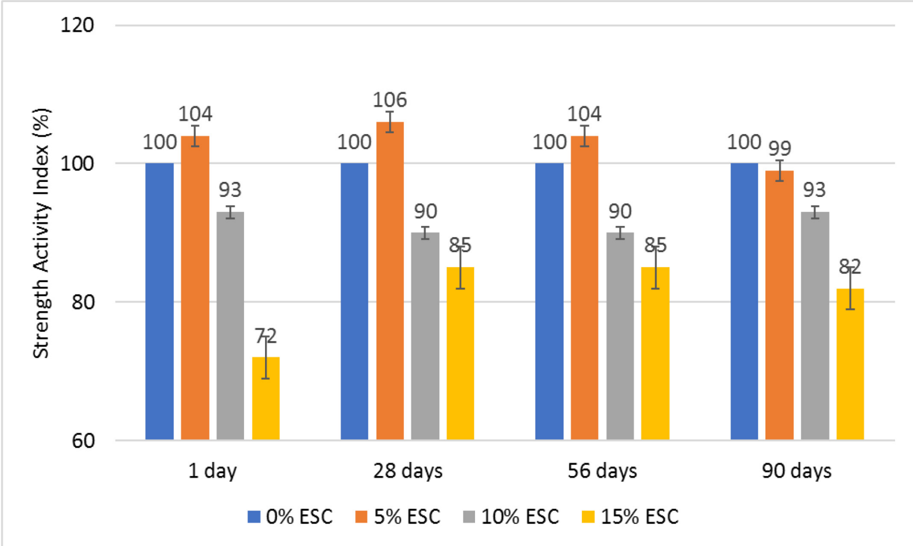

Fig. 4. Strength activity index of eggshell concrete

4.3 Flexural strength

Table 4 showed the flexural strength result of eggshell concrete. The flexural strength of 0% ESC control specimen was 6.439 N/mm^2 at 7 days and 8.810 N/mm^2 at 28 days. 5% ESC had 8.87% more strength at 7 days and 4.39% increase in strength at 28 days. 10% ESC and 15% ESC were weaker than control at both tested ages. The superior performance of 5% ESC could be explained by the abundance of calcium carbonate and good filling effect of eggshell concrete. At higher percentage of replacement however, the performance of specimens was affected due to excessive water absorption of eggshell powder, which indirectly reduced the water-cement ratio of the mix [19]. Without sufficient water, the initial hydration process was affected, and the internal packing of the concrete was weaker as the concrete aged. The flexural strength of eggshell concrete followed a similar pattern with compressive strength, which was within expectation as compressive and flexural strength of concrete were usually correlated with each other [43].

Table 4. Flexural strength test result

Specimen	**Flexural Strength (N/mm^2)**	
	7 days	**28 days**
0% ESC	6.439	8.810
5% ESC	7.066	9.197
10% ESC	6.147	8.017
15% ESC	5.300	6.044

4.4 Relationship between flexural strength and compressive strength

An empirical relationship between flexural strength and compressive strength of concrete exist [39-40]. The expression was outline in many standard codes as shown in Table 5. Many researches also attempted to derive a more accurate expression especially when replacement materials were involved [41-42]. The viability of flexural strength of eggshell concrete was determined by using the expressions given to compute the flexural strength based on various design codes. The 28 days compressive strength of eggshell concrete was used, and the result of each set of data was compared with the experimental data obtained in this study. From Figure 5, the experimental data had a similar trend when plotted with other sets of data from design codes. The value of experimental data had significant differences with the China and India code, but was accurately represented by the expression from EC-2. However, an unusual sharp drop was observed for 15% ESC compared to other sets of data. This may be due to the poor packing and bonding of the concrete as excessive amount of eggshell absorbed too much water required for a normal hydration process [47].

