EM Concrete Feasibility

Hachinohe Institute of Technology
Shuichi Sugita

1. Introduction

The theme of today's lecture is "EM Concrete Feasibility". If we change our viewpoint, we can see a lot of possibilities and the area where we have the highest expectation is the improvement of the concrete durability.

Our highest expectation of using EM in concrete material is the durability of concrete, that is, improvement in the ability against deterioration of the concrete, or to restrain this deterioration. I would like to talk from this view point.

2. Concrete Characteristics

In order to understand the deterioration problems of concrete, as a reference, firstly I'd like to talk about concrete's peculiar problems.

(1) Concrete's Structure Inhomogeneity

Concrete's structure contains composite materials, consisting of 70-75% volume of aggregate and 25-30% volume of hardened cement paste. The particle composition includes macro items such as coarse aggregate to micro items such as cement particles. Furthermore, the hardened cement paste structure contains cement hydrate and small/large voids. It is indispensable to understand the inhomogeneity and void characteristics with regard to the concrete deterioration problem.

(2) Materials Separation is Unavoidable

Concrete is the unification of cement, aggregate and water, having a great difference in material densities, which are mixed by force, therefore it is called "Materials Segregation". The greater density materials sink to the bottom and the lighter density materials rise to the top due to this relative motion. At the time of placing the concrete vibration compaction is carried out, which has the tendency to highlight the segregation even more. This will also raise the inhomogeneity of the concrete structure.

(3) Concrete is a Living Creature

Since olden days, it is said "Concrete is a living creature" and there are significant resemblances.

For example:

- In the hardened cement paste, starting with the hydration reaction there are various other reactions that progress over dozens of years.

- The passing of air, coming and going, as it breathes.
- As with blood and water, there are movements of the materials (Liquid, Salt, Alkaline) through voids.
- Deterioration begins as the concrete ages, same as humans.
- If the concrete is made with love, it will be magnificent.

3. Concrete and Concrete's Structural Deterioration

(1) Recent topics on concrete deterioration

Everything on earth, no matter whether it's an animated object or inanimate, it is a natural providence to see a deterioration phenomenon, with increase in age, to rot away. This is caused by an oxidation phenomenon, which is a natural phenomenon called "The law of increasing entropy". We are concerned that the life-span may gradually shorten due to environment problems and other things. Especially with regard to concrete, in recent years, this tendency is remarkable and it is not only because of the technical problems but we are receiving severe criticism in our society. In June of this year, the Asahi Newspaper reported on their front page that the defect apartments belonging to the Urban Development Corporations had been rebuilt, which I could not believe. Although the concrete was said to last for more than 50 years, there were many cases reported that the concrete was failing after 10 to 15 years. Therefore, the term "Early Deterioration" of the concrete became recognized socially, as it seemed to become a general term not only a technical term. The know-how of concrete's research / technology is constantly showing advanced progress, as with other fields, however it is a very ironical story that this is not reflected in the end product and that it concludes in very bad results.

On the other hand, when I see some old concrete structures, which were built more than 70 to 100 years ago, that are still in good shape, I can recognize once again that concrete is a material of which longer life can be expected. When I observe the concrete materials and the application method of olden times and now, I can see the outline of this.

(2) The Cause of Concrete / Concrete Structure Deteriorations and EM Effect

Concrete is a brittle material and originally it has some defects. For example, cracks, extremely weak tensile strength and bending strength unlike its compressive strength, acid-resistance and carbonation by carbon dioxide in the air, alkali-aggregate reaction related to the aggregate. Usually, there are many cases to combine the steel materials such as reinforcing bar etc. in the concrete structures, in that case rust of the reinforcing bars plays are very important role.

- **Cracks**

  There are many types of cracks and it is normal that the crack caused by drying shrinkage appears on the surface of any concrete. Generally, as this crack is called a hairline-crack, mostly the width is small and the depth is shallow, and there is a possibility for this to become an initial factor of concrete deterioration. It can be greatly decreased based on the mixing proportion of concrete, usage of chemical admixture and application method.

  Within the scope of an on-site investigation of our EM concrete structures, we did not observe any drying shrinkage cracks. This is the first incidence where we felt a difference between EM concrete and normal concrete. I can say that EM concrete is very strong against drying shrinkage cracks and clearly reduces this first cause, which could possibly be the initial factor in this deterioration problem.

