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Effects of Effective Microorganism on Properties of Blended Cement Concrete

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ABSTRACT

Concrete is an artificial rock that is made with a mixture of cement, aggregates and water with certain proportion. Concrete is one of the material that is most widely used in the construction industry. Cracks that occurs in concrete structure require regular maintenance and special type of treatment which will be very expensive, particularly to the massive concrete structures that bear loads or main structures members. So, to overcome this problem, EM (Effective Microorganism) concrete is introduced to study the potential of EM concrete in filling the cracks. By mixing EM with concrete mixture, the effect on the properties of concrete is assessed whether this EM concrete increase the workability, strength, durability and other properties related. In this study, understanding the function and mechanism of EM in concrete is crucial. This research is undergoing a positive development nowadays in achieving sustainability of concrete, needed for environmental reasons. Several parameters and concrete properties was tested in the experimental procedure and the effect of EM in concrete were assessed in this study. The optimum mixture for EM sample that contributes to the maximum strength properties was 10% mixture of EM in the concrete admixtures. The performance of EM were measured through its fresh and hardened properties of the concrete. From this experimental study, the optimum EM mix to be added in the concrete is 10%, slump of EM concrete had increase by 11.4%. Compressive strength of the EM concrete also increase and modified compression strength is higher than cube compressive strength by the average of 5% for all samples. UPV value shows increasing pattern after concrete were pre-load at 28 days of curing, indicated that the potential of EM filling the cracks. Furthermore, the EM concrete had higher shrinkage and expansion strain compared to the control concrete. While water absorption shows that concrete with dry during condition does absorb more water because of the capillary action that occurs in dry concrete compared to concrete in water curing condition. Lastly, EM concrete show lower rate of carbonation process than control concrete by 50% because the mechanism of EM concrete had made the concrete less permeable compared to the control concrete. From this study, it can be concluded that the properties and behavior of EM concrete almost similar with the normal concrete. However, EM concrete does have the potential in filling the crack of concrete and further studied is crucial in understanding the mechanism and reaction of EM in concrete.

Key Words*:* Effective Microorganism (EM), , micro cracks, properties of concrete, mechanism of EM

Introduction

Concrete is one of civilization's most durable building materials. The ancient Romans used concrete 2,000 years ago to make structures that still stand today. People now used the material's modern version by adding aggregates such as sand or gravel held together by a cement and water paste and more than all other construction materials combined. The world produced 4.3 billion metric tons of cement in 2014, and this production will keep increasing as more sidewalks, buildings, and bridges get built in an increasingly urban world (Prachi, 2016). Concrete is made of cement, aggregate and water in certain proportions. The concrete hardens due to the hydration process between cement and water. Concrete is high in compressive strength but low in tensile strength. By installing steel or other material reinforcement into the concrete member, tensile forces can compensate by the reinforcements.

However, during casting, hydration process that occur can contribute cracking in concrete, such as plastic cracking, plastic shrinkage crack, cracks on matured concrete, etc. This phenomenon in concrete structure which allows the water and different types of chemical into the concrete through the cracks will decreases their durability, strength, and also affect the reinforcement when it comes in contact with water, CO_2 and other chemicals. This reaction will contribute to the corrosion of steel in concrete because the concrete has been exposed to the component through the cracks.

The purpose of introducing EM in concrete is to produce a new breed of concrete that uses living things to enhance the properties. An understanding on the bacterial activity towards cement hydration, its chemical phase and microstructure examination will help researchers to further explore the application of microorganism in concrete. In this study, parameter that is suitable are tested through experimental procedure and the results obtained were discussed. The main aim of this study is to determine the effect of EM on the properties of concrete including fresh and hardened state.

Experimental Laboratory

The specimen or concrete mix proportion were designed for grade 40 using DoE method. The size of specimen is 100 mm x 100 mm x 100 mm for cubes. Other specimen were the prism which the size are 100 mm x 100 mm x 500 mm. Type of cement that were used in this study was Portland Composite Cement that has the serial of MS EN 197-1 CEM II/B-M (V-L) 32.5R which is suitable for general purposes in constructions. CEM II/B-M (V-L) 32,5R is Portland Composite Cement that contains 64-79% clinker and 21-35% mixed addition of siliceous fly ash and limestone. This Portland Composite Cement is from Lafarge. The EM was obtained from suppliers companies from Japan. EM product comes in liquid from and widely used in agriculture. EM was stored in an airtight container and placed in cool place to ensure the quality of EM.

Optimum Mix Design Proportion of EM

The EM admixture was added in concrete mix with different percent in water content. To study its optimum EM in water content, nine cube were prepared with different percent EM which are 5%, 10% and 15% from the amount of water content. The mould size was 100mm x 100mm x 100mm. The mix proportion of EM amount were cast separately into three batch with different percent amount of EM. The cube were tested for compressive strength at 3 days and the result are shown in Table 1. The density of concrete samples was in the range of 2280 to 2395 kg/m^3.

Figure 1 shows the 10% amount of EM was found to produce higher compressive strength compared to 5% and 15 %. The compressive strength started to decrease when the percentage replacement more than 10%. Therefore, in this experimental ten percent of mix proportion EM from amount of water cement content was used in the preparation of the sample.

