Properties of Normal Cement Concrete Containing Effective Microorganism

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Abstract. Crack formation is a natural phenomenon when concrete is exposed to extreme weather and normally related to the durability of the concrete. The formation of cracks may lead to deterioration of concrete strength as the water and air will penetrate into the concrete due to the existing of voids. Recently, a research about self-healing concrete based on effective microorganism (EM) is being studied in order to prolong the service life of concrete. This study is focusing on the effect of EM on fresh and hardened properties of concrete. The parameters of the study include the curing period, curing method (water and air curing) and type of concrete (ordinary portland cement concrete (OPC) and EM concrete). The cubes and prisms samples were cast and cured under different conditions before testing. Testing of Ultrasonic Pulse Velocity (UPV), was carried out on both cubes and prisms specimens while the compressive strength test used cube sample, flexural and expansion and shrinkage test used prisms sample. From the test results, it was found that there was an increase in compressive strength at 7 days with 93% (OPC) and 82% (EMC) compared to 3 days strength for water cured samples. For air cured sample, the strength is slightly lower (90%) than water cured sample (OPC) while for EMC, the strength is slightly higher (86%) than water cured samples. The flexural strength of the OPC prisms at 7 days for both water and air cured samples was higher than the EMC sample by 78% and 70%, respectively. Based on the UPV result, the EMC with water cured samples show higher value of UPV which means the samples have faster travel speed followed by the OPC for water cured sample and both air cured sample for OPC and EMC. Water cured sample for EMC has higher rate of expansion compared to OPC while the air cured sample for both OPC and EMC have almost similar rate of shrinkage value. Therefore, this study concludes that the use of EM has positive effects on the properties of concrete.

Introduction

Concrete is widely used construction materials as it becomes a major contribution in construction industry because of its high compressive strength, low cost and easily available [1]. Once concrete has reached the limit of its tensile stress, it will cracks. Most structures that use concrete are designed not to crack in order to let the embedded steel reinforcement carry the tensile stresses [2]. Crack formation is a typical phenomenon in concrete that can hardly be avoided. Small cracks with a crack width smaller than 0.2mm are generally considered unproblematic while larger cracks can potentially threaten the integrity of the concrete structures [3].

Normally, when crack occur in concrete, automatically it will be related to the durability of the concrete. Durability can be increased by preventing the influx of water, oxygen and other substances [2]. To prevent the ingress of water, oxygen and other materials, a lot of studied had been done to improve the quality of the concrete. In some occation, concrete used in construction site was added with too much of water in the concrete mix in order to make it easier to be poured and compacted. This will result in the strength of the concrete will be greatly reduceed when the concrete mix contain excessive water. Besides, shrinkage also can cause the concrete to crack due to the improper curing as curing is one of the most important aspects in producing a good quality concrete. Proper curing will enhance the strength and durability of the concrete while improper curing will cause the concrete to have more voids and become less dense.

To overcome these problems from occuring in concrete, a researcher introduced an alternative design principle of self-healing materials that follows the concept of damage management [4]. Self-healing materials have to serve some roles and meet several properties which is the damages should be known, followed by the movement of healing agent to meet the damage and also triggering repair the damage. The ideal self-healing materials are cheap and superior materials with the ability to heal defects, multiple times, completely and autonomously. Other researcher has given an overview of the characteristics for self-healing concrete in order to reduce costs of repair and maintenance [5]. As the word 'self', the concrete is expected to repair the crack itself by the incorporation of healing agent in the concrete mix without human interference.

The main objectives of this research are to study the effects of fresh and hardened properties of the concrete with the incorporation of effective microorganisms (EM). All specimens were tested at the age of 3, 7 and 28 days and compared with control concrete.

The objectives of this research are as follows:

a) To study the effect of EM in concrete on the fresh and hardened properties of concrete
b) To investigate the effect of curing methods, water and air curing, on the properties of EM concrete
c) To investigate the effect of EM on the crack healing in concrete using Ultrasonic Pulse Velocity method
d) To determine the effect of EM on the expansion and shrinkage of concrete

Previous Study

The topic of self-healing concrete actually has been investigated in the past several years. A well known researcher gives a useful overview of his literature search related to this field [6]. Reports by several researchers state that early research of self-healing concrete mainly focused on water retaining structures or reservoirs where the main issues was leakage [7,8]. In 2005, another researcher has given a nice overview of different causes of autogenic healing in which the materials by nature has the ability of healing [9]. Possible causes of self-sealing is said to have a formation of calcium hydroxide or calcium carbonate, sedimentation of particles, continued hydration and swelling of the cement matrix [9].

