INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 14 NO. 2 (2023) 153-167

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Experimental Evaluation on Physical and Mechanical Properties of Concrete Containing Green Mussel Shell *(Perna viridis)* Powder as an Admixture

Muhammad Shabery Sainudin[1], Nor Hazurina Othman[1,2*], Nickholas Anting Anak Guntor[1], Nur Hafizah A. Khalid[3], Siti Nor Aishah Mohd-Salleh[4]

[1]Cluster of Structural and Material Engineering, Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[2]Advanced Concrete Material Focus Group, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[3]Department of Structure and Materials, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, 81310, Johor, MALAYSIA

[4]Faculty of Integrated Life Sciences, Quest International University, Ipoh, 30250, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2023.14.02.016
Received 16 February 2023; Accepted 27 February 2023; Available online 08 May 2023

Abstract: Mussel shell is a type of waste that is generated abundantly. However, the presence of chemical components such as calcium (CaCO3) in mussel shells has shown its potential as filler materials in concrete designing. Therefore, this paper presents the experimental result for the physical and mechanical properties of concrete containing 1%, 2%, 3% and 4% Mussel Shell Powder (MSP) as additional material under 2.73% sodium chloride solution. The MSP has been cleaned, grinded and sieved 75µm sizes in order to obtain its final product. Compressive strength, split tensile, and capillary water absorption were determined. Statistical analysis was performed to investigate the correlation and level of significance using IBM SPSS in determining the optimal mix design for modified concrete. The performance of MSP concrete and control specimens are the main factor that been observed in this study. The increment percentages of MSP in concrete had led to reduce on its mechanical strength, however improved in its absorption rates. According to statistical analysis, it shows that low MSP percentages giving a significant value for compressive strength and very strong correlation coefficient compared to control specimens, thus it indicated minimum MSP percentages are more potential in improving concrete physical and mechanical performance.

Keywords: Mussel shell powder, admixture, physical and mechanical properties, significant, correlation, optimum

1. Introduction

Durability is one of the vital criteria should be deliberates in concrete's designing for infrastructure and building components. It prescribes concrete ability in withstanding without significant deterioration and maintaining

*Corresponding author: hazurina@uthm.edu.my

concrete performance during its life services (Demis & Papadakis, 2019). In other words, it was designed by considering the durability aspect which regard to its life span. Generally, concrete durability is resembled through its quality and engineering performances to be long-lasting against an external load. However, it may depend on various factor, i.e., concrete resistance towards alkali-silica reaction and sulphate, protection against corrosion for reinforcing concrete, mixes design, type of cement's selection, alternative materials use, heat of hydration reaction, resistance against aggressive the environment, etc. (Fodil & Mohamed, 2018; Neville, 2011). In recent years, concrete exposure to an aggressive environment is one of the most concerning studies among researchers in identifying its durability (Manjunath *et al.*, 2019). More recently, literature has emerged that the reaction of aggressive exposure potentially changes the crystal structure and causes an adverse effect to concrete durability (Mehta & Monteiro, 2014; Gruyaert *et al.*, 2012; O'Connell *et al.*, 2012). It was also supported by several researchers such as Shi *et al.* (2017) and Qiao, Suraneni & Weiss (2018). Thus, these might cause a major impact on concrete durability and its performance.

Pore's availability in is the key that artery depending on transportation rates due to concrete's porosity or permeability characteristics (Liu *et al.*, 2018; Jivkov *et al.*, 2013). High porosity will resulting higher rate of ingression and absorption. However, concrete pores can be minimized through a significant application of admixture, which potentially improves concrete permeability and strong effect against aggressive agents (Liu *et al.*, 2018; Jivkov *et al.*, 2013; Zhang *et al.*, 2017; Siad *et al.*, 2015; Roig-Flores *et al.*, 2015; Mehta & Monteiro, 2014). Since long, admixture had become one of the significant interests in most research, especially on mineral by-product type's admixture. This admixture is also known as materials that have no bond properties and act as inert materials (Neville, 2011). On the other hand, its reaction with cement's hydration helps in improving hydration reaction for hardening processes (Mehta & Monteiro, 2014). Besides that, it was also potentially promoting sustainability in concrete production by current practices(Hazarika *et al.*, 2018).

Table 1 - Chemical composition of seashells (Lertwattanaruk *et al.*, 2012)

Parameter (%)	Materials		
	Mussel shells	Cockle shells	Oyster shell
$CaCO_3$	95.6	97.13	96.8
SiO_2	0.73	0.98	1.01
Na_2O	0.44	0.37	0.23
Al_2O_3	0.13	0.17	0.14
MgO	0.03	0.02	0.46
Fe_2O_3	0.05	0.06	0.07
SO_3	0.34	0.13	0.75
SO_4	0.11	0.07	0.43
Cl	0.02	0.01	0.01

Seashell is a by-product material that has the potential to be used in concrete designing. Chemically speaking, seashells consist of more than 95% of calcium carbonate ($CaCO_3$) by weight, which makes it as the major component and suitable to be used as filler materials in concrete (refer to Table 1) (Lertwattanaruk *et al.*, 2012; Martínez-García *et al.*, 2017; Olivia *et al.*, 2015). A filler consists of uniform properties on its fineness that essentially act as beneficial elements in improving concrete durability, permeability, and workability (Neville, 2011; Sainudin *et al.*, 2019). A previous study by Olivia *et al.* (2015) stated that the utilisation of cockle shells as cement partial replacement in OPC concrete potentially in improving concrete mechanical strength. They found that the increment of curing duration on 7, 28, and 91 days with a 4% replacement showed an increment in tensile and flexural strength compared to OPC concrete due to bonds interface improvements between cement paste and aggregates in it.

In another major study by Lertwattanaruk *et al.* (2012), considering the used of ground seashell consists of short- necked clam, green mussel, oyster, and cockle as replacement materials in mortar cement plastering had improved its properties compared to conventional cement. It was reported that the existing seashell in mortar increased concrete strength, less drying shrinkage, and lower thermal conductivity. However, the increment of replacements' percentages up to 20% for each type of seashell had reduced its mechanical compressive strength. Therefore, the replacement of seashell shall be used in limited in a small quantity. Since seashell has more significant effects in reducing the concrete porosity rather than its strength. Thus, it may be suitable to create less permeable concrete.

According to Makhloufi *et al.* (2016), the application of $CaCO_3$ with additional materials such as blast furnace slag and natural pozzolan in mortar showed a lower deterioration of specimens in magnesium sulfate solutions. They mentioned that filler materials ($CaCO_3$) acted as the secondary role in reducing the ingestion of magnesium sulfate ($MgSO_4$) with percentages of less than 30% from 90 to 180 days. Based on expansion analysis, it showed that specimens with percentages of 10% $CaCO_3$ indicated the lowest expansion effect compared to ordinary Portland cement (OPC) mortar. A study by Safi *et al.* (2015) concludes that the substitution of crush seashell as substitution sand by fine aggregates into 5 mm particle sizes could improve concrete porosity and absorption. The replacement percentage of seashells more than 50% significantly reduced its percentages of porosity due to particle distribution of seashells, which fit uniformly between surface grains. Thus, less porosity will inhibit the ingestion of water diffused into concrete microstructure through its capillary resulting in fewer absorption rates.

Based on previous literature, it has been justified that calcium carbonate ($CaCO_3$) is potentially useful in enhancing and improving concrete durability and permeability (Food and Agriculture Organization of the United Nations, FAO, (2018). Thus, this study is focusing on exploring mineral admixture consists of mussel shell waste as concrete additional materials, which then cured under sodium chloride (NaCl) solution. Overall, this research was conducted to identify the physical and mechanical properties of mussel shell powder concrete, in which the data from tasted specimens were analyzed using statistical analysis through significant and correlation tests to determine the optimum MSP percentages.