Table 5. Flexural strength based on design standards

Code	Source	Expression
EC-2	Europe	$f_f = 0.201 f_c$
JTG D40-2011	China	$f_f = 0.435\ f_c^{\ 0.713}$
IS 456 - 2000	India	$f_f = 0.7\ f_c^{\ 0.50}$

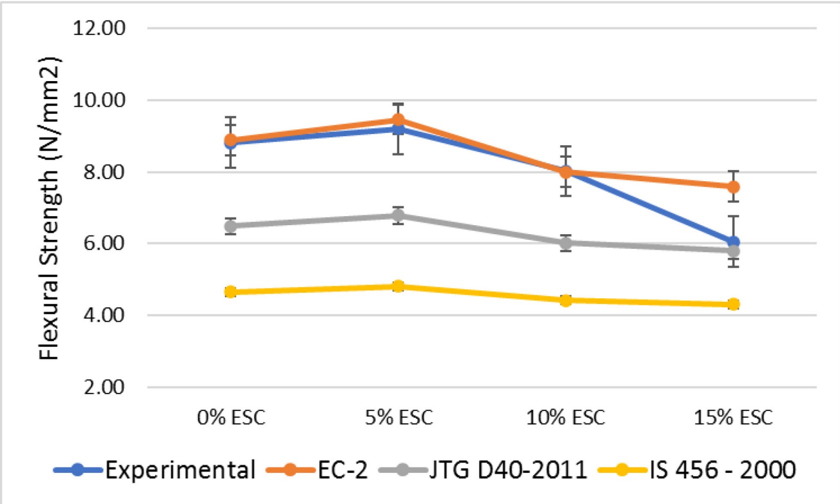

Fig. 5. Flexural strength result comparison

4.5 Split tensile strength

Table 6 showed the split tensile strength of eggshell concrete. At 7 days, the split tensile strength of control specimen was 4.902 N/mm^2, which increased by approximately 10% at 5% ESC. A similar trend happened for 28 days, with the control specimen achieved split tensile strength of 6.392 N/mm^2 and increased by 15% to 7.372% for 5% ESC. For 10% ESC, the split tensile strength of concrete specimens was about 4% less than control specimen. At 15% ESC, the strength of concrete specimen drops further to about 13% lower than the control. which agreed with the strength pattern of other mechanical tests conducted above. The optimal strength was achieved at 5% for all tests. This served as a verification of the relation between the variables, as the flexural strength and split tensile strength of concrete was often directly proportional to its compressive strength [36-37].

Table 6. Split tensile tests result and strength index

Specimen	Split Tensile Strength (N/mm^2)			
	7 days	Index (%)	28 days	Index (%)
0% ESC	4.902	100	6.392	100
5% ESC	5.386	110	7.372	115
10% ESC	4.686	96	6.188	97
15% ESC	4.291	88	5.587	87

4.6 Water absorption

Figure 6 showed the water absorption of eggshell concrete. For all cases except 15% ESC, the percentage of water absorption was below 2%, which was classified by BS 6349 [48] as high quality concrete that can resist critical environment. The water absorption of control specimen was 1.818%. 5% ESC had the lowest water absorption of 1.620%, and subsequent specimens with higher percentages of eggshell powder showed an increase in water absorption. Regardless, all samples showed very low percentages of water absorption by concrete standard. The pattern is similar to that of mechanical strength of eggshell concrete. A lower water absorption may be attributed to increased strength, reduced chance to corrosion of reinforcement, and improved resistance of concrete in aggressive environment. Analysis by linear regression method showed strong correlation ($R^2 > 0.80$) between water absorption with compressive strength, flexural strength and split tensile strength at 28 days as presented on Table 7. For all three variables, R^2 value fell above 0.80, with the correlation between split tensile strength and water absorption being the highest at 0.951. The correlation gave an insight into the mechanism of how eggshell powder improved mechanical strength and lowered water absorption at the same time. While mechanical strength of concrete may be attributed to various factors, water absorption of concrete was commonly related to the internal packing of concrete microstructure. At 5% eggshell replacement, concrete achieved the best microstructure and packing, causing a reduction in water absorption and subsequence improvement of mechanical strength.