  Of course, cracks due to “kyoyo” load, which means shifting load and cracks due to inequality in settlement of the basic structure will appear.

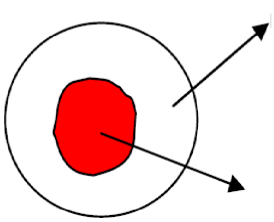
- **Compressive Strength**

  The initial strength significantly increases. There are few differences regardless of the type of the EM material. Although it contributes to quickening the application time, the setting time has a tendency to be shortened, so we need to be careful with regard to the useable application time, such as transportation, placing and so on.

  In addition, based on the investigation of the EM concrete structure we feel that the strength development in relation to material age is stronger than normal.

- **Carbonation**

  The hardened cement paste consists mainly of a Calcium Silicate Hydrate (C-S-H) and a Calcium Hydroxide therefore it shows high alkalinity because of the Calcium Hydroxide. It reacts with the Carbon Dioxide in the air and will gradually change in to Calcium Carbonate and Water. As Calcium Carbonate, being cement’s raw material is limestone it results in Calcium Carbonate returning to rock. Then alkalinity is gradually lost and becomes neutralized. The cycle of Oxidation->Reduction->Oxidation is the normal natural cycle which is common to iron and in general corresponds to the process passage of the material Deterioration->Disintegration. In the case of humans, it is the same where people become sick and age through oxidation reaction. The loss of alkalinity reinforces the condition for rust development.



Neutralization domain (is not dyed by phenolphthalein)

Non-neutralization domain (is dyed by phenolphthalein)

Carbonation of cylindrical test pieces

The equation is:

① **The carbonation of Calcium Hydroxide**

$Ca(OH)_2+CO_2=CaCO_3+H_2O$ ••••• (i)

According to the concrete engineering, which I studied, I learned that "Concrete is neutralized by carbonation but except for that there are no other particular problems." There are reference books stating that concrete's compressive strength increases through carbonation. Because the molecular weight of $CaCO_3$ is greater than $Ca(OH)_2$, more compacted, therefore I understand that mass increases and strength rises. My understanding was like this for a long time, but in recent years the true character of carbonation has been more clearly clarified. The main point is that all the hydrates, which have structured the hardened cement paste, will carbonate and these equations are shown as follows.

② **Carbonation of Calcium Silicate Hydrate (C-S-H)**

$3CaO•SiO_2•3H_2O+3CO_2=3CaCO_3+SiO_2+3H_2O$ ••••• (ii)

The C-S-H is the core material of hardened cement paste and it decomposes the raw material of cement. $CaCO_3$ is limestone and SiO_2 is an amorphous material from clay. We already knew it from quite a long time within the laboratory but in recent years it has been verified on actual deteriorated structures.

③ **Carbonation of Ettringite**

$3CaO•Al_2O_3•3CaSO_4•32H_2O + 3CO_2$

$= 3CaCO_3+2Al(OH)_3+3CaSO_4•32H_2O+23H_2O$ ••••• (iii)

Ettringite is a hydrate, which reacts with Gypsum the setting time regulating agent during the initial stages of hydration reaction, and forms sharp crystal like needles similar to a hedgehog's back By using an electron microscope we can clearly see this state, however, it is almost impossible to see it in a carbonated progressed hardening state.

$CaCO_3$ is from limestone, $Al(OH)_3$ is from clay, $CaSO_4 \cdot 32H_2O$ is from Gypsum.

④ Carbonation of Friedel's Salt

$$3CaO \cdot Al_2O_3 \cdot 3CaCl_2 \cdot 10H_2O + 3CO_2$$
$$= 3CaCO_3 + 2Al(OH)_3 + CaCl_2 + 23H_2O \quad \cdots\cdots \text{(iv)}$$

The Chloride Ions that penetrate the hardened cement paste form Friedel's Salt and stabilizes. It won't be the reason for rust, however Friedel's Salt breaks down by carbonation into Calcium Chloride CaCl2, which dissolves in a solution and is the cause of the rust development of the reinforcement (bars).
Furthermore, I would like to mention the bad influence that carbonation brings.