2. Materials and Experimental Methods

2.1 Materials and Sample Preparation

Seashells or mollusks from Perna viridis (green mussel shell) types were selected, which is one of the highest productions in Johor compared to other states in Malaysia based on the statistical report by the Department of Fisheries Malaysia respectively (Malaysia Fishery Department, 2022). At first, the mussel shell was cleaned to remove dirt, then dried in a drying oven for a temperature of 180ºC for 1hour. Then, the mussel shell was crushed with Los Angeles Abrasion machine and sieved to obtain less 75µm particle size. Materials used such as OPC and MSP in this study follow according to ASTM C128-01 and BS EN 1097-6: 2013, with the specific gravity value of 3.09 for OPC and 2.51 for MSP, respectively (10g samples) (British Standard Institution 2013; Teychenné *et al.*, 1997). Fig. 1 and Fig. 2 show the mussel shell and MSP used in this study.

MSP concretes were mixed in 5 different batches denoted as NC, MSP1C, MSP2C, MSP3C, and MSP4C. The test specimens were designed according to the Design of Normal Concrete Mixes with water to cement ratio of 0.51 (Teychenné *et al.*, 1997). The weights of materials used for Portland cement, coarse, and fine aggregates were 0.42 kg, 1.21 kg, 0.57 kg, respectively for 0.001 m^3 mould (cube sizes 100mm × 100mm × 100mm). Whereas, for 0.0024 m^3 mould (cylinder sizes 200mm × 100mm) were 0.84 kg of cements, 2.42 kg of course aggregates, and 1.14 kg of fine aggregates. Each of the materials were wrapped using plastic to prevent the presence of moisture in it.

Table 2 shows the percentages of mix proportion for cube and cylinder moulds including the weight of MSP admixture used. Whereas, the curing method used in this study is the water curing method, in which the specimens immersed totally in water after unmolding. This method is selected due to its effectiveness and comprehensiveness way of covering the total surface area of each specimen. Sodium chloride (Bendosen C1119-3301231) solvent as in Fig. 3 was used with mixed percentages of 2.73% of the total weight of water used for curing purposes. The temperature of cured water was maintained at 20 ºC to 29 ºC according to a minimum and maximum temperature reading.

Table 2 - Mix proportion for specimens

Samples	Percentages admixture	MSP (kg)	
		Cube sizes	Cylinder sizes
NC	100% concrete	0	0
MSP1C	100% concrete + 1% MSP	0.024	0.048
MSP2C	100% concrete + 2% MSP	0.048	0.096
MSP3C	100% concrete + 3% MSP	0.072	0.145
MSP4C	100% concrete + 4% MSP	0.096	0.193

2.2 Experimental Works

Compressive strength analysis is one of the analyses to be obtained in this study to identify its maximum strength when exposed to loads. This analysis is measured on cubic sizes 100mm × 100mm × 100mm according to the BS EN 12390-3:2009 (British Standard Institution, 2009). Its strength was observed based on 7, 28, and 90 days curing for each percentage of MSPC specimens. Whereas, split tensile analysis is devoted to this study to identify the strong resistance of MSPC specimens toward tension that can cause cracking. This test is observed based on the EN BS standard 12390- 6:2009 with cylindrical sizes of 100mm (diameter) × 200mm (length) for each specimen (British Standard Institution forSplitting Tensile, 2009).

On the other hand, capillary water absorption is served for the determination of water absorption through its capillary. This test is carried out using another sample of cube sizes (100mm × 100mm × 100mm) and measured based on 7, 28, and 90 days of curing. The standard follows as in the RILEM CPC 11.2 (RILEM, 1982). The specimens were weighted according to an oven-dried mass of 105 ºC for 24 hours. Each specimen was covered with tape for each side surface to promote absorption through one surface area. Fig. 4 shows the description of capillary water analysis and its capillary absorption was calculated by using the following Eq. (1).

$$\frac{Q}{A} = k\sqrt{t} \qquad (1)$$

Where:

k : Capillary water absorption coefficient (cm/s)

Q: Quantity of water absorbed (cm^3)

A: Area of water absorption (cm^2)

t : Time (s)

Fig. 1 - Mussel shells

Fig. 2 - Mussel shells powder

Fig. 3 - Sodium chloride (Bendosen C1119-3301231)

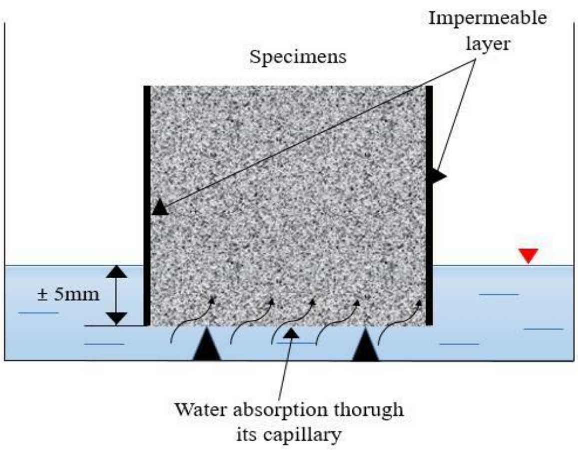

Fig. 4 - Capillary water absorption test

3. Results and Discussions

3.1 Analysis of Compressive Strength for Tested Specimens

Based on the compressive analysis, the increasing percentages of MSP tend to reduce concrete mechanical strength. As data presented in Fig. 5, it shows a strength reduction with an increment of MSP up to 4% (MSP4C) on 7, 28, and 90 days compared to the control sample (NC). According to Lertwattanaruk *et al.* (2012), it is due to the properties of the materials of seashells itself that categorised as less reactive materials when corporate with Portland cement that causing less reaction. On the other hand, according to a study by Lee *et al.* (2008), they stated that the reduction of compressive strength may due to the formation of thaumasite ($CaSiO_3 \cdot CaCO_3 \cdot CaSO_4 \cdot {}_{15}H_2O$) calcium–silicate–sulfate–carbonate minerals that can be derived as in Eq. (2). Thaumasite formation could lead to CSH leaching, reducing C_3A, changes the mono-ettringite phase (AFm) and effecting the hydration-aluminum compound in cement (Sun & Chen, 2018; Ramezanianpour & Hooton, 2013). This crystal compound occurred due to the high content of $CaCO_3$ (CO_3, carbonate ion) and the existence of calcium silicate hydrate (CSH), which could promote the assaulting of sulfate (SO_{4-}) from solution in concrete specimens. However, thaumasite formation in this study remains clearly explained due to unclear chemical analysis on SO_{4-} ingression in concrete. Thus, further research needs to be done in order to identify the accuracy of thaumasite formation in MSP concrete.

$$CaSiO_3 + CaCO_3 + CaSO_4 + 15H_2O \rightarrow CaSiO_3.CaCO_3.CaSO_4.15H_2O \qquad (2)$$

Although overall data shows a descending trend with the increments of MSP percentages. However, there is an increment in concrete strength for MSP1C with 41.7MPa and 46.9MPa for 28 and 90 days, respectively. It indicates a higher value compared to other specimens. Studies by Hawlett, (1998) and Bonavetti et al. (2001), mentioned that $CaCO_3$ compound in mussel shells chemically reacted with C_3A, then formed calcium carboaluminate ($C_3A \cdot 3CaCO_3 \cdot 32H_2O$) compound at ettringite phase (AFt) in Eq. (3) and turned into calcium mono-carboaluminate ($C_3A \cdot 3CaCO_3 \cdot 12H_2O$) compound at mono-ettringite phase (AFm) in Eq. (3a). This compound has the potential to increase concrete strength and its ultimate strength (Li et al., 2018). A study by Hashim & Nhabah (2018), the limited amount of $CaCO_3$ in nano form could improve the compressive and split tensile strength compared to normal concrete on 7 and 28 days. Therefore, the minimum percentages MSP is still reasonable to be applied in the concrete mixture in order to increase its mechanical properties.