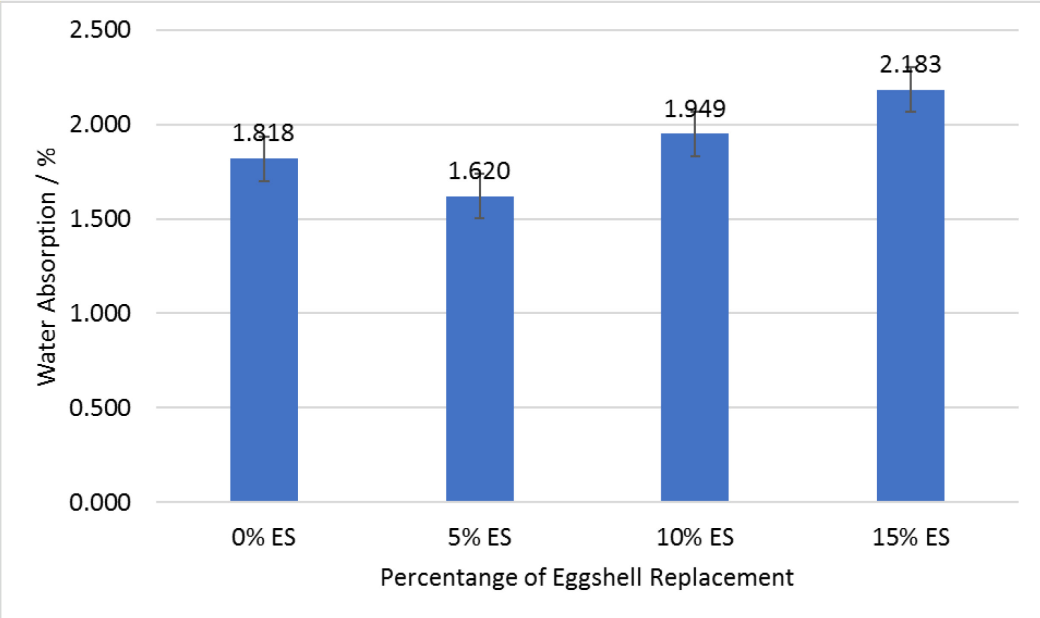

Fig. 4. Water absorption of eggshell concrete

Table 7. R^2 value water absorption verses mechanical strength

Parameter	R^2	Expression	Relationship
Compressive strength	0.944	y = -17.32x + 75	Negative correlation
Flexural strength	0.919	y = -5.70x + 18.80	Negative correlation
Split tensile strength	0.951	y = -3.06x +12.18	Negative correlation

4.7 Carbonation

Figure 7 showed the result of carbonation test on eggshell concrete specimens. The control specimen without eggshell powder replacement was the most carbonated, with a carbonation depth of 5.0mm. The depth of carbonation decreased with more percentage of eggshell powder being incorporated to replace cement. At 15% eggshell replacement, the carbonation dropped to 3.5mm. The reduction in carbonation depth was shown in Scanning Electron Microscope test in which a dense microstructure and less void was observed when eggshell powder was added. The superior filling effect of eggshell powder made it harder for water to permeate the concrete. Carbonation test on eggshell concrete had also been conducted through the use of carbonation chamber in other research [49] and the same pattern was observed. Moreover, the carbonation resistance of all sample are relatively high as rubber crumb replacing sand formed a strong packing with natural aggregate [27]. Hence it can be concluded that eggshell concrete had greater resistance to carbonation and water penetration.