Some investigators claimed that in the last 5 years of their research, the design of materials with healing ability have becoming more and more popular in a wide range of applications and materials [4,10]. Concrete basically has its own natural autogenous healing properties and self-healing actually is an old phenomenon in concrete. Besides, concrete can be modified to build in autonomous crack healing because it is said that autogenous healing are limited to small cracks and needs water in order to heal and also it is hard to control [1].

A research report stated that a researcher had introduced the built in polymeric materials as self-healing properties [11]. After that, in 1979 and 1981, a research about thermoplastics and cross link system as self-healing properties was published. However, self-healing materials start to attract a lot of focus when researchers published their paper about self-healing using polymer based materials [12].

Self Healing Agent

Healing agent mainly consists of bacteria and a mineral precursor compound. However, a few factors must be considered in order to choose a self-healing agent. Bacteria chosen must compatible and should survive and remain active in the highly alkaline environment [2]. The principle mechanism of bacterial crack healing is that the bacteria act as a catalyst and transform a precursor compound to a suitable filler material [3].

According to a study conducted, bacteria should remain viable for a long period of time as the concrete structures were designed to last at least for 50 to 100 years [2]. Majority of healing agent consist of the organic precursor compound and it is said that the most suitable compound appeared to be the calcium lactate as its application as a main healing agent resulted in increasing concrete compressive strength values [12].

Methodology

This research concentrates on the properties of effective microorganism (EM) incorporated with ordinary portland cement (OPC). Besides, normal concrete without EM was prepared as control (CC) in order to compare with EM concrete (EMC). The focus of this study was to investigate the workability of concrete by conducting slump test, the compressive and flexural strength of the concrete, the effect of EM in crack healing process in concrete by Ultrasonic Pulse Velocity (UPV) test and the expansion and shrinkage of the concrete.

Mix Design and Materials

Mix design is the process of selecting suitable ingredients of concrete and determining their relative quantities to achieve the required strength. Raw materials used in this study include OPC, fine aggregates, coarse aggregates, water and EM. Concrete strength used in this research was grade 30. The size of mould of 100 x 100 x 100mm cube and 100 x 100 x 500mm prism were used in this study.

Table 1: Grade of Mix Concrete

Concrete strength	30 N/mm^2
Type of cement	Ordinary Portland Cement
Maximum nominal size of aggregates	10 mm
Type of coarse aggregates	Crushed granite
Maximum water-cement ratio	0.55

The raw materials such as fine and coarse aggregates were kept in room temperature to maintain the moisture of the aggregates. Besides, the OPC also was kept in the air tight container to prevent the cement from absorbing the moisture at the atmosphere. All moulds were prepared and covered with layer of oil before concrete mixing and pouring process. The mixing process need to be carried out carefully to ensure that the EM is incorporated and mix well with the cement by using concrete mixer. After 24 hour, the concrete cube and prism samples were demoulded and cured in the designated curing process.

Specimens Preparation

A total of 36 cubes and 16 prisms were cast and prepared in this research. Every concrete mixture was used to prepare concrete samples to be tested at the age of 3, 7 and 28 days for cube and 7 and 28 days for prisms. The quantity of EM used in the concrete mix was 10% by replacing the amount of total water content.

Table 2: Mix proportion of control and EMC

Type of concrete	Volume (m^3)	Cement (kg)	Water (litre)	Fine aggregate (kg)	Coarse aggregate (kg)
CC	0.195 (+25% wastage)	88.6	48.8	153.1	165.9
EMC	0.195 (+25% wastage)	88.6	43.9	153.1	165.9

Result and Discussion

The result and discussion of this study are focusing on the effect EM on the fresh and hardened properties for both control concrete (CC) and effective microorganism concrete (EMC). The result presented in this part include workability, compressive strength, flexural strength, value of UPV and expansion and shrinkage of the concrete.