$$C_3A + 3CaCO_3 + 32H_2O \rightarrow C_3A \cdot 3CaCO_3 \cdot 32H_2O \qquad (3)$$
$$C_3A + 3CaCO_3 + 12H_2O \rightarrow C_3A \cdot 3CaCO_3 \cdot 12H_2O \qquad (3a)$$

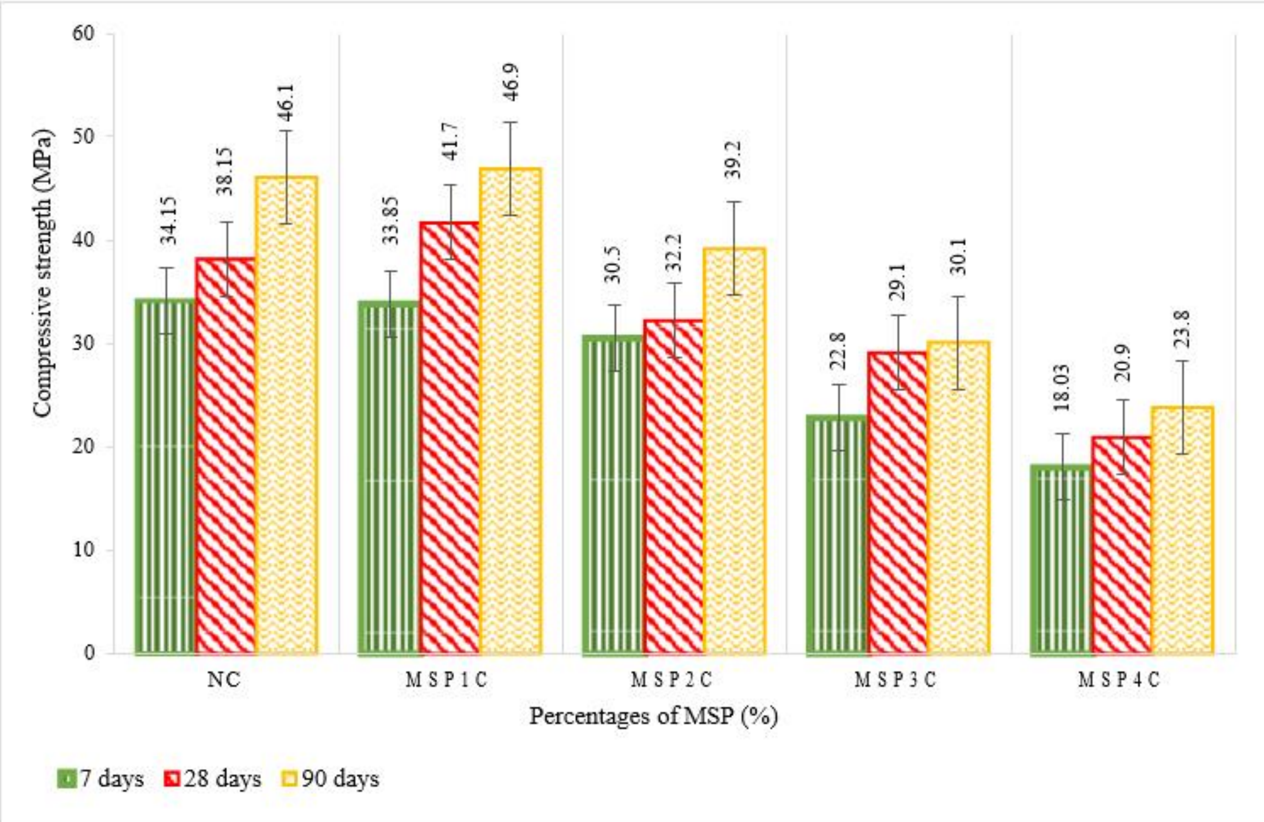

Fig. 5 - Compressive strength concrete specimens

3.2 Split Tensile Strength of Tested Specimens

Split tensile strength was analyzed from 100 m × 200 m cylinder specimens with water to cement ratio (w/c) of 0.51, then cured in NaCl solution as mentioned in the previous section. From the experimental results for this analysis, it is observed that normal concrete (NC) gives a higher split tensile strength on 7, 28, and 90 days respectively. Compared to MSP concrete, it shows a decreasing value of strength with the increments of MSP. Both graphs in Fig. 5 and Fig. 6 almost give the same trends that indicate the decline pattern. A similar split tensile strength reduction also reported by Olivia *et al.* (2017) with the increments of seashell powder in concrete by 4% compared to normal specimens. Hence, it is generally noticed that the filler effect of MSP does not improve in concrete split tensile strength.