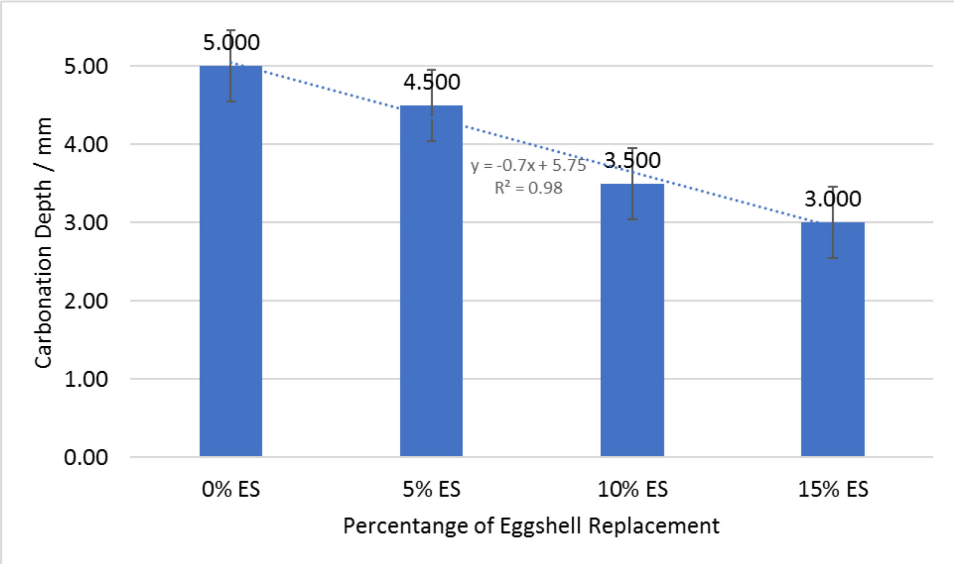

Fig. 7(a). Carbonation depth plot of eggshell concrete

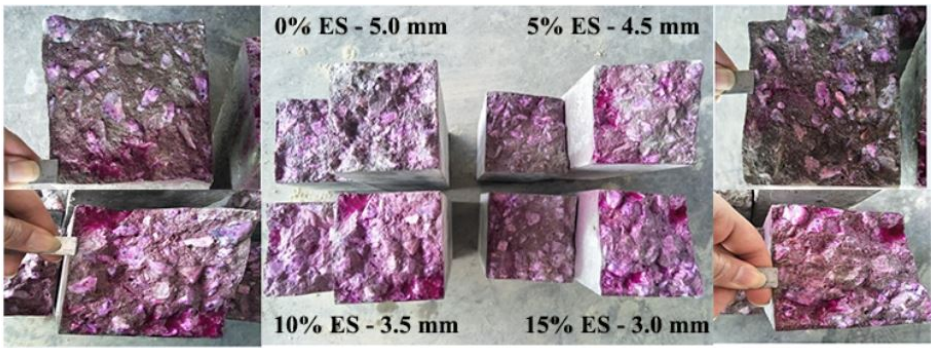

Fig. 7(b). Carbonation depth of eggshell concrete specimens

4.8 X-ray Diffraction

Control specimen of eggshell concrete and the specimen with greatest performance (5% eggshell) were subjected to microstructure analysis using X-Ray Diffraction. Scanning was done at the diffraction angle of 5º to 90º in 2θ. The XRD of the two specimens were shown in Figure 8. It was observed that the specimens contained Quartz, Calcite, and Portlandite as major phase. Calcite, or $CaCO_3$ formed peaks in the result of both specimens. Calcite is one of the major components of cement, and is supplemented by eggshell which contains a high content of the compound [16]. $CaCO_3$ serves as a filler as well as accelerator of hydration process in concrete. The highest peak of calcite compound was found at 37º for control specimen and 27º for 5% eggshell concrete. However, the intensity of control specimen peaked at about 8000 counts while the intensity of eggshell concrete reached approximately 15000 counts. The increased intensity may be the explanation to the superior mechanical performance of eggshell concrete, as $CaCO_3$ is responsible for the hydration and strength gain of concrete [50].