⑤ Material Movement in the Hardened Cement Paste

Specifically, this is a concentration phenomenon of salt, which is the movement of Chloride Ions to the carbonized surface and it can be considered a problem that even for concrete which internally has an average salinity within a permissible level, there are cases that the salinity concentration at reinforcement positions can be in excess of the permissible level as this is caused by concentrated movement internally. Moreover, it is alkali metal ions such as sodium and the potassium that move in the opposite direction to chloride ions, that is, moving from the internal area towards the surface, from non-carbonated domain to carbonated domain. These are deeply related with efflorescence. Efflorescence is one of strong indications of concrete deterioration.

As per the above mentioned items, I believe that you have understood that concrete carbonation has a large influence on dissolving the hydrate, and on reinforcement rust development.

4. Effectiveness of Carbonation Restraint by EM Materials

Concrete carbonation is not desirable for concrete or reinforcement bars. The key point for prevention of concrete deterioration is carbonation restraint, so is there any effective way to achieve this? Actually, the reason why I had an eye on EM is with regard to one specific point, which would be the effect for carbonation restraint. The conclusion as a result of having read "An Earth Saving Revolution Ⅰ, Ⅱ, Ⅲ" over and over again, is "Carbonation Restraint", that is to say it is a very effective restraint material.

(1) On-site Investigation of an Actual Structure

First, let's talk about the result of the onsite investigation. I had checked the inner and outer walls at the Tropical Plant Resources Institute, Inc., but I was unable to measure

the carbonation. To check the depth of carbonation, a 1% phenolphthalein solution is sprayed on the concrete and colour change is observed, whereby if it is alkaline it turns red or if it is neutral there will be no colour change. Of course, the colour doesn't change on an air-exposed surface, however, after lightly sanding the concrete surface it clearly changes colour proving that it is not neutral. The same result is obtained with a random inspection of the test piece. At the time of the investigation, it was the 4th year since being built, so normally the carbonation depth of the concrete would be estimated to be 2mm to 3mm but the result was different from the estimation. I checked many other buildings, although it wasn't many years after they were completed, naturally there was no neutralization. Therefore, based on the result of the investigation there was enough data to expect the anti-carbonated power of EM material.

(2) Research Room Accelerated Test

The accelerated test is based on inserting a concrete test piece, which has been dried by standard curing for 28 days, in the test tank which has been set to 5% concentration of carbon dioxide, temperature of 20 degree Celsius and 60% humidity and leaving it in the test tank. We remove the test piece after a certain period and measure the colour depth by spraying the phenolphthalein on the cracked surface. This result is very interesting and we obtained the data which proves the result of our on-site investigation.

Conclusion Summary:

- All used EM materials have same levels of effectiveness.
- Depending on the used amounts, the depth of carbonation stops at the stage of 2mm~3mm of progression and even if the test duration is longer it won't progress any further. In other words, the carbonation depth is curtailed to a constant value.
- As for normal concrete in comparison, the carbonation depth becomes deeper and deeper with the progression of the testing time, and finally the complete cross section carbonates and there is no colour changing at all.

These conclusions are very important. We test with 5% concentration of carbon dioxide, which is about 170 times that of the carbon dioxide concentration in the air (however, recent data shows this concentration to be 0.034% not 0.03% due to an increasing of carbon dioxide. In that case, it is 147 times.), 60% humidity, therefore the possibility arises that carbonation is unlikely in the actual air condition.

5. Summary: EM Concrete Feasibility

The following are things that I knew about the nature of EM which are deeply related to concrete, before I started researching:

- Strong against salt: By research of soil damage from salt.
- Strong against rust: There is already a patent covering EM which does not let iron rust.
- Strong against “Sick-House”: We can say that this is the “allergy” of the house. People who live inside the EM structured houses will reduce their allergies, so called “Healthy House”.
- Strong against earthquakes: We do have an example showing that an EM Materials built structure is earthquake-resistant. However, this will be logically researched from now on.
- Strong against radioactivity: Proved in the Republic of Belarus. Possibility of the concrete usage at the nuclear power facilities.
- Stronger foaming action: Development of the chemical agent using EM which has considerably stronger foaming action.

There might be other issues, however these are the stories that I know of related to concrete.

In addition to these, the issues that I talked about today,

- Drying shrinkage crack resistance
- Carbonation resistance

will be added.

Further to considering these things we can say that EM materials will not only improve the basic defects which concrete have but they have huge possibilities to solve the recent severe problems of concrete deterioration or early stage deterioration.

The Feasibility of EM is:

“A Concrete Saving Revolution”