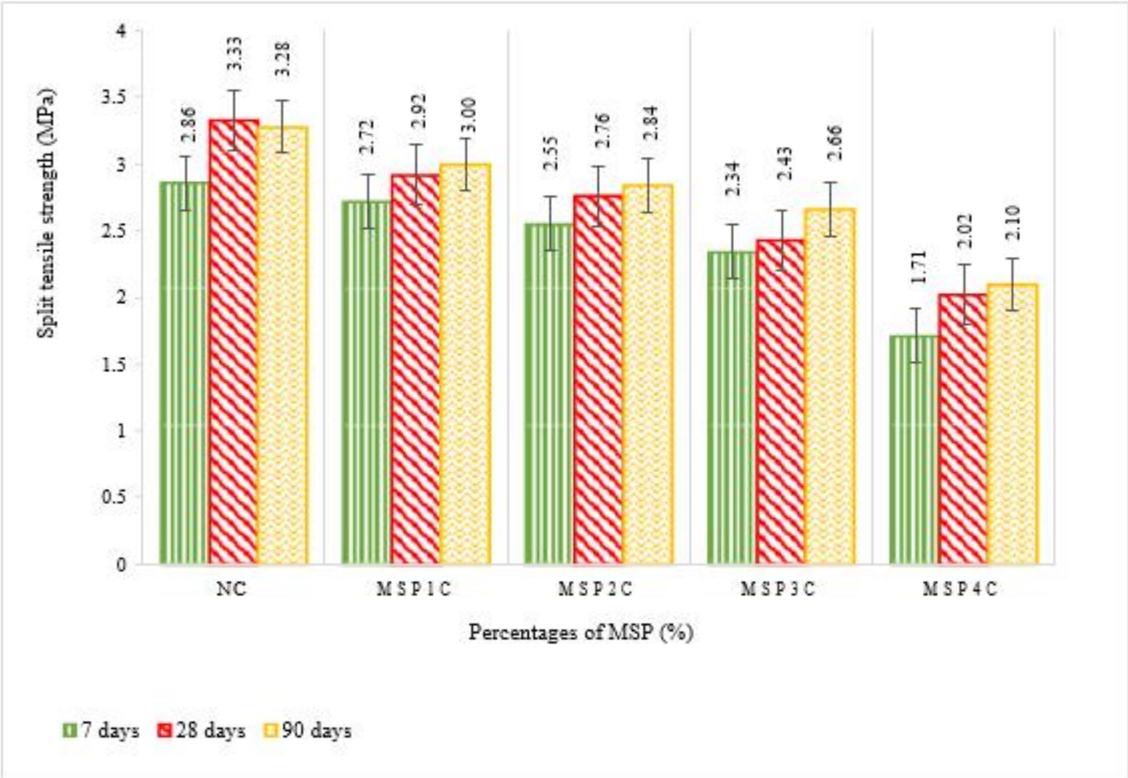

Fig. 6 - Split tensile strength concrete specimens

However, NC shows a small reduction in tensile strength at 90 days. It may due to the absence of filler materials in concrete specimens, which make it more permeable compared to MSP concrete. Since there are no filler materials used in control specimens and the existence of sulfate ion (SO_{4-}) in solution, thaumasite reaction may not occur due to the less amount of carbonate (CO_{3-2}). On the other hand, a high concentration of chloride (Cl-) from solution potentially might cause the reason for NC losing its split tensile strength. According to Ragab *et al.* (2016) and Wang *et al.* (2019), a reaction of Cl- with C_3A in concrete causes the formation of Friedel's salt ($3CaO{\cdot}A1_2O_3{\cdot}CaCl_2{\cdot}10H_2O$) Eq.4. This could affect the mechanical properties of concrete due to pressure that occurred from Friedel's salt formation in concrete that exhibits the bonding-lose in the inner concrete micro-structure (Qiao *et al.*, 2018). This also was supported through a study by Jones *et al.* (2003). He stated that Friedel's salt mechanism started to form at the age of more than 50 days after Cl- entering the concrete inner part. Therefore, NC at 90 days giving a reduction in its tensile strength value compared to 7 and 28 days.

$$12CaO{\cdot}7Al_2O_3 + 9Ca(OH)_2 + 7CaCl_2 + 61H_2O \rightarrow 7\ (3CaO{\cdot}Al_2O_3{\cdot}CaCl_2{\cdot}10H_2O) \qquad (4)$$

3.3 Analysis for Capillary Water Absorption

Capillary water absorption test was conducted in this study to evaluate the filler effect of MSP materials on concrete capillary pores. The results of this analysis were presented in Fig. 7. Overall, it is noticeable that the capillary water absorption for each specimen on 7 days is higher compared to 28 and 90 days. This is because the hardened paste consist of poorly un-hydrated crystal in various compounds that cause the existence of un-consistence pores at an early age (Neville, 2011). Therefore, it is resulting in a higher water absorption on its capillary pores. Besides that, there were inconsistent reading for tested specimens with increment percentages of MSP. Nevertheless, the increment seems to be in a small range that is less than tenths digit and does not correlate with compressive and split tensile strength. Thus, it was verified that the less capillary micro-structure does not give major effects on concrete mechanical properties for tested specimens.

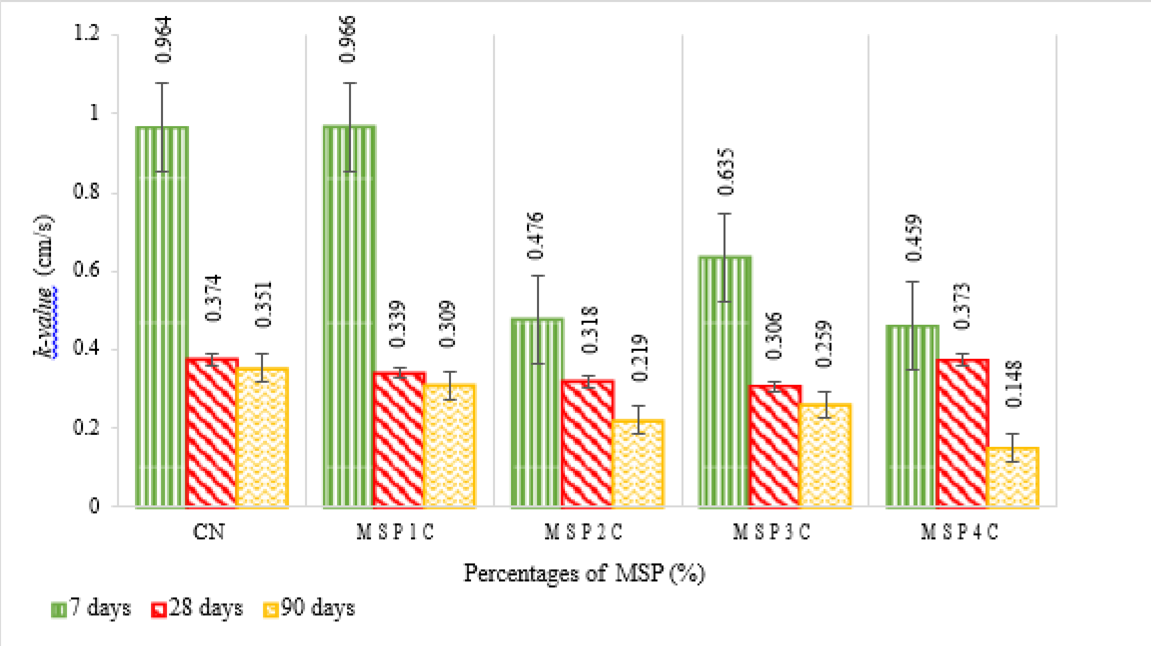

Fig. 7 - Capillary water absorption of concrete

Referring to the same graph, it is clearly noticed that the increment percentage of MSP up to 4% had reduced the capillary water absorption. MSP4C indicates the lower k-value that is 0.148cm/s in 90 days compared to other specimens (NC, MSP1C, MSP2C, and MSP3C). According to a study done by Li and Kwan (2015), the application of fines filler in concrete could reduce the water penetration depth and Cl ingestion (RCPT analysis) to concrete microstructure due to smaller sizes of the capillary pore in it. Even though their research materials are focusing on the utilisation of lime filler, however, its data observed still can be referred in this study since lime and mussel shell having similar major chemical compound consist of $CaCO_3$ (Lertwattanaruk *et al.*, 2012) or derived as calcium oxide (CaO) in each material (Prošek *et al.*, 2019; Ontiveros-Ortega *et al.*, 2018).

3.4 Statistical Evaluations

3.4.1 Correlation Analysis for Tested Specimens

The correlation test was adapted in this study to identify the strength relationship between the dependent variable and the independent variable (Kremelberg, 2011). It defines the strength of each variable according to its correlation coefficient (r) value. This analysis also represents the linear equation strength between variables. The nearest r-value to 1 or -1 will give a very strong correlation coefficient. Positive and negative symbols indicate its positive correlation (direct linear line) or negative correlation (inverse linear line) (Privitera, 2012). According to the graph correlation, the y-axis indicates dependent variables whereas the x-axis indicates independent variables. Table 3 indicates correlation value between each dependent variables while Table 4 indicates the correlation coefficient between dependent variables for each percentage of MSP used. Clearly, it is noticed that the compressive strength and split tensile strength initiate a strong correlation value (r =0.912), which near to 1.00 with a positive linear line as in Fig.8. Compressive strength and split tensile give almost a similar trend with the increment of percentages of MSP used. It shows that both variables are directly relatable to each other. This also was supported by Akinpelu *et al.* (2019) and Chhorn *et al.* (2018). Thus, split tensile strength trends line can be predicted with compressive strength.

