Some properties of concrete mixed with effective microorganisms and the on-site investigation of the completed structures

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Abstract

In recent years, the deterioration of concrete structures is a significant social problem in Japan. To solve this problem, researchers and engineers are conducting the research and technical development for solution of the problem. They proposed various techniques and materials in the past, but they fail to find out any reliable and effective methods at present. The effective microorganisms, which were invented by one of the authors, showed remarkable performance in the agricultural and environmental fields. The authors selected four kinds of materials from these, and started to study the feasibility of their application to admixture for concrete, and to help solve the deterioration problem. As a result, the study revealed the possibility of solving the deterioration problem. We report some data that suggest that the considerably effective admixture can be produced. Some results obtained from indoor experiments are as follows. (1) This new admixture has the fairly powerful surface activity, the effect of air entraining (AE) agent, i.e., gassing reaction, and the effect of water reducing agent, i.e., the function to disperse the agglomerated particles. (2) The compressive strength at day 3 and day 7 of curing was compared. The strength of this admixture was found to be larger by 30 to 50% than that of control. It means that initial strength increased. (3) We conducted the acceleration test with carbon gas concentration of 5%, humidity of 60% and temperature of 20℃. The result showed almost complete suppression of carbonation. This is a very promising result for solution of concrete deterioration problem.

Keywords: Effective microorganisms materials, admixture, initial strength, carbonation, coefficient of air permeability at the surface layer, drying-shrinkage crack

1. Introduction

The premature deterioration of concrete structures in Japan was already reported by mass media etc. as a social problem as early as more than 20 years ago. The causes of deterioration are not limited to materials and application, but they include technical, social and ethical aspects. Some causes are evident. Contamination of earth environment is multiple pollution. Likewise, deterioration of concrete is also multiple deterioration. In such a case, it is difficult to specify the causes. In such a situation, we started research and development of concrete that uses effective microorganism (EM). We found that workability of fresh concrete improves, that initial strength increases remarkably, and that it suppresses carbonation almost perfectly. We obtained the data about durability represented by neutralization. We consider that this material will blow new breath into concrete industries in the future.

2. Materials and Methods

2.1 Materials for experiment

The following materials were used. 1) cement: ordinary Portland cement made by Sumitomo Osaka Cement Co., Ltd. (density: 3.16g/cm^3), 2) fine aggregate: diabase crushed sand (density in saturated surface-dry condition: 2.87 g/cm^3, FM=2.55), 3) coarse aggregate: hard sandstone crushed stone (density in saturated surface-dry condition: g/cm^3) , 4) admixture: AE agent (natural resinate AE agent), water reducing agent (highly-efficient water reducing agent from the polycarboxylic acid), 5) EM material: EM-No.1, EM-No.3, EM-X, EM ceramics. 〔1〕, 〔2〕、〔3〕

Description of EM: The raw materials include five families ten genuses of EM (lactic acid bacteria, yeast, actinomyces, zymotic eumocetes, photosynthetic bacterium). They are cultured alternately by aerotropism and anaerobiosis. Several product groups are available. In this study, we used four kinds of products as mentioned above.

2.2 Type and mixing of concrete

Concrete and various materials were mixed according to the recipe shown below. A target air content is 5% and a slump is 8 cm. For this test, we used EM-No.1, EM-No.3 and EM-X. They are all liquid. We diluted them in 15%, 10% and 5% in water, and used it as water. EM ceramics are mixed with cement in 15%, 10%, and 5% of the total quantity after mixing. The types and mixing of concrete are shown in the recipe.

Table 1

Table of mixing parameters

Target air volume 5%, slump 8cm

W/C (%)	Gmax mm	Type of product	s/a (%)	Unit volume (kg/m3)					AE*C (%)	SP*C (%)
				W	C	Ceramics	S	G		
		C55				-	834	1077	0.03	-
		Ceramics-5				15.4	827	1068	0.03	0.18
		Ceramics-10				30.7	820	1059	0.35	0.3
		Ceramics-15				46.1	813	1050	0.04	0.35
		EM-No.1-5				-				-
		EM-No.1-10				-				-
55	20	EM-No.1-15	425	169	307	-			0.025	-
		EM-No.3-5				-				-
		EM-No.3-10				-	834	1077		-
		EM-No.3-15				-				-
		EM-X-5				-				-
		EM-X-10				-			0.02	-
		EM-X-15				-				-

＊ We used EM-No.1, EM-No.3 and EM-X. They are all liquid. We diluted them in 15%, 10% and 5% in water, and used it as water.