Slump Test

To determine the workability of the concrete mix, the slump test was conducted. The slump test results of the concrete mixes are shown in the Figure 1. For the CC mix, the average slump was 111 mm which show higher degree of workability and the targeted slump is in the range. Meanwhile for the concrete mix with EM, the average slump recorded was 132 mm.

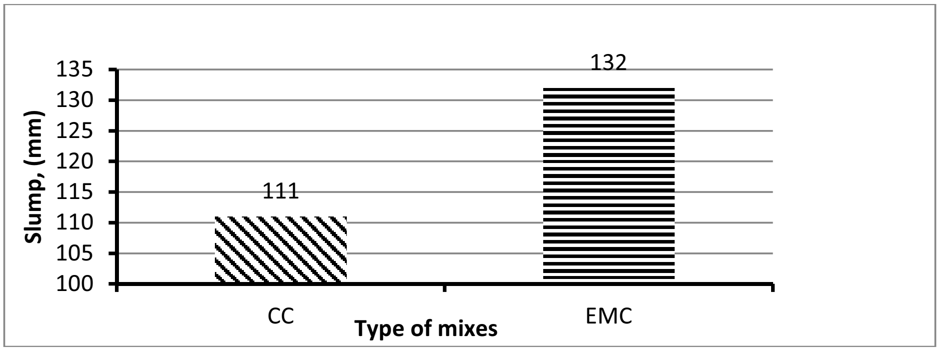

Figure 1: Relationship of slump and the type of concrete mix

Figure 1 shows that the workability of the EMC mix was higher than the CC mix. The amount of water has been replaced by 10 percent using EM and it was found to cause the EMC mix to have higher slump value compared to the control mix. Thus, the result shows that the EM affected by enhancing the workability of EMC concrete compared to the CC mix. For the type of the slump, both CC and EMC mixes recorded a true slump shape but with different form as shown in Figure 2. The CC mix has a firm true slump shape compared to EMC mix which looked flaccid due to the addition of EM. In addition, the colour of the EMC concrete was slightly darker than the CC mix.

Figure 2: Types of slump for (a) CC mix and (b) EMC mix

Compressive Strength

For the compressive strength test, the rate of loading of the machine used for the test was 0.06 kN/s for the cube specimens. Both types of concrete mixes were tested to find the strength of the concrete at 3, 7 and 28 days. The weight of all samples has been recorded for the calculation of the density of the samples and all samples has been tested using compressive strength machine. The average strength of the concrete for water curing (W) and air curing (A) specimens and modified compression test for both type of mixes are shown in Table 3.

Table 3: Cube and modified compression strength

Types of mixes	Types of curing	Cube Strength (MPa)			Strength ratio (%)		Modified Compression (MPa)		Strength ratio (%)
		3	7	28	3/28	7/28	7	28	7/28
CC	W	21.1	33.9	36.4	58	93	19.8	30.6	65
	A	21.1	31.6	35.3	60	90	19.1	31.4	61
EMC	W	25.8	34.7	42.2	61	82	22.9	28.0	82
	A	23.4	29.8	34.6	68	86	22.7	26.6	85

As shown in Table 3, the strength ratios of 3 to 28 days for cube CCW and CCA were 58% and 60%, respectively. Similar results were also recorded for EMCA samples which gained 68% compared to EMCW that only achieved 61% of the 28 day cube strength. However, both types of mixes had achieved more than 40% of concrete strength at the age of 3 days. On the other hand, at age of 7 days, the strength for CCW (93%) was higher than CCA (90%) in contrast with EMCW specimens only achieved 82% while EMCA (86%). The results show that the samples achieved the required strength for both type of mixes.