Table 3 - Correlation analysis between each dependent variable

	Compressive strength	Split tensile strength	Capillary water absorption
Compressive strength	1	0.912	-0.076
Split tensile strength		1	0.041
Capillary water absorption			1

On the other hand, it was verified that the strength relationship for the compressive strength and capillary water absorption had given a weak strength with less gradient line as in Fig. 9. A similar result was also noticed between the strength relationship for split tensile strength and capillary water absorption as in Fig. 10. Since compressive and split tensile strength indicate a higher r-value compared to other dependent variables, thus this variable would be selected for further correlation analysis between each percentage as shown in Table 4. Subsequently, it can be seen that the compressive strength for MSP1C and MSP4C mostly indicates a higher r-value, which nearest to 1.00 and -1.00. However, further verification shows that MSP1C resulting in a stronger correlation with coefficient correlation (r) for each variable that nearest to 1.00 and -1.00 compared to MSP4C. Therefore, it was clearly shown that MSP1C resulting in the strongest significant correlation value.

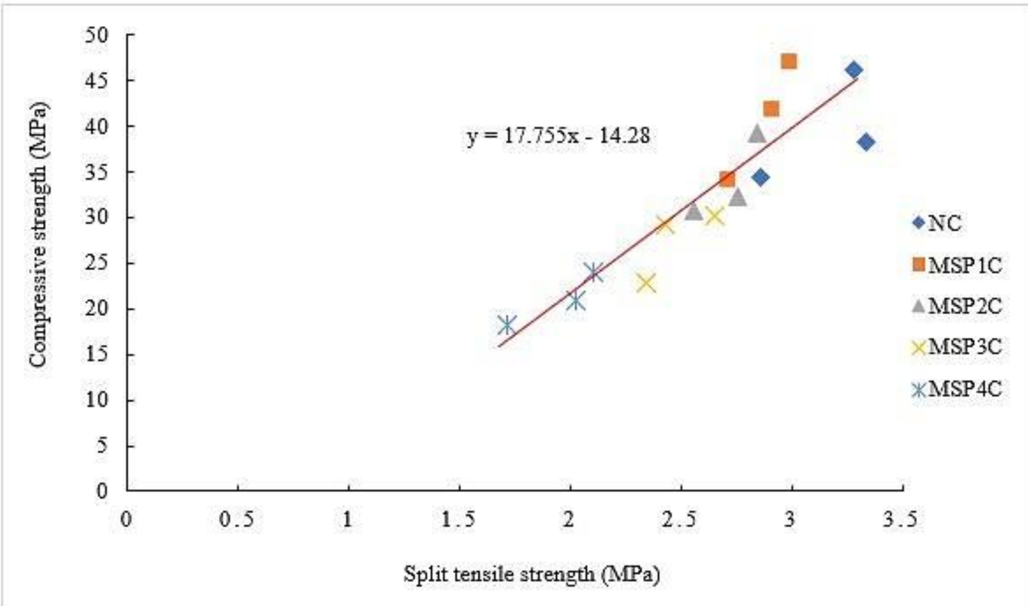

Fig. 8 - Relationship between compressive strength and split tensile strength on 7, 28 and 90 days curing

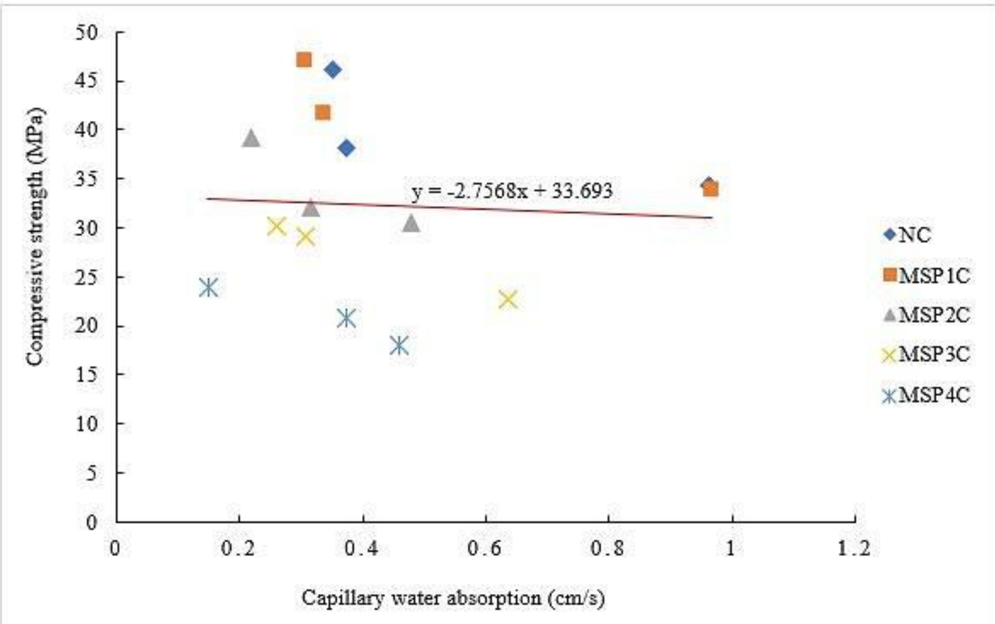

Fig. 9 - Relationship between compressive strength and capillary water absorption on 7, 28 and 90 days curing

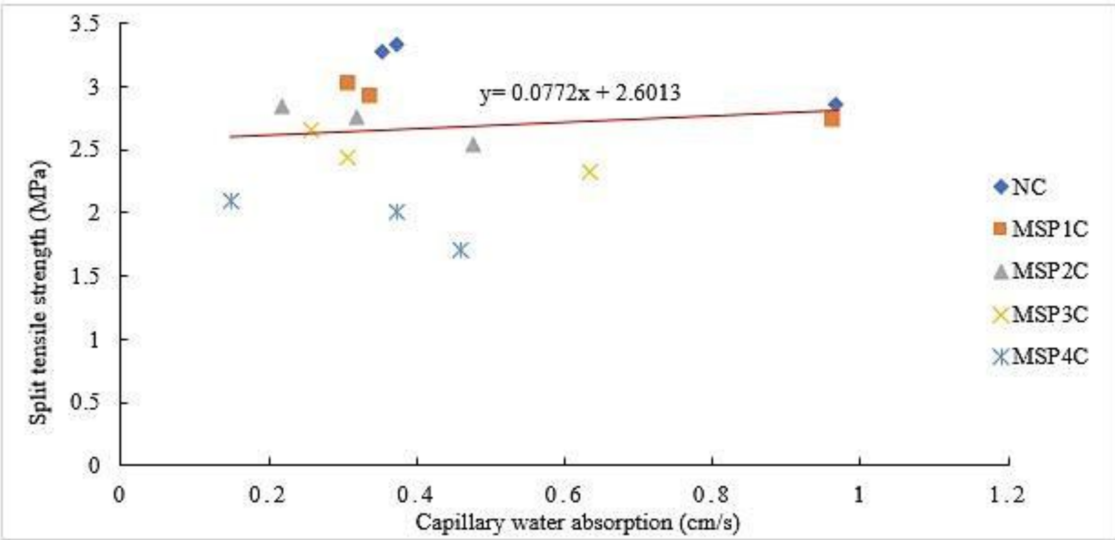

Fig. 10 - Relationship between split tensile strength and capillary water absorption on 7, 28 and 90 days curing

Table 4 - Further correlation coefficients between percentages of MSP

Dependent variables	NC (Split tensile)	MSP1C (Split tensile)	MSP2C (Split tensile)	MSP3C (Split tensile)	MSP4C (Split tensile)
NC (Compressive)	0.690	0.908	0.903	0.998	0.869
MSP1C (Compressive)	0.975	0.990	0.991	0.994	0.978
MSP2C (Compressive)	0.574	0.836	0.830	0.996	0.786
MSP3C (Compressive)	0.975	0.988	0.989	0.790	0.997
MSP4C (Compressive)	0.811	0.969	0.967	0.970	0.940

3.4.2 ANOVA Test for Statistical Analysis

The test of significant was carried out in this study to evaluate the significant level of an additional percentage of MSP to the experimental parameters tested in this study. The results of the analysis were summarized in Tables 5–10. Referring to Table 5–7, the highest mean for compressive, split tensile and capillary water absorption analysis was MSP1C (28), NC (28), and NC (7), respectively. Meanwhile, the lowest mean obtained was MSP4C (28), MSP2C (90), and MSP4C (90), respectively. However, in order to identify either there were significant effects, for the mean value of MSP used and curing time to physical and mechanical properties of specimens, ANOVA two-way was applied. It was necessary due to data collecting in this study consisted of more than one fix factor (independent variable), with more than two levels (k), which indicates the percentages of MSP used (Landau & Everitt (2004). Thus, significant value can be determined through *p*-value from IBM SPSS result as in Table 8.