＊ EM ceramics are mixed with cement in 15%, 10%, and 5% of the total quantity after mixing.

2.3 Production method and property of fresh concrete

(1) Production method of fresh concrete is as follows.

We used a mixer (two-axis, forced mixing type mixer) and the mixing time (1. cement + fine aggregate + coarse aggregate:1 min, 2, 1+ water+EM:1 min) to produce fresh concrete 〔5〕

(2) Property of fresh concrete

We used a Washington type air meter (about 7L) and the constant pressure method (air-chamber pressure method). In this test, the AE agent was mixed with concrete to improve workability. The fresh concrete with 15% EM-No.1 added also contain the AE agent whose quantity is mentioned in the recipe. This fresh concrete generates so much air that the air meter was unable to measure it. EM-No.1 contains various organic acids, ester and other organic compounds and abundant minerals. These compounds form hydrophobic groups and hydrophilic groups, and they show dispersion and surface activity. They show the effect of AE agent, i.e., gassing reaction, and the effect of water reducing agent, i.e., the function to disperse the agglomerated particles. When concrete is placed at construction sites and fresh concrete is adjusted, it produces much gas. At present, we are testing EM alone and combination with AE agent. We are studying the mechanism in detail. This test was conducted according to the technique specified in JIS A 1128:1999.

2.4 Compression test of concrete

(1) Preparation of test piece

We prepared the test piece for experiment according to JIS A 1132. All test pieces are cylindrical, measuring 100 $\phi \times$ 200mm. We used a rigid, plastic, lightweight frame to form test pieces. We poured concrete in two layers and compacted it with a table vibrator. The compaction time was 3 to 5sec/layer for concrete with high ratio of water and binding material. It was 5 to 8sec/layer for concrete with low ratio of water and binding material. The formed concrete was placed on a glass plate and protected with a wet waste cloth to prevent dryness. After the elapse of 48 hours, it was subjected to water curing in the 20±3℃ constant-temperature circulation water tank until the predetermined material age was reached.

(2) Test method

The loading method was performed according to JIS A 1108.

2.5 Acceleration carbonation test

(1) Test conditions

The acceleration carbonation test is generally conducted in a high-concentration carbonic-acid-gas cure tub. In this test, we used carbonic-acid-gas concentration of 5%, the temperature of 20℃, and humidity of 60%. The age of material was two weeks, four weeks, and six weeks.

(2) Test method

1) When the 100 $\phi \times$ 200mm test cylinder reached the material age (28 days), we dried it for six days in a thermostatic chamber. The top and bottom surfaces were sealed with primer silicone.

2) Under the above-mentioned conditions, we conducted carbonation acceleration. Three test pieces each were taken for the age of two weeks, four weeks, and six weeks.

3) After the test pieces reached each material age, we used a compression tester and split them. We dried the split surface completely. We sprayed phenolphthalein (1% ethanol solution containing about 15% water, JIS K 8001) with a sprayer.

4) We measured in the unit of millimeters the depth of the segment that was not discolored. We measured neutralization at 10 points to obtain the average neutralization depth. The 10 points start at 25mm apart from the placing base and are spaced at intervals of 15mm in the placing direction.

3. The spot test of EM-containing concrete structures

The EM-containing concrete structures are already used at hospitals, schools, apartments, residence, etc. A major characteristic of this structure is glossy appearance of concrete. It is a beautiful concrete structure. However, a detailed investigation was not conducted until now. So, we did not clarify the dynamic characteristics and carbonation acceleration etc. of the EM-containing concrete. In this study, we conducted a total of 16 visual observations and nondestructive tests for EM-containing structures located in Okinawa prefecture. Moreover, for some buildings, under owner's permission, we were able to obtain samples of concrete walls and 100mm ϕ cylindrical concrete samples. The test results are as follows. 〔4〕

3.1 Investigation of crack

We conducted visual inspection of cracks of concrete structures. Cracks included the crack due to dry shrinkage. crack due to load, crack due to uneven settlement of structures.