Table 1: The amount of percent bacteria in water cement content

% of bacteria in water-cement content	Weight (kg)	Compression Strength (N/mm^2)	Average compressive strength (N/mm^2)
5	2.35	26.88	**26.07**
	2.37	25.18	
	2.40	26.16	
10	2.33	31.28	**31.11**
	2.34	30.64	
	2.28	31.42	
15	2.29	21.53	**21.18**
	2.29	20.54	
	2.28	21.46	

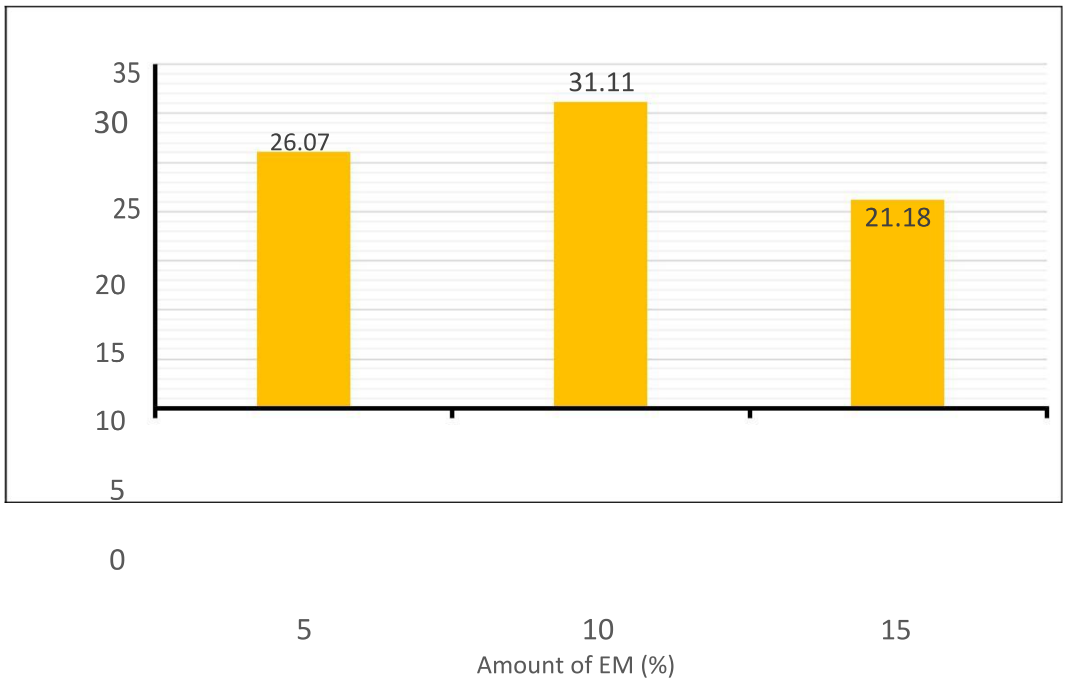


Figure 1: Optimum Percentage of EM in Concrete

Preparation of Sample

Casting process was divided into four batches which are control sample and EM sample. Table 2 shows the type of preparation sample during this research. There are four types of sample which are water curing, air curing, pre-cracks water curing and pre-crack air curing for both of control and EM sample.

Before the concrete is poured into the moulds, the moulds were coated with the as a release agent to ensure the concrete did not stick at the mould and easier to remove the specimen from the mould.

The composition of concrete is given in Table 3 based on the DoE method. There are two type of mix that are used in this experimental study. One was concrete that containing EM and the other was the control concrete, namely the normal mix design of concrete.

The difference is that the EM concrete will be added with 10% of EM by the weight of water that had achieved in the optimum mix design earlier. Twelve cube with the size of 100 x 100 x 100 mm were prepared for each sample to determine the compressive strength at 3 days, 7 days, 28 days and 56 days. Two prisms with the size of 100 x 100 x 500 mm were prepared for each sample to determine the properties of concrete at 7 and 56 days. The coarse aggregate employed in this study was crushed aggregate with maximum size of 10 mm. while the fine aggregate was crushed type and 47% passing 600 µm sieve.

Table 2: Types of Sample

Sample	Name of sample	Types of sample	Types of curing
Control	CONCAC	Cubes	Air curing
	CONCWC		Water curing
	CONPAC		Air curing (pre-loaded)
	CONPWC		Water curing (pre-loaded)
	PCAC	prisms	Air curing
	PCWC		Water curing
EM	EMCAC	Cubes	Air curing
	EMCWC		Water curing
	EMPAC		Air curing (pre-loaded)
	EMPWC		Water curing (pre-loaded)
	EMPAC	prisms	Air curing
	EMPWC		Water curing

Table 3: Material Compositions of Concrete Mixture

Quantity (m^3)	Cement (kg)	Water (L)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)
1.0	500	230	740	904

Pre-Loading of Sample

After curing process in air and in water for 28 days, micro cracks were generated by a uniaxial compression load of about 40% from the ultimate compressive strength at 28 days. Three sample at age 28 days were tested compressive strength earlier to indicate the ultimate compression load. For pre-crack sample, 6 sample were prepared for both control and EM concrete which are used for testing at 56 days, respectively. The reason pre-loading is conducted at 28 days of curing simply because the concrete specimens have gone through a maturity process that is almost done where the strength have achieved 99% and the hydration process almost completed. During the process of pre-loading at 28 days is conducted, UPV test were conducted before and after the pre-loading. After the pre-loading process, the cube concrete specimens were stored in both of curing conditions and tested for compression at 56 days. The cube were labelled nine points to determine the pulse velocity of the cracked concrete and in order to identify the effect of EM.