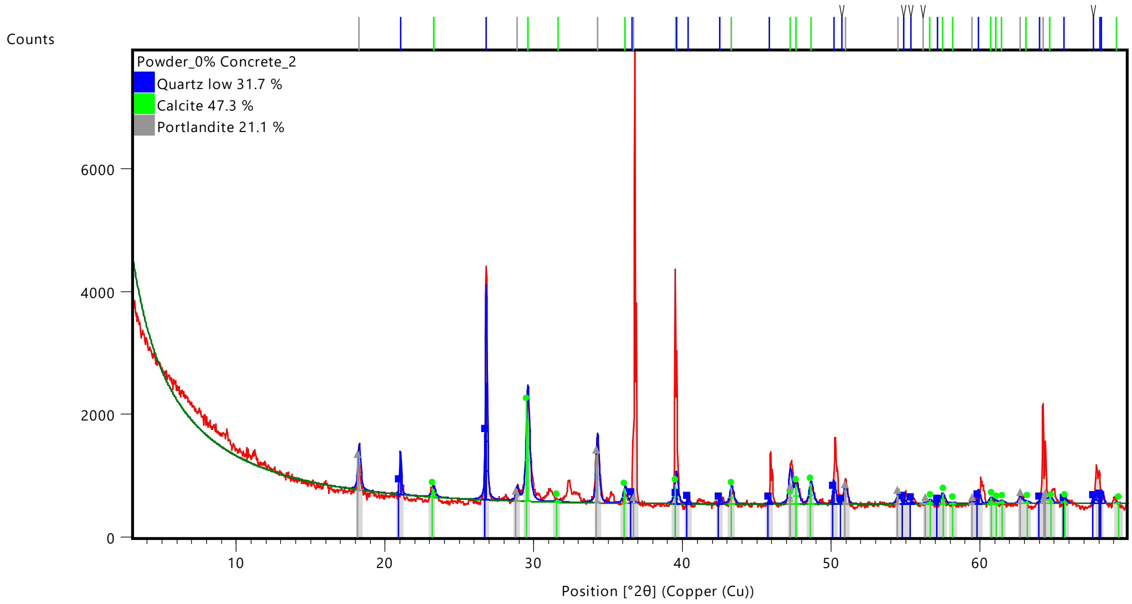

Fig. 8(a). XRD of control specimen

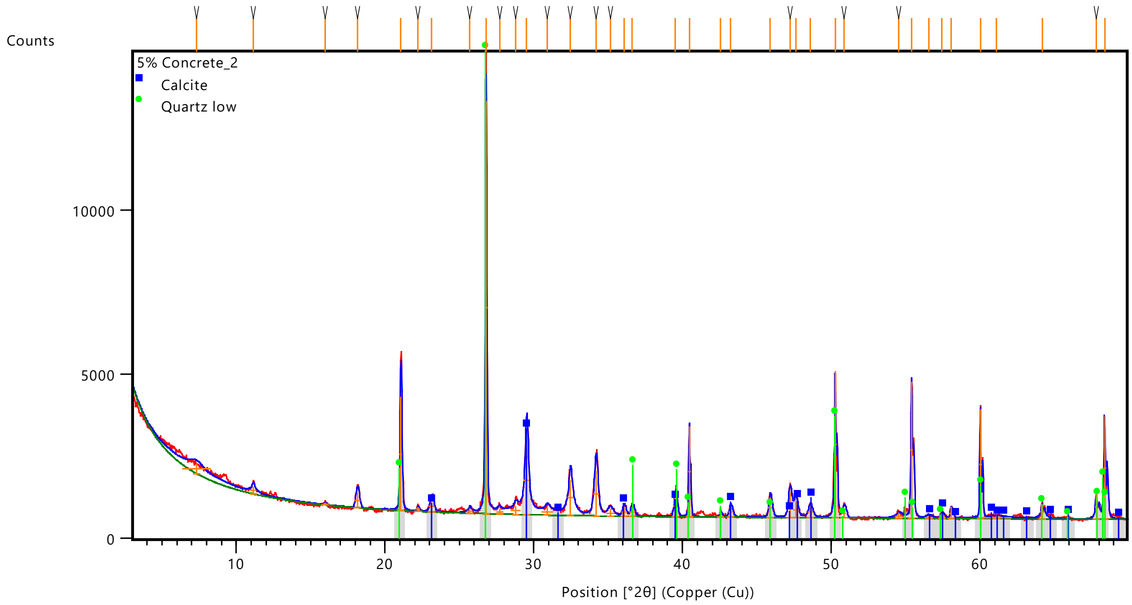

Fig. 8(b). XRD of 5% eggshell concrete

4.9 Microstructure Analysis

Scanning Electron Microscope (SEM) was conducted to study the microstructure of concrete with Energy Dispersive X-Ray (EDX) for the identification and quantification of elements. The microstructure of control specimen and 5% eggshell concrete was studied and compared. The magnification used was 10kx. The result was shown in Figure 9. From the analysis of control concrete at Figure 9(a), the C-H-S gel formed by hydration was shown as white, cloudy sponge. A region of darker spot was identified as a void within the microstructure. Ettringite, which was identified as needle-like crystals were found within and around the void. Ettringite was divided into two types. Primary ettringite was a constituent of hydration remained on aged concrete due to incomplete hydration, while secondary ettringite was stable and evidently developed within air voids. Since the SEM test was performed on 28 days sample, it was believed that the hydration process had been completed and the ettringite was secondary ettringite since it was found around the void. Secondary ettringite is oftenly found around air void regardless of the types of mix, but the crystals are stable and is not associated with cracking or deterioration [51]. For 5% ESC showed in Figure 9(b), the C-H-S gel was found to be more uniform with less pores observed. Voids and ettringite were not apparent from the scanning. It showed an improved microstructure, which may be attributed to the filling effect of eggshell powder improving the pozzolanic reaction to produce concrete with denser microstructure [52]. EDX analysis discovered an increase among of calcium element on concrete with 5% eggshell powder cement replacement. The calcium element in the control concrete was around 67% by atomic weight, while calcium in 5% ESC was about 73% by atomic weight. The result agreed with XRD analysis which was also conducted in this project. Based on the study, the rich content of CaO in eggshell powder [5] had contributed to an increase of C-H-S gel in the concrete and a finer pore structure which causes an increase in mechanical performance as indicated in the mechanical strength of concrete performed in the present study.