3.2 Evaluation test of the concrete by the physical measurement (nondestructive test)

We conducted the following tests of concrete. 1. We conducted an estimate compressive strength test, using a digital Schmidt hammer. 2. We evaluated the gas permeability of surface, using a gas-permeability tester (TORRENT). 3. We evaluated ultrasonic propagation speed of concrete, using an ultrasonic tester for concrete.

3.3 Neutralization test

We rubbed the surface of concrete with the sandpaper. Then, the surface was sprayed by the phenolphthalein reagent (JIS K 8001) that is used for the acceleration neutralization test. As necessary, the surface of concrete was rubbed deeper.

4. Test results and discussion

4.1 Result of compressive strength test (EM ceramic-containing concrete)

Figure 1 shows the relation of compressive strength versus age of concrete containing EM ceramics in 5%, 10%, and 15% and having the ratio of 55% water and binding-material. Figure 3 shows the compressive-strength ratio. As the graph shows, the higher age increases the strength. The increasing order is the control material, 5% EM ceramics, 10 % EM ceramics and 15% EM ceramics. After the age of 3 days, 10% EM ceramics and 15% EM ceramics are stronger than the control and 5% EM ceramics. Between the age of 7 days and 28 days, EM ceramics-containing concrete is clearly stronger. However, 5% ceramics does not change noticeably. Figure 2 shows the compressive-strength ratio. Between the age of 3 days and 28 days, the ratio is higher in all kinds of EM ceramics-containing concrete. At any age, the higher percentage of EM results in the higher ratio. Particularly, 10% EM ceramics and 15% EM ceramics show the highest ratio at the age of 3 days. Based on these results, we set air volume at 5% and conducted air-content correction (Figure 2 and Figure 4). Any change was not noticed, because the air volume is almost the same as the control material.

4.2 Result of compression test for EM ceramic-containing concrete

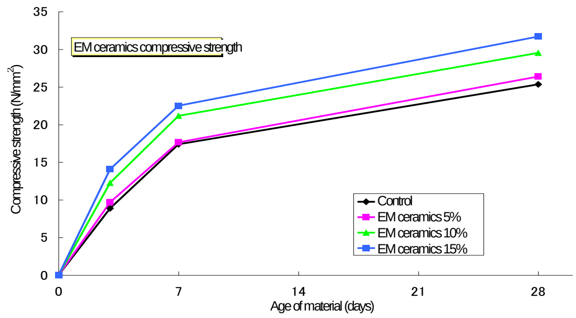


Fig. 1 (EM ceramic compressive strength)

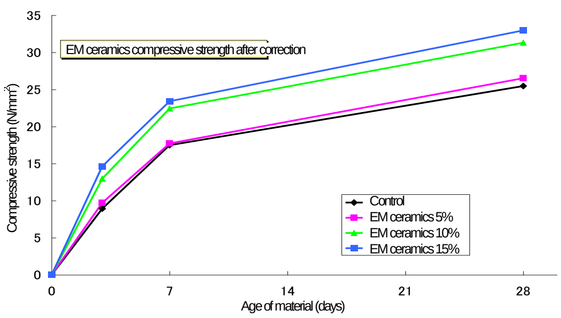


Fig. 2 (EM ceramic compressive strength after correction)

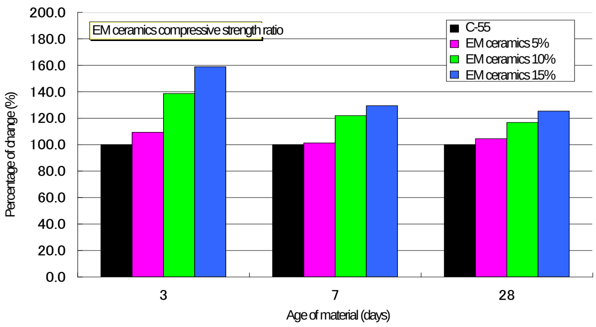


Fig. 3 (EM ceramic compressive strength ratio)

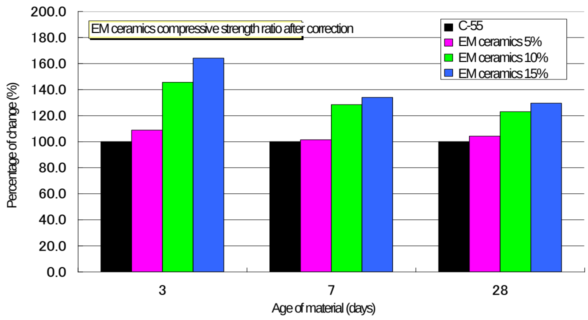


Fig. 4 (EM ceramic compressive strength ratio after correction)