Based on results shown in Table 8 for the ANOVA test, it was observed that there is no significant difference of curing time on the compressive strength of specimens, since the calculated *p*-value is greater than 0.05. It shows that the interaction between percentages of MSP and curing time (p=0.783) on compressive value is not significantly difference. As in a similar table, it also shows that there is no significant difference of MSP percentages, curing time, and interaction between MSP percentages with curing time on concrete split tensile strength, with *p*-value is more than 0.05. Besides that, results for capillary water absorption analysis were also indicated similar outcomes between percentages of MSP, including the interaction between MSP and curing time analyzed (p> 0.05). According to a study by Makhloufi *et al.* (2016), they found that filler materials became more dominant at the age of more than 90 days. This had led to a smaller difference mean between each value that causing no significant different in results. Besides that, since all the specimens were cured using NaCl solution, it might cause some chemical reaction between hydration products and chemicals in the solution that could change concrete behavior as mentioned in previous section. Thus, these reactions may effect on concrete performance that causes no significant interaction between certain variables.

Table 5 - Statistical analysis on compressive strength

Sample	N	Mean (MPa)	Max (MPa)	Min (MPa)	Std. deviation
NC (7)	3	33.700	35.50	32.80	1.559
NC (28)	3	25.433	39.80	26.50	22.088
NC (90)	3	40.000	44.60	37.70	3.984
MSP1C (7)	3	33.367	34.30	32.40	0.950
MSP1C (28)	3	41.700	43.90	40.00	1.998
MSP1C (90)	3	31.267	47.10	46.70	27.078
MSP2C (7)	3	20.200	30.60	30.00	17.496
MSP2C (28)	3	32.167	32.70	31.70	0.503
MSP2C (90)	3	26.133	35.50	23.90	22.669
MSP3C (7)	3	22.767	24.30	22.00	1.328
MSP3C (28)	3	29.067	29.60	28.10	0.839
MSP3C (90)	3	30.133	31.80	28.10	1.877
MSP4C (7)	3	18.033	18.80	16.70	1.159
MSP4C (28)	3	13.933	21.20	20.60	12.070
MSP4C (90)	3	15.867	24.60	23.00	13.764

(*) = curing time

Table 6 - Statistical analysis on split tensile strength

Sample	N	Mean (MPa)	Max (MPa)	Min (MPa)	Std. deviation
NC (7)	3	1.907	2.15	1.79	1.651
NC (28)	3	3.330	3.41	3.15	0.156
NC (90)	3	2.190	3.45	3.12	1.904
MSP1C (7)	3	2.707	2.76	2.68	0.046
MSP1C (28)	3	2.920	3.23	2.81	0.272
MSP1C (90)	3	1.997	3.08	2.91	1.731
MSP2C (7)	3	1.700	2.57	2.53	1.472
MSP2C (28)	3	2.767	2.79	2.75	0.021
MSP2C (90)	3	0.947	1.05	0.91	1.640
MSP3C (7)	3	2.430	2.53	2.38	0.087
MSP3C (28)	3	2.433	2.53	2.35	0.112
MSP3C (90)	3	2.660	2.87	2.42	0.227
MSP4C (7)	3	1.707	1.80	1.63	0.086

MSP4C (28)	3	2.027	2.12	1.97	0.081
MSP4C (90)	3	1.370	2.12	1.99	1.188

(*) = curing time

Table 7 - Statistical analysis on capillary water absorption

Sample	N	Mean (MPa)	Max (MPa)	Min (MPa)	Std. deviation
NC (7)	3	0.964	0.964	0.965	0.001
NC (28)	3	0.250	0.374	0.233	0.216
NC (90)	3	0.234	0.351	0.219	0.203
MSP1C (7)	3	0.644	0.966	0.545	0.558
MSP1C (28)	3	0.339	0.339	0.338	0.001
MSP1C (90)	3	0.309	0.309	0.309	0.001
MSP2C (7)	3	0.317	0.376	0.298	0.275
MSP2C (28)	3	0.318	0.318	0.317	0.001
MSP2C (90)	3	0.219	0.223	0.217	0.001
MSP3C (7)	3	0.635	0.636	0.634	0.001
MSP3C (28)	3	0.204	0.217	0.201	0.177
MSP3C (90)	3	0.259	0.260	0.258	0.001
MSP4C (7)	3	0.459	0.459	0.458	0.001
MSP4C (28)	3	0.373	0.373	0.373	0.001
MSP4C (90)	3	0.148	0.201	0.117	0.001

(*) = curing time

Table 8 - ANOVA analysis for physical and mechanical analysis

Respond	Factor	Type III sum of square	df	Mean square	F	Sig.	Result
Compressive strength	MSP	2062.437	4	515.609	3.213	0.026	Significant (*p<0.05*)
	Curing time	87.782	2	43.891	0.274	0.763	Not significant (*p>0.05*)
	MSP*Curing time	750.287	8	93.786	0.584	0.783	Not significant (*p>0.05*)
Split tensile strength	MSP	6.230	4	1.557	1.478	0.234	Not significant (*p>0.05*)
	Curing time	5.884	2	2.942	2.793	0.077	Not significant (*p>0.05*)
	MSP*Curing time	4.693	8	0.587	0.557	0.804	Not significant (*p>0.05*)
Capillary water absorption	MSP	0.227	4	0.057	1.682	0.180	Not significant (*p>0.05*)
	Curing time	1.177	2	0.588	17.458	0.00001	Significant (*p<0.05*)
	MSP*Curing time	0.578	8	0.072	2.143	0.062	Not significant (*p>0.05*)

However, according to the same table stated before, it shows that there was a significant different on the fixed factor for MSP percentages on compressive strength (*p=0.026)* and curing time on capillary water absorption analysis (*p=0.00001*). Hence, it is noted that percentages of MSP and curing time had given an effect on the properties of MSP concrete. Since there was a significant difference in the physical and mechanical properties of concrete, thus a Post-Hoc analysis was developed in this analysis. The ANOVA test is known as analysis variance, which is done to identify the overall different mean in groups (Berkman & Reise, 2011). However, this analysis only provided a significant result but not the exact point of the difference was located (Berkman & Reise, 2011; Gray & Kinnear 2012). Therefore, Post-Hoc analysis was observed to identify the exact point where the different point was located (Anting *et al.*, 2017). In this study, Post-Hoc analysis was conducted on curing time since it was a significant different on it compare to other fix factors (*p<0.05*). In order to observe the exact different between each factor, *Fisher's Least Significant Difference* (LSD) with a multi-comparison test is performed with α value of 0.05, which means *p< 0.05*. The result obtained was shown in Tables 9 and 10.