Based on Figure 3, the EMCW was the highest strength, followed by CCW, CCA and EMCA. Both mixes show an increment of strength throughout the age. At the age of 3 days, the CCW and CCA have the same value of strength (21.1 MPa) but start to increase from 7 days onwards with 33.9 MPa (CCW) and 31.6 MPa (CCA) and end up with 36.4MPa for CCW and 35.3 MPa for CCA. For the EMC mix, both samples of different curing conditions have different value of strength at 3 days with 25.8 MPa (EMCW) and 23.4 MPa (EMCA). The EMCW at 28 days had the highest strength (42.2 MPa) compared to CCW (36.4 MPa) while EMCA only achieved 34.6 MPa slightly lower from CCA. This shows that the EM has good effect on concrete cube samples with proper curing. As the amount of water for CCA has been reduced by EM and it may insufficient for the concrete to promote the hydration process.

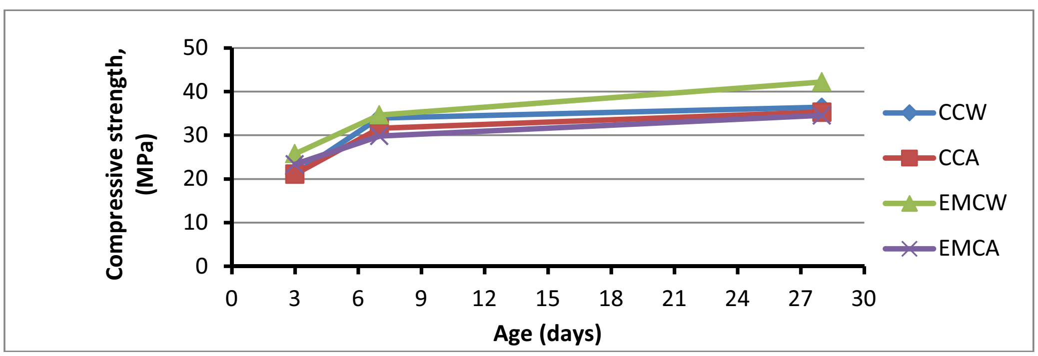

Figure 3: Relationship between age of concrete samples with compressive strength

Moreover, Table 3 also shows the result of modified compression after the prisms sample had been tested for flexural at 7 and 28 days. The strength ratio of EMCA (85%) was higher than EMCW (82%) meanwhile for CC mix, CCA only achieved 61% strength compared to CCW with 65%. The modified compressive strength for EMC mix are almost the same with cube strength but contrary with CC mix, the cube strength ratio for modified compression test was lower than the cube strength ratio.

Figure 4 shows the relationship between age of concrete and modified compression strength. From the figure, the modified compression strength of concrete at 7 and 28 days shows a significant difference where the CC mix gained higher strength compared to EMC mix. The modified strength of CCW (19.8 MPa) and CCA (19.1 MPa) at 7 days increased to 30.6MPa and 31.4 MPa, respectively at 28 days. Meanwhile, the EMCW (22.9 MPa) mix at 7 days is higher from CCW and similar to EMCA (22.7 MPa) but lower than CCW and CCA at 28 days with 28.0 MPa (EMCW) and 26.6 MPa (EMCA). All of the results had achieved the required strength in fact more than grade 30 for cube strength except for EMC modified compression strength with only 28.0 MPa (EMCW) and 26.6 MPa (EMCA). This is possibly due to the sample preparation and improper compaction during compacting process.

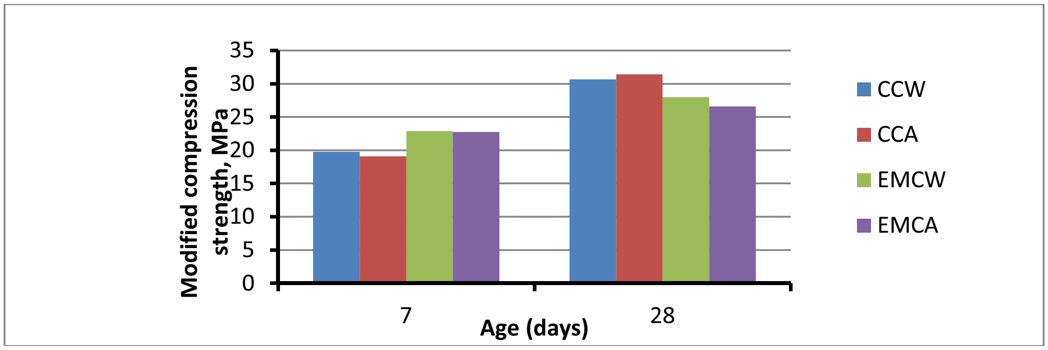

Figure 4: Relationship between age of concrete with modified compression

Figure 5 shows the failure of concrete cube samples for water and air curing. The colour of the concrete in water curing (a) was darker compared to air curing (b). Both of the samples has undergo a normal concrete failure. Figure 5 indicates that the failure of both samples was due to failure in bonding.