4.3 Result of compressive strength test (EM-No.1-containing concrete)

Figure 5 shows the relation of compressive strength versus age of concrete containing the diluted EM-No.1 in 5%, 10%, and 15% and having the ratio of 55% water and binding-material. As the figure shows, the 5%, 10% and 15% are equally strong, except the control. After the age of 3 days, EM-containing concrete is stronger than the concrete. Between age of 7 days and 28 days, the 5%, 10% and 15% are stronger in this order. Figure ６ shows compressive strength ratio. Between the age of 3 days and 28 days, the ratio is higher than in EM-No.1-containing concrete than in the control. Until the age of 7 days, the 5% and 10% show the ratio of about 130%. At the age of 28 days, the ration decreases to 120% or less. The 15% show the ratio of about 120% consistently between the age of 3 days and 28 days. Based on these results, we conducted the air-content correction. The graph for compressive strength after correction shows at all the ages that the strength increased by 10% compared before correction. The compressive strength ratio after correction, at 5%, increased by about 15% at all the ages. The higher percentage of EM resulted in the larger increase.

4.4 Result of compressive-strength test for EM-Ns.1-containing concrete

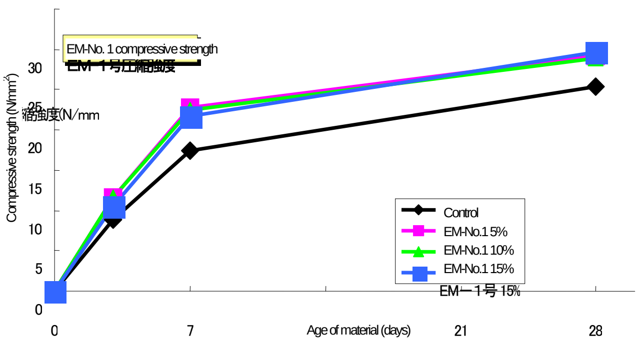


Fig. 5 (EM-No.1 compressive strength)

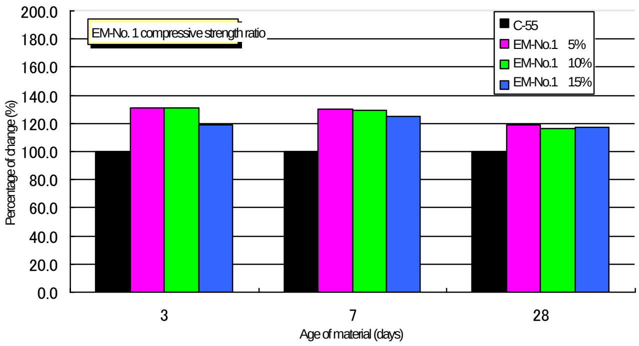


Fig. 6 (EM-No.1 compressive strength after correction)

4.5 Result of compressive strength test (EM-No. 3-containing concrete)

Figure 7 shows the relation of compressive strength versus age for concrete containing the diluted EM-No. 3 in 5%, 10%, and 15% and having the ratio of 55% water and binding-material. Figure ８shows the strength ratio of the same concrete. At the age of 3 days, the strength is almost the same as the control. At the age of 7 days, the 10%, 5% and 15% became stronger in this order. At the age of 28 days, the 10% did not increase the strength. The strength is lower than the control. Figure ８ shows the compressive strength ratio. At the age of 3 days, the ratio for 5% and 10% is as large as about 140%. According as the age increases, the ratio decreases. At the age of 28 days, the 10% is weaker than the control. The graph for compressive strength after air correction shows, at all the ages, the increase of strength by about 10% compared with before correction. The 5% at all the ages showed the increase by 10% minus. The 10% at all the ages showed the increase by about 10%. According as the age increase, the strength ratio decreases gradually.