Furthermore, there are also prisms specimen that is tested at 7 and 56 days respectively. For 7 days of curing process, the prisms were tested for flexural and modified compression to find the strength properties. For 56 days of curing process, the prisms were tested for shrinkage and expansion, flexural, modified compression and carbonation for the mechanical properties of concrete.

Results and Discussions

Several laboratory tests were conducted to investigate the mechanical properties in fresh and hardened concrete which are slump test, compressive strength test, ultrasonic pulse velocity (UPV) test, flexural test, modified compression test, shrinkage and expansion test, carbonation test and surface water absorption test.

Slump Test

The slump for each mix are shown in Table 4. The slump of EM sample was higher than the control sample in the range of 150 – 160 mm for control sample and 170

– 180 mm for EM sample. Slump test for EM sample had increased by 11.42% compared to the control sample. This indicated that the addition of EM to the concrete mix had improved the workability of concrete. Figure 2(a) and (b) show the slump of control sample and EM sample, respectively.

Table 4 : Slump of Sample

	Sample	**Slump (mm)**
Control Sample	Water Curing	150
	Air Curing	150
	Pre Crack (Water Curing)	160
	Pre Crack (Air Curing)	160
EM Sample	Water Curing	170
	Air Curing	170
	Pre Crack (Water Curing)	180
	Pre Crack (Air Curing)	180

a) Control sample

b) EM sample

Figure 2(a) and (b): The Slump of Control Sample and EM Sample.

Compressive Strength

Development of Concrete Compressive Strength

Figure 2 shows the compressive strength development of all concrete mixes. It can be seen in the figure that EM water curing sample has higher compressive strength compared to other samples. All the sample had achieved its design strength on the 28 days of curing. This is probably because these Portland Composite cement have high initial strength according to its design specification. The strength will continue to develop and enhance until 56 days of curing. In this figure it also indicates that sample in water curing have obtain higher compressive strength compared to the air curing for both EM and control sample.

The EM concrete proved to be efficient in enhancing the properties of the concrete by achieving a very high initial strength increase and produced calcium carbonate has filled some percentage of void volume thereby making the texture more compact and resistive to seepage (Ravindranatha et al, 2014).

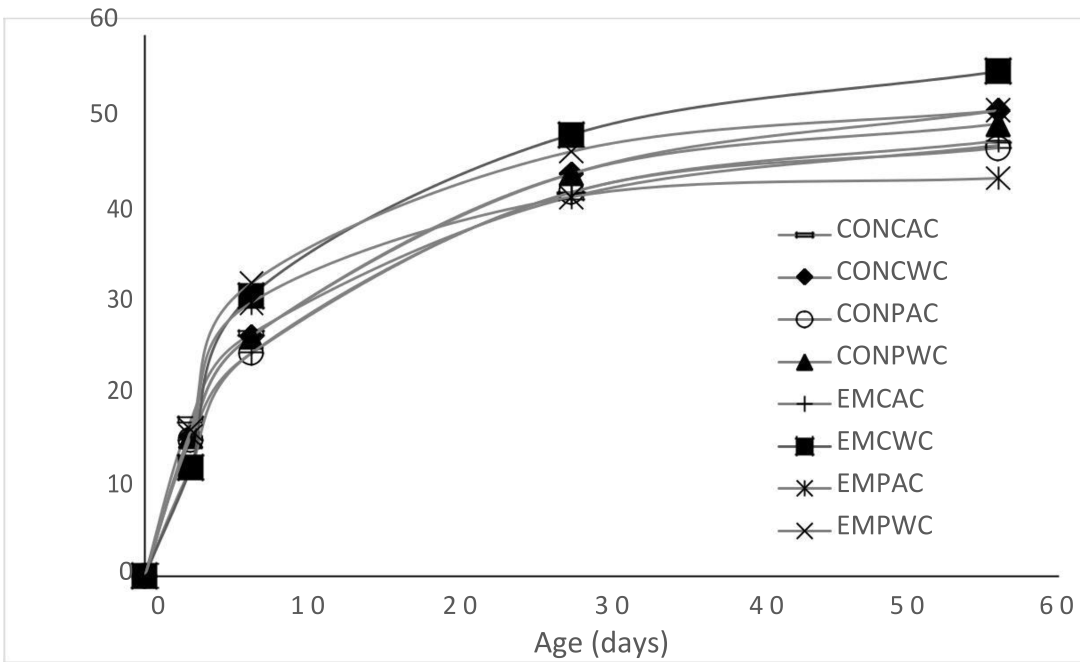


Figure 3 : Compressive strength for control and EM sample

Table 5 shows the compressive strength of all sample at the ages of 3, 7, 28 and 56 days. It can be seen from Table 5, the strength ratio indicated that there are showing the increasing pattern of compressive strength for all samples. After 28 days of curing, most of the sample continue to increase the compressive strength above 10% and only two sample have increase below 10%, which are EM samples with pre-crack for air curing and water curing. This is probably because the sample had been gone through the pre-loading stages at 28 days of curing, whereas the samples had been disturbed. However, the mechanism that occurred inside the concrete after pre-loading indicates that EM concrete able to react and improve the compressive strength of concrete.

Table 5: Compressive Strength of Sample

Type of sample	Curing	Age (days)	Compressive Strength (MPa)	Strength Ratio (%)		
				3/28 days	7/28 days	> 28 days
CONCAC	Air	3	17.34	41.2	64.0	13.6
		7	26.91			
		28	42.04			
		56	47.75			

Table 5 : (cont..)