(a) water (b) Air

Figure 5: Failure of concrete cube

Flexural Strength

The flexural test was carried out using prism with two different curing regimes in water (W) and air (A). The ages of prisms tested are 7 and 28 days. The control load applied in this test was 0.13kN/s. Similar to compressive strength test, the average strength of samples were recorded and shown in Table 4. The size of the prisms used in this test was 500 x 100 x 100 mm.

Table 4: Flexural strength of concrete

Types of mixes	Types of curing	Flexural Strength (MPa)		Strength ratio (%)
		7	28	7/28
CC	W	2.2	2.8	78
	A	1.4	2.0	70
EMC	W	1.7	3.0	57
	A	1.6	2.9	55

Table 4 shows the flexural strength of concrete at 7 and 28 days for both mixes. The strength ratio at 7 days for CCW and CCA was successfully achieved the required strength with 78% and 70%, respectively. However, the EMCW and EMCA only achieve 57% and 55%, respectively compared to CC mixes. This is might due to some inaccuracy in the preparation of the samples. Figure 4.6 illustrates the relationship between age of concrete with flexural strength.

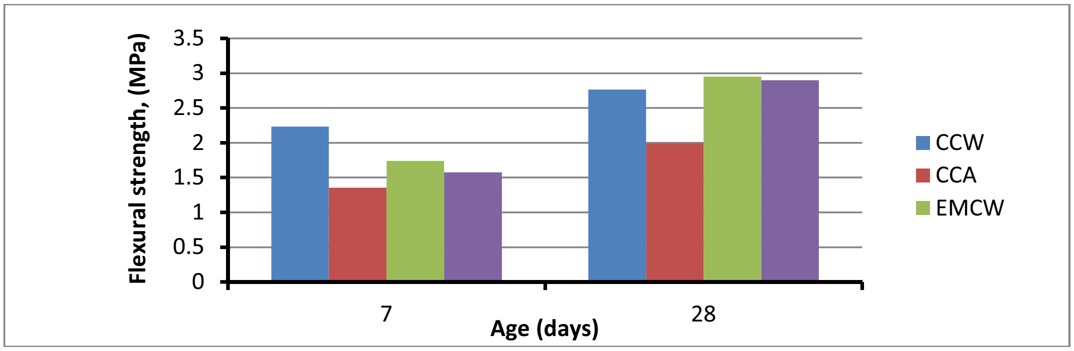

Figure 6: Relationship between age of concrete with flexural strength

From Figure 6, the highest strength of flexural sample at 7 days was CCW with 2.8 MPa while the lowest was CCA with 1.4 MPa due to the air curing process. In contrast with the strength at 28 days, the highest strength was EMCW with 3.0 MPa followed by EMCA (2.9 MPa) and CCW (2.8 MPa) and remain the lowest was CCA (2.0 MPa). Thus, the effect of EM was obvious on flexural strength especially on EMC as the strength of concrete increase rapidly compared to CC.

The mode of failure for prisms are shown as in Figure 7. Figure 7 (a) was the water cured prisms sample while 7 (b) was the air cured prisms sample. Similar with cube sample, the failure of the prisms was due to the failure in bonding between the aggregates and cement paste.

(a) water curing (b) air curing

Figure 7: Failure of concrete prism

Ultrasonic Pulse Velocity (UPV)

UPV test is good for establishing the uniformity of concrete for measuring and detecting cracks and for measuring the deterioration of concrete due to fire. For this test, both CC and EMC specimens had undergo the test but a special case for EMC samples as it had to undergo a pre-crack process first in order to identify the effect of the EM in the samples. Basically, this test is important because the changes made by the EM after the pre-crack process shows the existence of the microorganisms. Both cube and prism samples were tested and the result of the UPV test were the average speed of pulse passing through the samples for the cubes and prisms.