4.6 Result of compressive strength test for EM-No.3-containing concrete

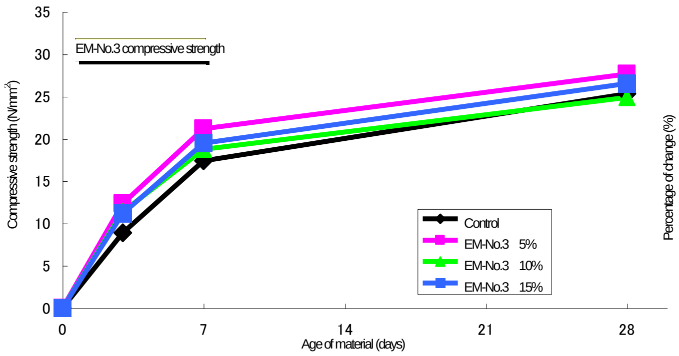


Fig. 7 (EM-No. 3 compressive strength)

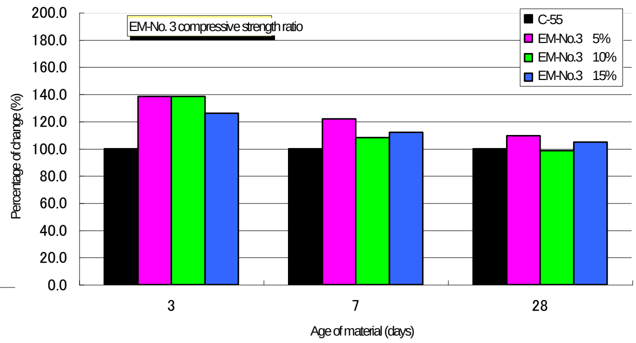


Fig. 8 (EM-No. 3 compressive strength ratio)

4.7 Result of compressive strength test (EM-X-containing concrete)

Figure 9 shows the relation of compressive strength versus age for concrete containing the diluted EM-X in 5%, 10%, and 15% and having the ratio of 55% water and binding-material. Figure 10 shows the strength ratio of the same concrete. At the age of 3 days, the strength is higher than the control. At the age of 3 days and 7 days, the 5%, 10% and 15% show almost the same strength. Until the age of 28 days, the 10% and 15% shows the increase of strength in parallel as the control does. The 5% shows the slight increase of strength. The graph of compressive strength ratio shows that the ratio is especially high at the age of 3 days. It also shows that the higher age results in the lower ratio. The strength ratio is high in the increasing order of the mixing ratio of 5%, 10% and 15%. Based on these results, we set the standard of air volume. The air volume was almost the same as the control, resulting in a slight change. The compressive strength increased at any age and any mixing ratio. The compressive strength ratio did not change very much.

4.8 Result of compression strength test for EM-X-containing concrete

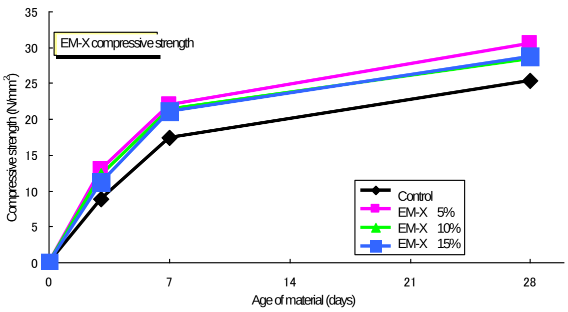


Fig. 9 (EM-X compressive strength ratio)

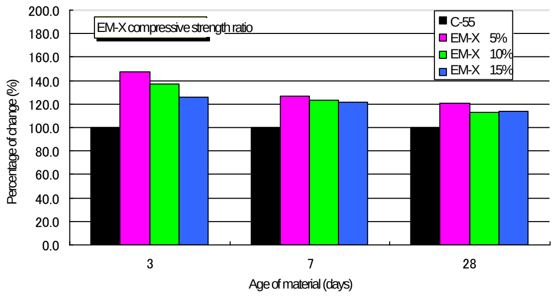


Fig. 10 (EM-X compressive strength ratio after correction)

4.9 Summary of compressive strength

We tested the compressive strength of concrete containing EM-ceramics, No.1, No.2 and X, respectively. The strength exceeded the control under all the conditions, both 55% water and binding-material and after correction. The concrete containing EM-ceramics in 10% and 15% was stronger than the control, beginning with the age of 3 days. The concrete containing EM-ceramics in 5% was as strong as the control, even at the age of 28 days. The concrete containing EM-No.1 was much stronger than the control. The increase was almost the same for all the mixing ratio of 5%, 10%, and 15%. The concrete containing EM-No.3 in 10% was weaker than the control at the age of 28 days. The concrete containing EM-X in 10% and 15% showed the same change, beginning at the age of 7 days. The rate of change decreased at the higher age. The above-mentioned fact proves that EM as admixture can increase the strength to some extent. Particularly, EM-No.1 and EM ceramics showed the most ideal result.