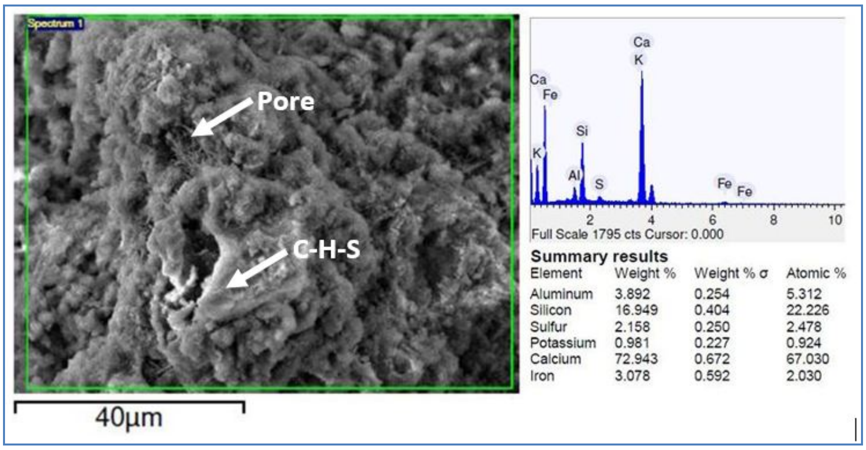

Fig. 9(a). Microstructure of control specimen

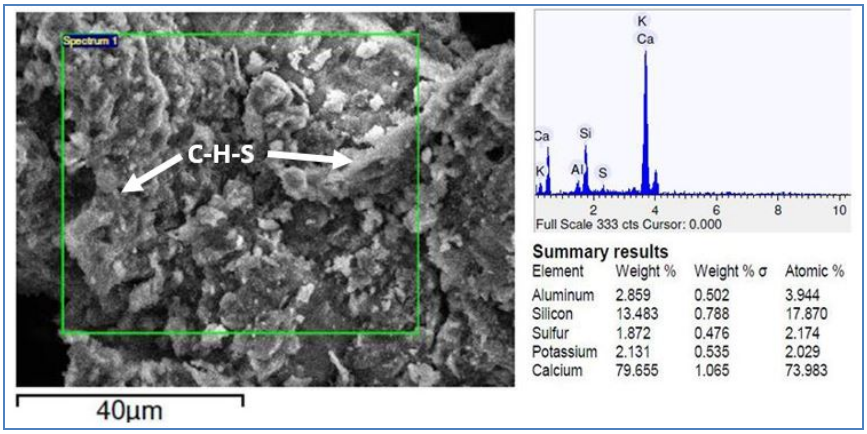

Fig. 9(b). Microstructure of 5% eggshell concrete

5.0 Conclusion

This paper studies the properties of concrete with eggshell powder and tyre crumb. From the results, partial replacement of cement with eggshell powder improved the compressive, flexural, and split tensile strength of concrete. Mechanical strength of concrete increased for up to 5% eggshell powder as cement replacement due to the supplement of calcium hydroxide and filling capability, but excessive replacement absorbs water required by concrete for proper hydration. The strength of concrete dropped beyond 10% and a sharp drop in strength was observed at 15% eggshell. The improvement in mechanical strength was followed by a reduction of water absorption and carbonation depth at 5% eggshell replacement. Quality of concrete was high due to low water absorption and carbonation of all specimens. Replacement of 5% sand with tyre rubber produces concrete with higher durability despite negatively affecting mechanical strength. The improvement is attributed to a better filling properties and denser microstructure of concrete due to the replacement. X-ray diffraction analysis of 5% eggshell concrete showed a higher content of $CaCO_3$ compared to control. Scanning Electron Microscope of eggshell concrete showed a higher density of C-H-S gel, finer pore structure and fewer voids compared to control due to the filling effect of eggshell powder. It could be concluded that 5% replacement of sand with tyre rubber and cement with eggshell powder is capable of producing concrete meeting the required strength while possessing higher durability.

Acknowledgement

This study was supported by the Malaysian Ministry of Higher Education and Universiti Malaysia Pahang under the research grant (RDU/UMP) vote number RDU190339.

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