Type of sample	Curing	Age (days)	Compressive Strength (MPa)	Strength Ratio (%)		
				3/28 days	7/28 days	> 28 days
EMCAC		3	12.03	28.3	58.3	13.6
		7	24.77			
		28	42.52			
		56	48.29			
CONPAC		3	15.06	35.4	58.1	11.4
		7	24.72			
		28	42.57			
		56	47.42			
EMPAC		3	15.57	37.1	72.2	5.1
		7	30.31			
		28	42.00			
		56	44.12			
CONCWC	Water	3	15.46	34.6	59.5	15.7
		7	26.55			
		28	44.65			
		56	51.66			
EMCWC		3	12.03	24.6	63.6	14.4
		7	31.09			
		28	48.91			
		56	55.96			
CONPWC		3	15.46	34.6	59.5	12.2
		7	26.55			
		28	44.65			
		56	50.08			
EMPWC		3	16.27	34.6	69.1	9.8
		7	32.53			
		28	47.07			
		56	51.66			

Ultrasonic Pulse Velocity (UPV)

The samples were tested for UPV test at 3, 7, and 28 continuously until 56 days to indicate micro cracks of the samples. In the same time, the samples without pre-loaded were also tested for UPV test in order to check the uniformity and porosity of the concrete samples. Figure 6 shows the comparison of UPV for all samples. From figure 6, it can be seen that pulse velocity of EM control sample water curing have the highest pulse velocity compared to other samples at the age of 28 days. For pre-cracked sample, the figure shows that EM sample in water curing have the highest pulse velocity compared to other pre-cracked samples.

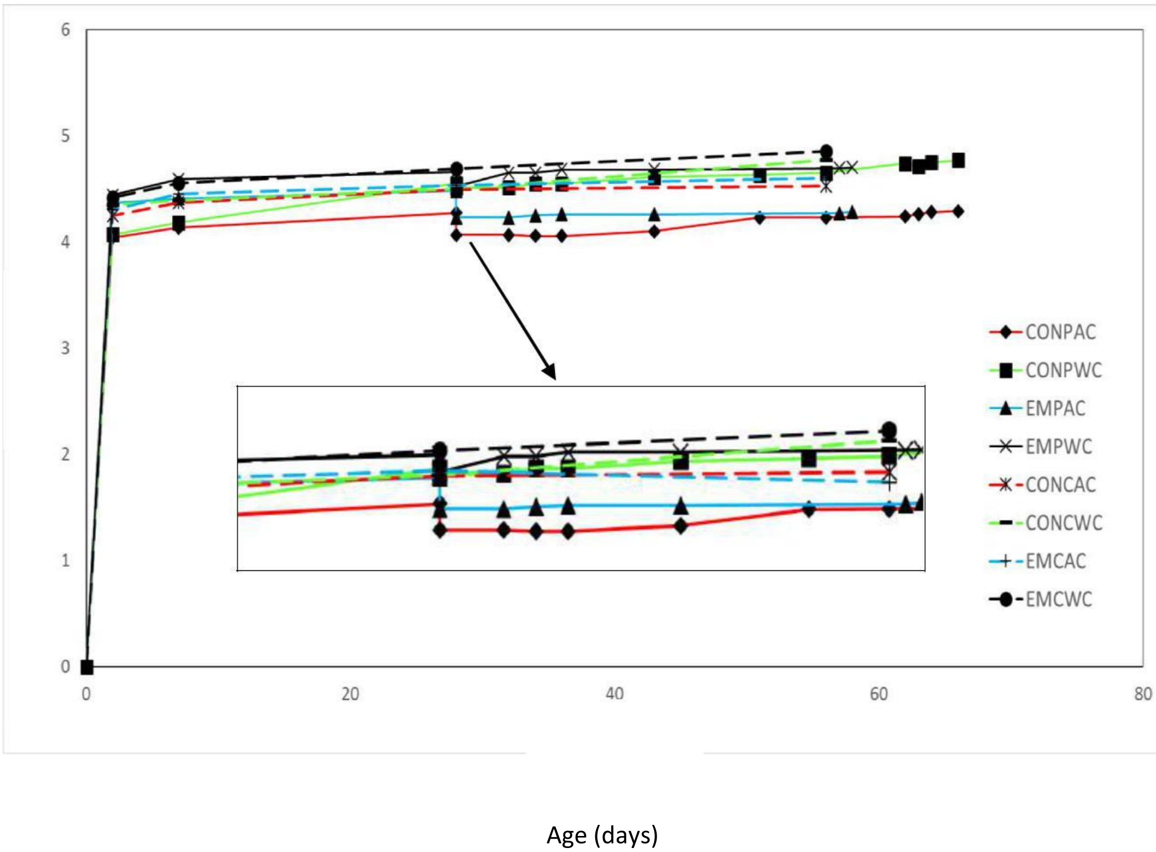


Figure 7 : Comparison Of UPV For All Sample

Table 6 shows the UPV results for sample without pre-cracks. This UPV test is done to compare between control concrete and EM concrete. From this table it can be seen that the percentage difference between control concrete and EM concrete have some significant increased. This indicated that adding EM in the concrete mix may result more dense and less permeable concrete.