5. Result of acceleration neutralization test

5.1 Result of neutralization test for EM ceramics-containing concrete

Figure 11 shows the result of neutralization test for EM ceramics-containing concrete. The concrete containing EM ceramics in 15% showed the neutralization depth that is 50% smaller than the control. The concrete containing EM-ceramics in 10% and 15% showed the neutralization depth that is 70% smaller than the control. When we increased the mixing ratio of EM ceramics above 10%, the neutralization depth did not change very much. The graph shows that mixing of EM ceramics itself does not accelerate neutralization.

5.2 Result of acceleration neutralization test (EM ceramics)

5.3 Result of EM-No.1-containing concrete neutralization test

Figure 12 shows the result of EM-No.1-containing concrete neutralization test. At the age of two weeks, the neutralization depth of this concrete decreased by 70% compared with the control. At the age of four weeks, the depth was the largest for the 10% containing concrete, and the depth was about 40% of the control. The depth at the age of six weeks was the same as the age of four weeks. This result suggests that the EM-No.1-containing concrete does not accelerate neutralization very much.

5.4 Result of acceleration neutralization test (EM-No.1)

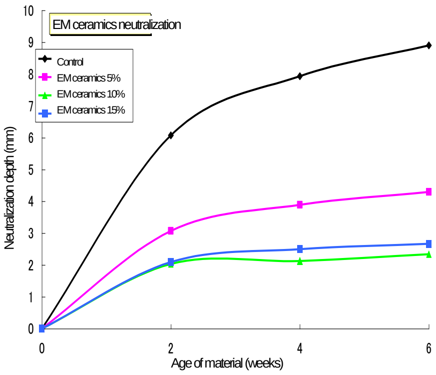


Fig. 11 (EM ceramic neutralization)

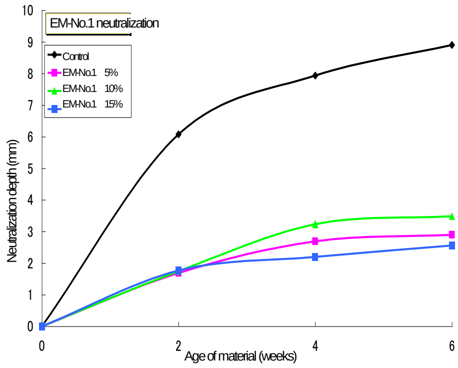


Fig. 12 (EM-No. 1 neutralization)

5.5 Result of EM-No. 3-containing concrete neutralization test

Figure 13 shows the result of EM-No. 3-containing concrete neutralization test. At the age of two weeks, the neutralization depth of this concrete decreased by 60% compared with the control. At the age of four weeks, the depth was the largest for the 10% containing concrete, and the depth was about 60% of the control. The neutralization depth of this concrete increases in the order of 15%, 5% and 10% of mixing ratio. At the age of six weeks, EM-containing concrete showed the decrease of neutralization depth. EM-No.3-containing concrete showed generally the decrease of neutralization depth compared with the control.

5.6 Result of acceleration neutralization test (EM-No. 3)

5.7 Result of EM-X-containing concrete neutralization test

Figure 14shows the result of EM-X-containing concrete neutralization test. At the age of two weeks, the 5% EM-X-containing concrete showed the decrease of neutralization depth by 70% compared with the control. For the 10% and 5%, the decrease is almost the same. At the age of four weeks, the neutralization depth is the largest for 5%, and the depth is about 40% of the control. From this result, when EM-X was mixed by more than 5%, the neutralization depth does not change remarkably. As the graph shows, it is difficult to promote neutralization of the EM-X-containing concrete.