Cube Specimens. Table 5 shows the UPV results of cube specimens at the age of 3, 7 and 28 days while Figure 8 shows the relationship of age of concrete and UPV. From Figure 8, the EMCW has the highest speed followed by CCW. Both CCA and EMCA had almost similar trend of speed however, at the age of 28 days, the speed of EMCA was a slightly higher than CCA.

As shown in Figure 8, both EMCW and EMCA samples had a sudden decreased of speed at the age of 7 days as the cube samples had undergone a pre-crack process. A shown in Table 5, at 7 days, the speed had dropped from 4399 m/s to 4274 m/s for EMCW and from 3958 m/s to 3895 m/s for EMCA as there were micro cracks in the samples. However, as the age of the concrete increase, the speed of UPV also increased as shown in Figure 8 until 28 days. This indicates that there are the existences of EM in the samples as it slowly heals the micro crack inside the cube specimens.

Meanwhile, the UPV value of CC mix was still lower than EMC samples even though the samples did not undergo the pre-crack process as can be seen in Figure 8. Besides, both CCW and CCA show a linear increment along the age of concrete. As the age of concrete increased, the UPV value for all samples also increased.

Table 5: UPV of cube specimens

Types of mixes	Types of curing	UPV (m/s)			
		3days	7days	Pre-crack	28days
CC	W	4055	4114	-	4398
	A	3909	3928	-	4100
EMC.	W	4071	4399	4274	4484
	A	3841	3958	3895	4146

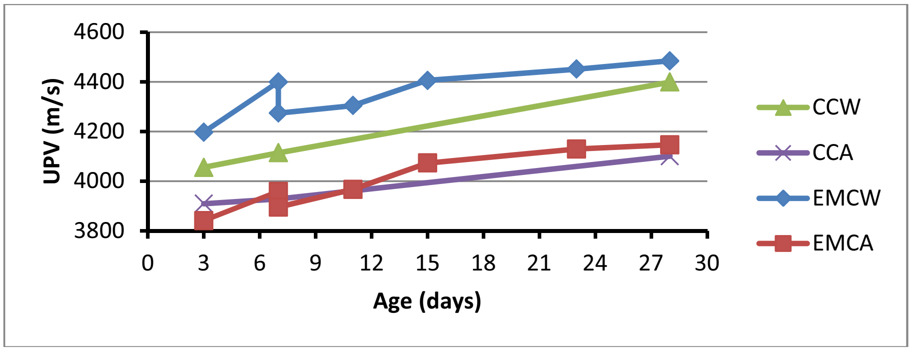

Figure 8: Relationship between age of concrete and UPV (m/s)

Prism specimens. Table 6 shows the UPV value for prisms specimens at the age of 7 and 28 days while Figure 9 shows the relationship of age of prism sample and UPV. From Figure 9, the highest UPV value at the age of 7 day was for EMCW with 4160 m/s, followed by CCW (4017m/s), EMCA (3947m /s) while the last was CCA (3756m/s). For samples at 28 days, the pattern was similar as at 7 days except the UPV value for EMCA was the lowest at this age.

Even though the prism sample did not undergo the pre-crack process, the UPV value for EMC was still the highest compared to CC. This can be said that the effect of EM was effective with the water cured samples compared to air cured samples. However, the UPV test had proven that the concrete gain strength gradually.

Table 6: UPV of prisms specimens

Types of mixes	Types of curing	UPV (m/s)	
		7	28
CC	W	4017	4316
	A	3756	4091
EMC	W	4160	4475
	A	3947	4073