Table 6: UPV for sample without pre-cracks

Days	**3**	**7**	**28**	**56**
CONCAC	4.25	4.37	4.49	4.52
EMCAC	4.30	4.45	4.53	4.60
% Difference	1.18	1.89	0.90	1.63
CONCWC	4.35	4.39	4.50	4.77
EMCWC	4.42	4.55	4.69	4.85
% Difference	1.54	3.57	4.05	1.65

Table 7 shows the result of UPV value for sample with pre-cracks. At 28 days of curing, micro cracks had been generated by uniaxial compression machine. Before pre-loading process is done UPV reading is recorded for the sample chosen. Then, pre-load take place and once more UPV value is recorded after the pre-load process had finished. Then, UPV value is recorded and the sample is observed for several days until 56 days of curing to assess the mechanism involved. Besides that, UPV test is to check the uniformity of the concrete mix and the effect of concrete properties when EM is applied in this experimental study.
From Table 7 it shows that the value of EM sample is higher compared to the control sample. The percentage value is increasing from control sample to EM sample shows that EM sample are denser and low permeability compared to the control sample.
From this table, it indicated that percentage pre-loading at 28 days curing are mostly more than 3% which are CONPAC, EMPAC and EMPWC. This results indicates that the micro-cracks after pre-loading stages are almost had the consistent pattern of cracks accept for CONPWC which had the lowest percentage, 0.88%.

Table 7: UPV for sample with pre-cracks

Days	**3**	**7**	**28 (before pre-loading**	**28 (after pre-loading)**	**% pre-loading at 28 days**	**32**	**34**	**36**	**43**	**51**	**56**
CONPAC	4.04	4.13	4.27	4.06	**4.90**	4.06	4.06	4.06	4.10	4.23	4.23
EMPAC	4.37	4.41	4.48	4.23	**5.58**	4.23	4.25	4.26	4.26		4.27
% Difference	**7.48**	**6.30**				**3.92**	**4.58**	**4.81**	**3.76**		**0.94**
CONPWC	4.07	4.18	4.55	4.51	**0.88**	4.51	4.55	4.55	4.61	4.63	4.65
EMPWC	4.44	4.59	4.66	4.52	**3.00**	4.65	4.65	4.68	4.68		4.69
% Difference	**8.33**	**8.93**				**3.01**	**2.15**	**2.78**	**1.50**		**0.96**

Figures 8 and 9 shows significance difference of increasing value for UPV after pre-loading at 28 days until 56 days for water curing and air curing respectively. The UPV value after 28 days shows some increasing pattern. Percentage increase after pre-loading at 28 days until 56 days for CONPAC, EMPAC, CONPWC and EMPWC, are 4.0%, 0.9%, 3.0% and 3.6%, respectively. This indicates that there are some possibilities that EM would fill the crack inside concrete, even though the percentage between control concrete and EM concrete are almost the same except for EMPAC.