5.8 Result of acceleration neutralization test (EM-X)

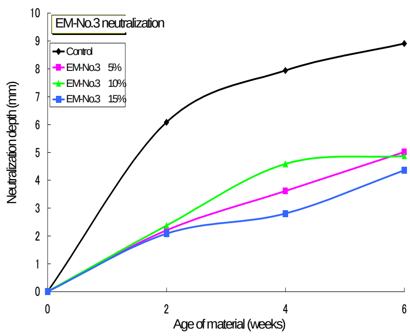


Fig. 13 (EM-No. 3 neutralization)

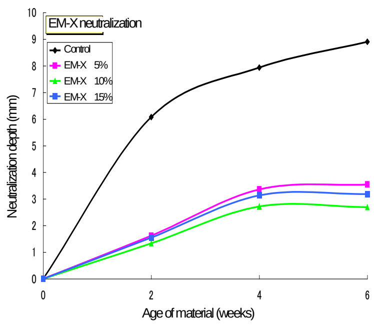


Fig. 14 (EM-X neutralization)

5.9 Summary of neutralization test

The result of neutralization test shows that neutralization becomes difficult for concrete containing every type of EM product. Particularly, the depth for EM-No.1 was the smallest, and promotion of neutralization was difficult. EM-X and EM-ceramics gave the same result. The difference of mixing ratio did not affect the depth. Finally, we found that EM-No.3 was less likely to suppress neutralization than other EM products.

6. On-site inspection of EM-containing concrete structures

1. Visual observation of appearance

Visual observation of appearance was performed for 16 EM-containing concrete structures. Every appearance was glossy. Dry-shrinkage did not occur. Some large buildings showed cracks due to subsidence of ground. The structures were 2 to 5 years old.

2. Physical (nondestructive test) measurement

We tested the followings. 1. We estimated the strength using a digital Schmidt hammer. We measured 20 points for 16 buildings where EM-containing concrete was used. The average result was 42 N/mm^2. The EM-containing concrete showed strength about 10% earlier than the ordinary concrete of the same age. 2. We used an ultrasonic tester (TICO) to measure the pulse speed. The speed of ultrasound traveling through substances depends on densities and elasticities. The pulse speed is correlated with the quality and strength of substances through which ultrasound travels. Therefore, we can use ultrasound to test homogeneity, crack, depth etc. of concrete structures. We paid special attention to quality of concrete. The average speed for 16 building was 4230 m/s, indicating that concrete is very homogeneous. 3. We used a gas-permeability tester (TORRENT) to measure gas permeability of concrete. This tester can measure the gas permeability of cover concrete in a short time. The greatest merit of this tester is that it employs two-chamber type shell. As a result, we can measure any point accurately, without being influenced by other points. The result is expressed by KT value (coefficient of air permeability). The smaller value means that the air tightness of concrete high and that the quality of concrete is high. We used this tester to investigate 16 buildings. The KT value was surprisingly small. The average was 0.86 KT[$10^{-16}m^2$]. About half of results showed the value of 0.0036 etc. The measurement range of this tester is 0.001 to 100. The test suggests that air tightness is very high for EM-containing concrete.

7. Discussion

7.1 Strength property of EM-containing concrete

We used EM for concrete and tested compressive strength. We mixed EM (EM ceramics, EM No.1, EM-No.3, EM-X) with the 55% water and binding-material ratio. We also measured the strength after correction. Under all the conditions, the strength was higher than the control. Particularly, EM-No.1-containing concrete was the strongest. At the age of 3 days, 7 days and 28 days, the values were the same for 5% and 10%, respectively. The compressive-strength ratio of change became gradually less noticeable at higher age. This means that EM products can be useful as admixture to some extent.

The pore distribution was as follows. At the age of 7 days, the 5% EM-ceramics containing concrete showed almost the same result as the control. For the 10%, the relative pore volume increased near 50nm. For EM-No.1 of the age of 7 days and mixing ratio of 5%, the pore volume was the largest at 80nm. For 10% and 15%, the peaks were found at 50nm. At any mixing ratio, the pore volume was larger than the control. For EM-No.3 of the age of 7 days, the peaks of 5%, 10% and 15% were 70nm, 60nm and 80nm, respectively. The pore volume was larger than the control. For EM-X of the age of 7 days, the peaks of 5%, 10% and 15% were 60nm. The relative pore volume for 5% and 10% was about 30%, while the volume for 15% was about 25%. For EM-X, the value at 10nm was higher than the control. This result suggests that the pore is generally noticeable at the age of 7 days. At the age of 28 days, the peaks did not change for any kinds. Others did not change so much.