Table 9 - Fisher's Least Significant Different result from multiple comparisons analysis on compressive strength

Samples		*p* value	Results
NC	MSP1C	0.691	Not significant ($p>0.05$)
	MSP2C	0.259	Not significant ($p>0.05$)
	MSP3C	0.346	Not significant ($p>0.05$)
	MSP4C	0.008	Significant ($p<0.05$)
MSP1C	NC	0.691	Not significant ($p>0.05$)
	MSP2C	0.131	Not significant ($p>0.05$)
	MSP3C	0.184	Not significant ($p>0.05$)
	MSP4C	0.003	Significant ($p<0.05$)
MSP2C	NC	0.259	Not significant ($p>0.05$)
	MSP1C	0.131	Not significant ($p>0.05$)
	MSP3C	0.848	Not significant ($p>0.05$)
	MSP4C	0.097	Not significant ($p>0.05$)
MSP3C	NC	0.346	Not significant ($p>0.05$)
	MSP1C	0.184	Not significant ($p>0.05$)
	MSP2C	0.848	Not significant ($p>0.05$)
	MSP4C	0.097	Not significant ($p>0.05$)
MSP4C	NC	0.008	Significant ($p<0.05$)
	MSP1C	0.003	Significant ($p<0.05$)
	MSP2C	0.097	Not significant ($p>0.05$)
	MSP3C	0.066	Not significant ($p>0.05$)

The least comparison means between each response can be derived through its significant value (*p-value*). From Table 9, there was significant different existed between NC to MSP4C and MSP1C to MSP4C ($p<0.05$). It shows that percentages of MSP are effecting the compressive strength for certain specimens, which cause a large difference in the mean. Filler materials such as MSP are very relatable to the mechanical strength of concrete due to its filler effect in reducing the number of micro-pores. However, an excessive amount could affect its mechanical characteristic, which causing strength loss with an increment of MSP. A similar result was also reported by Ismail *et al.* (2019). Thus, MSP usage should be minimised in small percentages. On the other hand, it was found that 7 days and 28 days curing time indicated a significant difference ($p=0.011$) as in Table 10. It was also given similar outcomes on 7 days and 90 days curing time with a *p-value* of 0.004. However, it was not statistically significant on curing time between 28 days and 90 days with $p>0.05$. It means that curing time between 28 and 90 days does not affect the capillary water absorption. Essentially to know that, the lesser value of water absorption through it capillary, the lesser quantity of micro-structure pores existing in the specimen. Therefore, a high value of water absorption through its capillary indicates a high void in specimens.

Table 10 - Fisher's Least Significant Different result from multiple comparisons analysis on capillary water absorption

Samples		***p* value**	**Results**
7	28	0.011	Significant ($p<0.05$)
	90	0.004	Significant ($p<0.05$)
28	7	0.011	Significant ($p<0.05$)
	90	0.677	Not significant ($p>0.05$)
90	7	0.004	Significant ($p<0.05$)
	28	0.677	Not significant ($p>0.05$)

4. Summary

MSP is one of the materials from mollusk species that consists of high calcium carbonates percentages, which could potentially act as filler materials when cooperated with concretes. The presence of MSP significantly increased the concrete compressive strength and reduced its capillary water absorption compared to control samples (NC). The results showed that an addition of 1% MSP had increased compressive strength specimens to 33.40MPa, 41.70MPa and 46.90MPa compared to control samples of 34.15MPa, 38.15MPa, and 46.1MPa on 7, 28, and 90 days respectively. Furthermore, the increments of MSP to 4% had reduced capillary absorption to 0.148 cm/s compared to NC with 0.351 cm/s in 90 days. Even though the increment percentages of MSP could improve concrete permeability in reducing its capillary pores, however, the results do not significantly improve in its mechanical properties. Since concrete was designed based on its mechanical properties, thus, the percentages of MSP should considerably minimised in order to maintain its strength properties.

According to evaluation using statistical analysis, it shows that MSP1C indicates strong correlation coefficients compared to MSP4C. Whereas, based on IBM-SPSS, Fisher's Least Significant Difference (LSD) analysis indicates that there was a statistically significant different on MSP 1% (p=0.003) on compressive strength of concrete specimens. Generally, with consideration for both analyses, it can be concluded that MSP 1% is the most reliable percentage used as concrete additional materials in concrete design. However, further study is required in this research such as chemical analysis in order to identify accurate outputs based on the discussion that has been made previously.

Acknowledgement

Communication of this research is made possible through monetary assistance by Universiti Tun Hussein Onn Malaysia and the UTHM Publisher's Office via Publication Fund E15216. The authors also are very thankful towards all the staffs of Structural and Materials Engineering as well as Faculty of Civil Engineering and Built Environment for providing access to their facilities for experimental purposes.

References

Akinpelu, M.A., Odeyemi, S.O., Olafusi, O.S. & Muhammed, F.Z. (2019). Evaluation of splitting tensile and compressive strength relationship of self-compacting concrete. Journal of King Saud University – Engineering Sciences. 31, 19– 25.

American Society for Testing and Materials. (2001). Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate. United States: ASTM C128 – 01.

Anting, N., Din, M.F.M., Iwao, K., Ponraj, M., Jungan, K., Yong, L.Y. & Siang, A.J.L.M. (2017). Experimental evaluation of thermal performance of cool pavement material using waste tiles in tropical climate. Energy and Buildings 142, 211–219.

Berkman, E.T. & Reise, S.P. (2011). A conceptual guide to statistic using SPSS. SAGE Publication.

Bonavetti, V.L., Rahhal, V.F. & Irassar, E.F. (2001). Study on the carboaluminate formation in limestone filler-blended cements. Cements and Concrete Research 31.pp. 853-859.

British Standard Institution (2013). Tests for mechanical and physical properties of aggregates. Determination of particle density and water absorption. United Kingdom: BS BS EN 1097-6.

British Standard Institution (2013). Tests for mechanical and physical properties of aggregates. Determination of particle density and water absorption. United Kingdom: BS BS EN 1097-6.

British Standard Institution, (2009). Testing hardened concrete– Part 3: Compressive strength of test specimens. United Kingdom: BS EN 12390-3.

British Standard Institution, (2009). Testing Hardened Concrete. Tensile Splitting Strength of Test Specimens. United Kingdom: BS EN 12390-6.

Chhorn, C., Hong, S.J. & Lee, S.W. (2018). Relationship between compressive and tensile strengths of roller-compacted concrete. Journal of Traffic and Transportation Engineering (English Edition). 5(3). 215-223.

Demis, S. & Papadakis, V.G. (2019). Durability design process of reinforced concrete structures- Service life estimation, problems and perspectives. Journal of Building Engineering 26, 100876.

Fodil, D. & Mohamed, M. (2018). Compressive strength and corrosion evaluation of concretes containing pozzolana and perlite immersed in aggressive environments. Construction and Building Materials 179, 25–34.

Food and Agriculture Organization of the United Nations, FAO, (2018). Aquaculture production by culture environment Malaysia. (Accessed on 19 November 2019) http://www.fao.org/home/en/.

Gruyaert, E.P.V., den Heede, Maes, M. & Belie, N.D. (2012). Investigation of the influence of blast-furnace slag on the resistance of concrete against organic acid or sulfate attack by means of accelerated degradation tests, Cem. Concr. Res. 42, 173–185.

Gray, C.D. & Kinnear, P.R. (2012). IBM SPSS Statistics 19 made simple. Psychology Press.

Hashim, A.M. & Nhabah, H.T. (2018). Influence of caco3 with nanoparticles on the mechanical characteristics and concrete microstructure. International Journal of Civil Engineering and Technology (IJCIET). 9 (10), pp. 799–808.