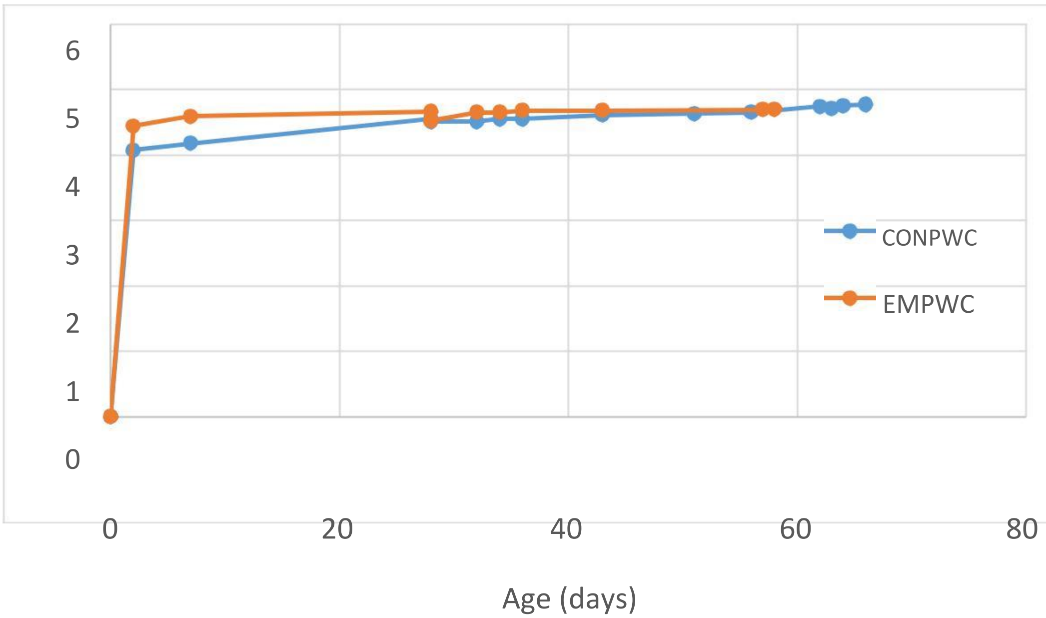


Figure 8 : Comparison of UPV for sample pre-crack water curing

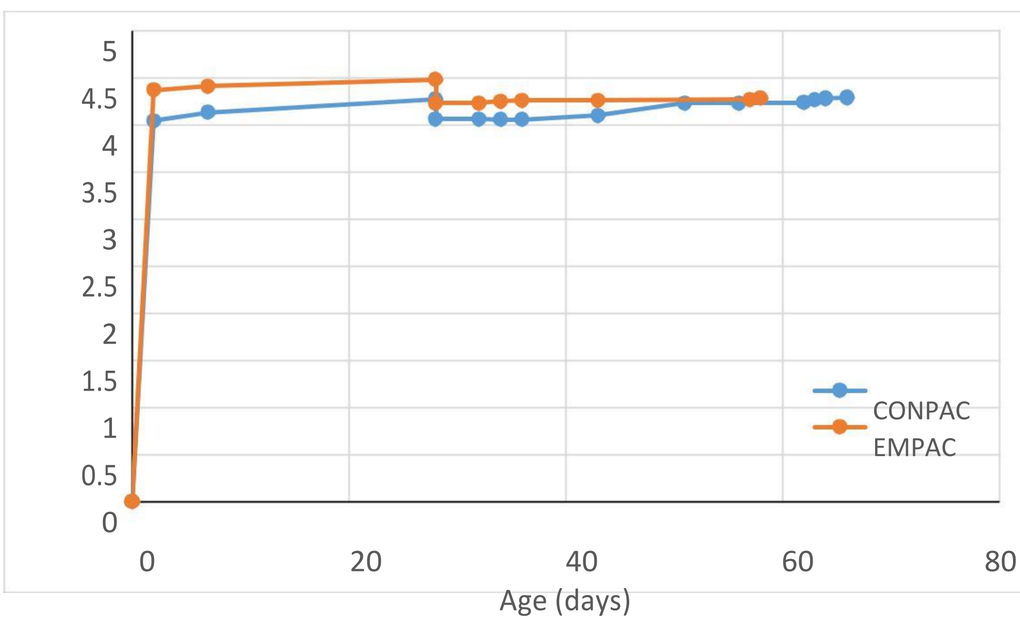


Figure 9: Comparison of UPV for sample pre crack air curing

Flexural Strength

Flexural test was carried out at age of 7 and 56 days. Same as the compressive strength test, the MOR of the samples was obtained and compared with control concrete as shown in table 8.

Table 8: MOR value of sample

Types Of Concrete	Curing	Age (Days)	Flexural Value (MPa)	Strength Ratio (%) 7/56 Days
CONCAC	Air	7	2.11	94.6
		56	2.23	
EMCAC		7	1.29	52.9
		56	2.44	
CONCWC	Water	7	2.21	69.7
		56	3.17	
EMCWC		7	1.87	96.4
		56	1.94	

Table 8 shows the strength ratio of MOR at the age of 7 days between control samples and EM samples through different curing exposure. From the table, it indicates that EM concrete water curing exhibited the highest strength ratio while EM in air curing had the lowest strength ratio with 96.39% and 52.87%, respectively. The highest flexural strength at 7 days was recorded for CONCWC (concrete control water curing) with water curing condition. The MOR of CONCWC was about 4.5%, 41.63% and 15.38% higher than CONCAC, EMCAC and EMCWC at 7 days curing, respectively. For concrete at the age of 56 days, CONCWC prism of water cured sample recorded the highest MOR value compared to other sample with 29.65%, 23.03% and 38.80% for CONCAC, EMCAC and EMCWC, respectively. This can be explained due to the existence of air voids inside the CONCAC and EMCAC because of the curing conditions. Air voids inside the sample creates more failure modes that will significantly reduce concrete compressive strength. On the other hand, EM concrete sample recorded lowest value of MOR compared to the control sample.

Modified Compression

Modified compression test is carried out after flexural test. Both section of prism after failure were tested under compression and compared with cubes compressive strength. Table 9 shows the output of the test conducted.

Table 9: Modified Compression Test Vs Cube Compressive Test Results

Types Of Concrete	Curing	Age (Days)	Modified Compression	Cube Compression	Strength Ratio

			(MPa)	(MPa)	(%)
CONCAC	Air	56	49.92	47.75	4.35
EMCAC		56	50.35	48.29	4.08
CONCWC	Water	56	55.45	52.05	6.13
EMCWC		56	58.65	55.96	4.59

From table 9, it can be seen that modified compression value is much higher than the cube compressive test. The highest percentage is CONCWC which is 6.13% and others such as CONCAC, EMCAC and EMCWC has the value of 4.35%, 4.08% and 4.59% respectively. This is because the strength of a modified cube is approximately the same as the strength of a standard cube of the same size. The restraint of the overhanging parts of the prism may result in a slight increase in ultimate strength so that it is reasonable to assume the strength of a modified cube to be, on average, 5% higher than a cast cube of the same size.

Shrinkage and Expansion

The change in the volume of drying concrete is not equal to the volume of water removed. The loss of free water, which takes place first, causes little or no shrinkage. As drying continues, adsorbed water is removed and the change in the volume of unrestrained hydrated cement paste at that stage is equal approximately to the loss of a water layer one molecule thick from the surface of all gel particles (Neville, 2011).

For the shrinkage and expansion test, a prism sample of 100 mm x 100 mm x 500 mm was prepared. Basically, two samples were prepared for both expansion and shrinkage test, which had been placed for water curing and air curing. Each sample were attached with the demec disc of 100 mm gauge length. Demec disk were glued at 100 mm apart on each side of the sample. After the glue dried, datum reading was taken from these demec points. The reading was continuously recorded until the end of the testing.

The expansion and shrinkage results and discussion of all sample tested are shown in the following figure. Figure 10 illustrates behavior of the samples when it is exposed to two curing condition, which is water curing and air curing. These type of curing provides different expansion and shrinkage strains due to several factors that influenced the expansion and shrinkage of the samples. From figure 10, it shows that EMCWC had the highest expansion strain compared to the CONCWC. Meanwhile, EMCAC had the highest shrinkage strain compared to the CONCAC. This occurs due to the concrete mixture that had been added with EM. This occurs because the concrete had experienced the loss of water for shrinkage properties. For the expansion properties concrete tends to absorb more water to reduce the loss of water during curing process in order to achieve the desired strength. Continued hydration, when a supply of water is present, leads to expansion. After the hydration process almost done, the value of shrinkage and expansion will be constant because there are no changes in volume.