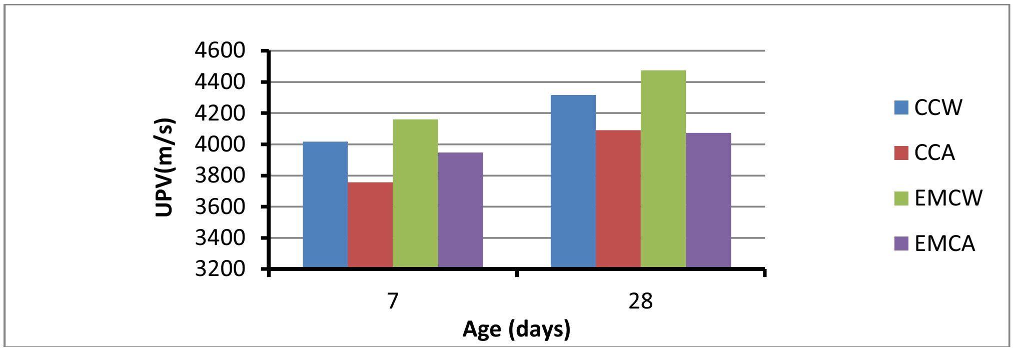

Figure 9: Relationship between age of concrete and UPV (m/s)

Expansion and shrinkage

This test was conducted to study the rate of expansion and shrinkage of the prisms for both CC and EMC samples. Table 7 and Table 8 show the value of expansion and shrinkage of prisms for CC and EMC. Based on Figure 10, the EMCW expand rapidly compared to CCW samples while the CCA samples shrink faster than EMCA samples. The expansion of EMCW sample was significantly higher than CCW possibly due to presence of voids is higher in EMCW compared to CCW which can cause the water to seep into it. However, for EMCA samples, the shrinkage of the concrete is lower than CCA. This was probably due to the effect of EM in the mixtures which will cause the concrete sample to shrink more than CC.

Table 7: Expansion and shrinkage of prisms (CC)

Age (days)	Expansion ($x10^{-6}$)	Shrinkage($x10^{-6}$)
4	0.000036	-0.000358
7	0.000107	-0.000466
9	0.000215	-0.000895
14	0.000251	-0.00129
16	0.000287	-0.00143
22	0.000322	-0.00175
28	0.000645	-0.00175

Table 8: Expansion and shrinkage of prisms (EMC)

Age (days)	Expansion ($x10^{-6}$)	Shrinkage($x10^{-6}$)
2	0.000198	-0.000143
5	0.000541	-0.000394
10	0.000631	-0.000752
13	0.000955	-0.000805
21	0.001062	-0.00117
24	0.001120	-0.00188
28	0.001140	-0.00158

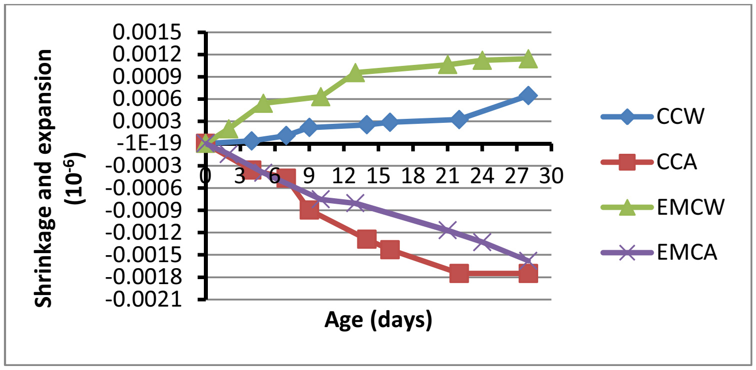

Figure 10: Relationship between age of sample with expansion and shrinkage

Conclusion

The conclusions that can be drawn from this research based on the experimental results are:

1. The effect of EM in EMC has increased the workability of concrete compared to CC due to the high slump value of mix.
2. Types of curing method was greatly affecting the strength of the concrete in this study. Most of the compressive strength for air cured samples was lower than water cured samples for both CC and EMC.
3. The results indicate that the EM incorporated in concrete shows a better compressive strength at the age of 28 days while for prisms sample, the EM did not really improve the flexural strength compared to CC.
4. The UPV result in this research shows that the EM did heal the micro crack of the EMC after the pre-crack process. Besides, the UPV value did increased after pre-cracking for both EMCW and EMCA. Morever, the UPV value for EMC samples was higher than CC.
5. Concrete for EMCW samples had expanded more than CCW while the shrinkage of EMC was lower than CC. This is possibly due to the voids inside the concrete which caused the ingress of water.

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