At the early age (3 or 7 days after mixing), the strength appeared remarkably. The difference becomes small at higher age. The details are now under investigation. The increase of initial strength is sometimes as high as 50%. Early removal of frames is possible to shorten the period of construction. This effect is seen in all EM products. This effect can shorten the period of construction. Not only that, this effect is important for prevention of initial frost damage of concrete at the construction site located in cold regions. 〔7〕

7.2 Characteristics of EM-containing concrete (EM concrete)

1. EM-No.1 is available in liquid. It has the effect of AE agent, water-reducing agent, and water-reducing agent of high performance. Air is introduced into concrete by the gassing effect. It is effective to disperse the agglomerated particles cement and fluidize concrete. In other words, the workability of concrete is improved. In recent years, they tend to build many large buildings and long and large bridges. They often require concrete of high strength and high fluidity. The liquid EM products such as EM-No.1 and EM-X may become the important materials of concrete. 〔６〕

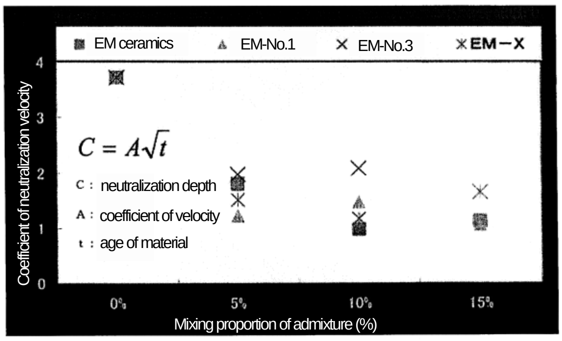
2. The initial strength improves. The period of rotation for frame molds becomes shorter. The construction speed improves. The damage of concrete in cold season is reduced, leading to the increase of profits.

3. Drying-shrinkage crack was not seen in most structures investigated. One of the major defects of concrete is drying-shrinkage crack. Its total absence in all the structures investigated suggests that EM products are suitable as material for concrete.

4. The coefficient of air permeability at the surface layer of concrete is very small compared with the ordinary concrete. It is smaller by a factor of two digits. It suggests that the internal structure is air tight, or that some substances suppress air permeability. The compounds in question were already identified. 〔8〕

5. It can suppress neutralization [carbonation]. There is no possibility of carbonation. The result of acceleration neutralization test was converted to the coefficient of neutralization of velocity, and it is shown in Figure 15.

Fig.15 (Coefficient of neutralization velocity).



This figure shows a neutralization depth expressed by C=A√t. (c = neutralization depth, A= coefficient of velocity, t= age of material). This figure indicates that all the EM products can suppress neutralization effectively. For the 5% EM-No.1-containing concrete, the coefficient of neutralization velocity was slightly larger than one. For the 10% EM-ceramics-containing concrete, the coefficient was the smallest, and almost the same as EM-No.1.

For the 15% EM-No.1-containing concrete, the coefficient was the smallest. EM ceramics showed almost the same trend. From this result, optimal mixing proportion is within 5% for EM-No.1 and 5%% or less for EM ceramics. We investigated 16 buildings that were 2 to 5 years old. We scraped the surface of structures and sprayed phenolphthalein. We proved that all the 16 EM concrete buildings were free from neutralization. In Thailand, we tested a large concrete building which was 10 years old, and found out no trace of neutralization. It is presumed that 10-year old buildings, at least their surface, are affected by carbonation. No trace was found. There were other buildings nearby that did not use EM concrete and that were as old as the first building. For the purpose of control, we investigated neutralization. We found that the surface of concrete was partially neutralized. We noticed efflorescence on the ceiling near the machine room and watery surroundings. The estimated compressive strength had not any large difference, but there was a tendency that EM concrete was higher. .

8. Conclusion

EM concrete has the improvement effect of fresh concrete. EM-No.1 and EM-No.2 are expected to have the gassing effect, water-reducing effect, and powder grain dispersion effect. To setting concrete, it was proved that initial strength presentation becomes large. The carbonation [neutralization] depth is expected to shows almost a steady-state value. Any single materials other than EM cannot improve the quality of concrete in so many aspects.

to have the strong effect for powder grain dispersion.

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