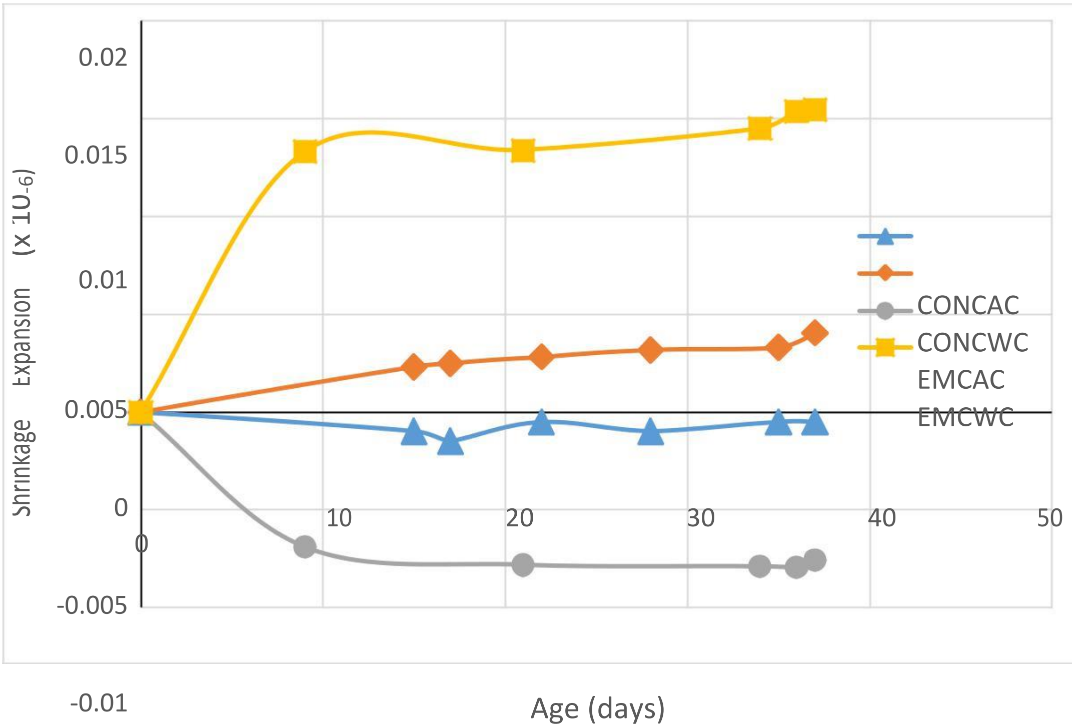


Figure 10 : Expansion and shrinkage of the samples

Water Absorption test

This test method is used to determine the rate of absorption of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function if time when only one surface of the specimen is exposed to water. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water. Figure 10 shows the result obtained from this test. From this graph, it indicated that for the air curing concrete for both control and EM sample will absorb more water compared to the water curing concrete. Furthermore, the figure also indicated that control sample does absorb more water than EM sample. Air curing EM sample absorb water until the sample become saturated. This is probably because of the porosity of air curing concrete that leads to the high capillary action and absorb more water. In the beginning of the test the sample had its initial absorption and towards the end of the test concrete had its secondary absorption. Water absorption is also strongly affected by the moisture condition of the concrete at the time of testing.