Hazarika, A., Hazarika, I., Gogoi, M., Bora, S.S., Borah, R.R., Goutam, P.J. & Saikia, N. (2018). Use of a plant based polymeric material as a low cost chemical admixture in cement mortar and concrete preparations. Journal of Building Engineering 15, 194–202.

Hewlett, C.P. (1998). Lea's Chemistry of Cement and Concrete. Fourth Edition. Elsevier, Butterworth Heinemann.

International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) (1982). Absorption of water by concrete by capillarity. Geneva: CPC 11.2.

Ismail N.N., Othman, N.H., Inn, G.W. & Sainudin, M.S. (2019). Physical and Mechanical Properties of Concrete Containing Green Mussel (Perna viridis) Shell Ash as an Admixture. IOP Conf. Ser.: Mater. Sci. Eng. 601, 012034.

Jivkov, A.P., Engelberg, D.L., Stein, R. & Petkovski, M. (2013). Pore space and brittle damage evolution in concrete. Engineering Fracture Mechanics 110, 378–395.

Jones, M.R., Macphee, D.E., Chudek, J.A., Hunter, G., Lannegrand, R., Talero, R. & Scrimgeour, S.N. (2003). Studies using 27Al MAS NMR of AFm and AFt phases and the formation of Friedel's salt. Cement and Concrete Research 33, 177 – 182.

Kremelberg, D. (2011). Practical Statistic: a quick and easy guide to IBM® SPSS® Statistic, STATA and other statistical software.

Landau, S. & Everitt, B.S. (2004). A handbook of statistical analyses using SPSS. Chapman & Hall/CRC.

Lee, S.T., Hooton, R.D., Ho-Seop Jung, Du-Hee Park & C.S. Choi (2008). Effect of limestone filler on the deterioration of mortars and pastes exposed to sulfate solutions at ambient temperature. Cement and Concrete Research 38, 68– 76.

Lertwattanaruk, P., Makul, N. & Siripattarapravat, C. (2012). Utilization of ground waste seashells in cement mortars for masonry and plastering. Journal of Environmental Management 111, 133-141.

Li, C., Jiang, L., Xu, N. & Jiang, S. (2018). Pore structure and permeability of concrete with high volume of limestone powder addition. Powder Technology 338, 416–424.

Li, L.G. & Kwan, A.K.H. (2015). Adding limestone fines as cementitious paste replacement to improve tensile strength, stiffness and durability of concrete. Cement & Concrete Composites 60. 17–24.

Liu, B., Luo, G. & Xie, Y. (2018). Effect of curing conditions on the permeability of concrete with high volume mineral admixtures. Construction and Building Materials 167, 359–371.

Manjunath, R., Narasimhan Mattur, C. & Umesha, K.M. (2019). Studies on high performance alkali activated slag concrete mixes subjected to aggressive environments and sustained elevated temperatures. Construction and Building Materials 229, 116887.

Makhloufi, Z., Aggoun, S., Benabed, B., Kadri, E.H. & Bederina, M. (2016). Effect of magnesium sulfate on the durability of limestone mortars based on quaternary blended cements. Cement and Concrete Composites 65, 186-199.

Malaysia Fishery Department, (2022). Aquaculture table. Malaysia Fishery Department. Accessed on 25 December 2022,https://www.dof.gov.my/index.php/pages/view/3343.

Martínez-García, C., González-Fonteboa, B., Martínez-Abella, F. & Carro- López, D. (2017). Performance of mussel shell as aggregate in plain concrete. Construction and Building Materials 139, 570–583.

Mehta, P.K. & Monteiro, J.M.P. (2014). Concrete: Microstructure, Properties and Materials. Third Edition. Mc Graw Hill.

Neville, A.M. (2011). Properties of concrete. 5th Edition. England: Prentice Hall.

O'Connell, M., McNally, C. & Richardson, M.G. (2012). Performance of concrete incorporating GGBS in aggressive wastewater environments. Construction and Building Materials 27, 368–374.

Olivia, M., Mifshellaa, M.M. & Darmayantia, L. (2015). Mechanical properties of seashell concrete. Procedia Engineering 125, 760 – 764.

Olivia, M., Oktaviani, R. & Ismeddiyanto. (2017). Properties of concrete containing ground waste cockle and clam seashells. Procedia Engineering 171, 658 – 663.

Ontiveros-Ortega, E., Rodríguez-García, R., González-Serrano, A. & Molina, L. (2018). Evolution of mechanical properties in aerial lime mortars of traditional manufacturing, the relationship between putty and powder lime. Construction and Building Materials 191. 575–589.

Privitera, G.J. (2012). Statistic for the behavioral sciences. St. Bonaventure University. SAGE Publications, Inc; Har/Dol edition.

Prošek, Z., Nežerka, V., Hlůžek, R., Trejbal, J., Tesárek, P. & Karra'a, G. (2019). Role of lime, fly ash, and slag in cement pastes containing recycled concrete fines. Construction and Building Materials 201. 702–714.

Qiao, C., Suraneni, P. & Weiss, J. (2018). Damage in cement pastes exposed to NaCl solutions. Construction and Building Materials 171, 120–127.

Ramezanianpour, R.M. & Hooton, R.D. (2013). Thaumasite sulfate attack in Portland and Portland-limestone cement mortars exposed to sulfate solution. Construction and Building Materials 40, 162–173.

Ragab, A.M., Elgammal, M.A., Hodhod, O.A. & Ahmed, T.E. (2016). Evaluation of field concrete deterioration under real conditions of seawater attack. Construction and Building Materials 119, 130–144.

Roig-Flores, M., Moscato, S., Serna, P. & Ferrara, L. (2015). Self-healing capability of concrete with crystalline admixtures in different environments. Construction and Building Materials 86, 1–11.

Safi, B., Saidi, M., Daoui, A., Bellal, A., Mechekak, A. & Toumi, K. (2015). The use of seashells as a fine aggregate (by sand substitution) in self-compacting mortar (SCM). Construction and Building Materials 78, 430–438.

Sainudin, M.S., Othman, N.H. & Shahidan, S. (2019). Performance of concrete containing mussel shell (Perna viridis) ash under effect of sodium chloride curing. Materials Science and Engineering 601, 012033.

Shi, Z., Geiker, M.R., Lothenbach, B., Weerdt, K.D., Garzón, S.F., Enemark-Rasmussen, K. & Skibsted, J. (2017). Friedel's salt profiles from thermogravimetric analysis and thermodynamic modelling of Portland cement-based mortars exposed to sodium chloride solution. Cement and Concrete Composites 78, 73-83.

Siad, H., Lachemi, M., Bernard, S.K., Sahmaran, M. & Hossain, A. (2015). Assessment of the long-term performance of SCC incorporating different mineral admixtures in a magnesium sulphate environment. Construction and Building Materials 80, 141–154.

Sun, J. & Chen, Z. (2018). Influences of limestone powder on the resistance of concretes to the chloride ion penetration and sulfate attack. Powder Technology, 338, 725–733.

Teychenné, D.C., Franklin, R.E. & Erntroy, H.C. (1997). Design of Normal Concrete Mixs (DoE). Second Edition. Building Research Establishment Ltd Garston Watford. BRE press.

Wang, X., Ni, W., Jin, R. & Liu, B. Formation of Friedel's salt using steel slag and potash mine brine water. Construction and Building Materials 220 (2019) 119–127 Contents

Zhang, J., Guo, J., Li, D., Zhang, Y., Bian, F. & Fang, Z. (2017). The influence of admixture on chloride time-varying diffusivity and microstructure of concrete by low-field NMR. Ocean Engineering 142, 94–101.