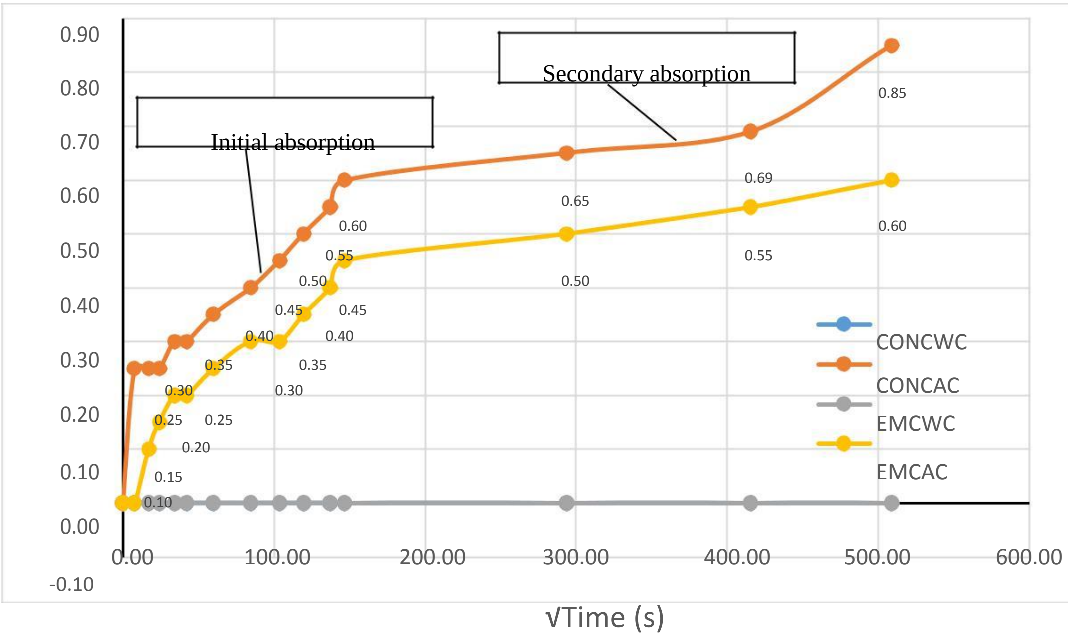


Figure 10 : Water absorption I (mm) Vs Time (√s) graph

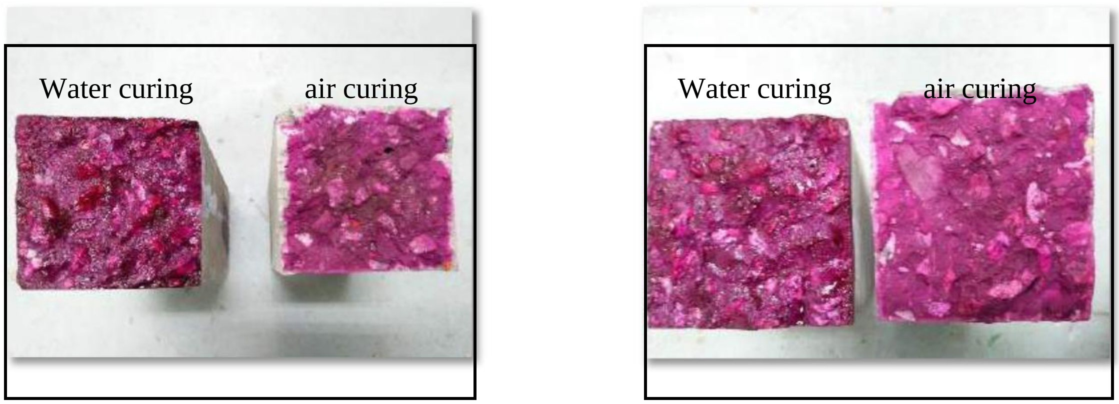
Carbonation Test

Carbonation of concrete is associated with the corrosion of steel reinforcement and with shrinkage. Carbonation is the result of the dissolution of CO_2 in the concrete pore fluid and this reacts with calcium from calcium hydroxide and calcium silicate hydrate to form calcite ($CaCO_3$).

Within a few hours, or a day or two at most, the surface of fresh concrete will have reacted with CO_2 from the air. Gradually, the process penetrates deeper into the concrete at a rate proportional to the square root of time. After a year or so it may typically have reached a depth of perhaps 1 mm for dense concrete of low permeability made with a low water/cement ratio, or up to 5 mm or more for more porous and permeable concrete made using a high water/cement ratio. The affected depth from the concrete surface can be readily shown by the use of phenolphthalein indicator solution. Phenolphthalein is a white or pale yellow crystalline material. For use as an indicator it is dissolved in a suitable solvent such as isopropyl alcohol (isopropanol) in a 1% solution. Carbonation test for this study had been done at 56 days of curing for prisms samples, both control and EM samples. The phenolphthalein indicator solution is applied to a fresh fracture surface of prisms samples after the flexural test.

Figure 11 (a) and (b) shows the results of carbonation process that occurred in the samples. The figure indicated that control and EM sample for air curing condition had gone through carbonation process because the outer part of the concrete does not have any changes in colour (colourless). If the phenolphthalein indicator turns purple, the PH is above 8.6. When the solution remains colorless, the pH of the concrete is below 8.6, suggesting carbonation. The depth of the carbonation process that occurred is about 1mm

– 2mm for both control and EM samples. This shows that carbonation does occurred as early as 56 days.



a) Control sample

b) EM sample

Figures 11 (a) and (b) : Carbonation test on fresh fracture concrete for both sample

Figure 12 : Carbonation on control and EM sample in air curing condition

Conclusion

The conclusion that can be drawn from the study are as follows:

i. The optimum mix that is suitable for this experimental study is 10% of mix proportion EM from amount of water cement content was used in the preparation of the sample.

ii. EM concrete improves the workability of the concrete by 11.42% compared to the normal concrete.

iii. The compressive strength of EM concrete are higher than normal concrete. This indicated that adding EM in the concrete mixture will increase the compressive strength of the concrete. Meanwhile, Modified compression of the prism samples are about the same as cube compressive strength. The modified compression is 5% higher than the compressive strength of cube.

iv. The UPV test recorded that EM concrete value is higher than the normal concrete, due to the effect of EM in making the concrete more denser and high permeability through the mechanism of EM reaction in the concrete. The percentage of pre-load stage shows that most of the pre-crack sample has the similar pattern of micro cracks. The strength of concrete is increasing even though it had been pre-load after 28 days. There are potential for EM in increasing the strength again after pre-cracks is generated.

v. Shrinkage and expansion of EM concrete shows a significant pattern in the graph, where EM concrete have the higher shrinkage for air curing sample and higher expansion for wet curing sample.

vi. For water absorption test, it indicated that for air curing sample the concrete will absorb water because of the capillary action which occurs at the surface of the concrete. Both normal and EM concrete for air curing have initial absorption and secondary absorption.

vii. Both normal and EM concrete for air curing experienced the carbonation process, but EM concrete have less exposure to the carbonation process compared to the normal concrete which almost 50% of carbonation rate compared to EM concrete. This shows that the EM concrete is more durable and resistance than the normal concrete to the environment exposure.

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