Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 78 (1998)

Artikel: An effective and eternal maintenance method for concrete tunnel structures
Autor: Furuya, Tokiharu / Iwasa, Takayoshi / Sasajima, Yoshihiro
DOI: https://doi.org/10.5169/seals-59068

An effective and eternal maintenance method for concrete tunnel structures

Tokiharu Furuya

Civil Engineer
East Japan Railway Co.Ltd.
Tokyo Japan

Takayoshi Iwasa

Civil Engineer
East Japan Railway Co.Ltd.
Tokyo Japan

Yoshihiro Sasajima

President
Japan Xypex Co.Ltd.
2-22-3 Minami-Aoyama,
Minato-ku,Tokyo,107,
Japan

Kimitaka Nishimura

Civil Engineer
East Japan Railway Co.Ltd.
Tokyo Japan

Yuzuru Kuramoto

Technical Department
Japan Xypex Co.Ltd.
2-22-3 Minami-Aoyama,
Minato-ku,Tokyo,107,
Japan

Yukinobu Nakamura

Technical Development Department
JGC maintenance Services Co.Ltd.
1-13-8 Kamiohokanishi
Kohnan-ku,Yokohama,233
Japan

Summary

This paper presents the results of study to confirm that a Cement Crystal Increasing Material is effective to make concrete itself impermeable and to suppress every kind of damage and deterioration, by increasing cement crystals in pores and voids of concrete body. It is a quite different method from ordinary ones by coating and injecting resinous materials which have properties that are different from concrete to the surfaces and into the cracks as physical barrier. The effects of application with the material was verified by permeability test and SEM (Scanning Electron Microscope) survey with concrete specimens and cylindrical test pieces from the concrete linings of some tunnels in service by applying this material.

1.Introduction

For many concrete lining tunnels, it has been a keen requirement to establish rational, effective and eternal maintenance method to give them tough and longer lives against damage and deterioration caused by water leakage from cracks or construction joints, frost damage, salt injury, AAR, and so on. Ordinary repair methods which have been applied so far to such concrete linings are to coat the surface with resinous materials as physical barrier, or to inject them into damaged places. However, these materials do not improve impermeability and other characteristics of concrete body itself. And it is fundamental disadvantages that they have tendency to deteriorate themselves in short period, which causes peeling from concrete with the passage of time, especially they are not adequate to apply for waterproofing to the areas against high pressure water leakage from back side of the lining.

The starting point of every damage and deterioration of concrete is caused by the movement of watersolution in cracks, pores and voids, and by various chemical reactions through the solution. From

this viewpoint, we applied a Cement Crystal Increasing Material (Xypex Concentrate: the code XC) which makes concrete lining itself impermeable and suppresses all causes of water leakage or deterioration lastingly and improves many characteristics of concrete itself. We verified the repairing effects which we confirmed on some tunnels. The report on one of them is written in page 5 and page 6.

2.Cement Crystal Increasing Material XC and Principle of Cement Crystal Increasing

2-1. Cement Crystal Increasing Material XC

XC is an inorganic powder form material which includes some kinds of catalysis compounds in it. The main chemical composition is shown in Table 1. And assistant materials used in repair methods by applying XC as main material are inorganic, cementitious materials which do not prevent cement gel ~ crystals increasing function with XC. They are shown in Table 2.

Table 1. Chemical Composition of XC

Component	Specification Range(%)
SiO_2	39~46
CaO	25~34
Al_2O_3	4~5
MgO	3~5
Na_2O	4~7
Fe_2O_3	1.5~3

Table 2. Assistant Materials

Name of Material	Code	Character of Material
Modify	XM	Sub-Cement Crystal Increasing Material
Pach'n plug	XP	Fast Setting Hydraulic Mortar
Extra plug	XE	Quick Setting Hydraulic Fine Mortar
Mild Pach'n plug	XMP	Non-shrink Fine Mortar
Gamma Cure	XG	Curing Agent of Crystalizing Accelerator

2-2. Mechanism of Cement Crystal Increasing by XC

The Catalysis Compounds (Calcium complex L: Ca, a kind of acid as a Chelate Ligand combined with Ca) compounded in XC exist as the size of complex molecule and they would diffuse extremely, naturally in deep and wide through solution in pores and voids of concrete or cement compound materials. The indispensable minimum density of the complexes in concrete to show the effect of impermeability by cement crystal increasing is under 1 ppm.

It is well-known that there exist a lot of silicic ions (Si^{2-}_3, Sio^{4-}_4, Si_2

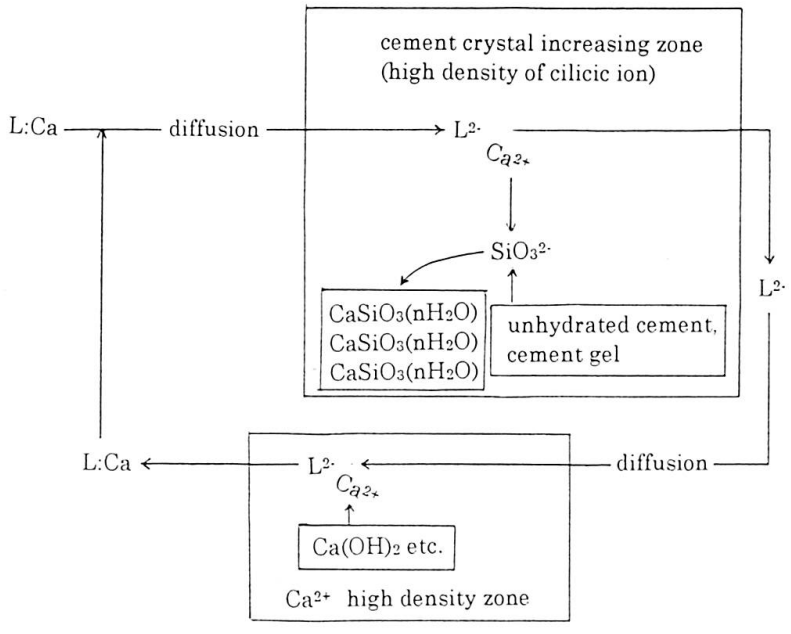


Figure 1. Basic Mechanism of Cement Crystal Increasing

O^{6-}_{7}) not only in young concrete or mortar but in those of over 20 years. Those silicic ions are combined with Ca^{2+} which are carried as Calcium Complexes (L : Ca) and produce cement gel ~ crystals. The basic mechanism of cement gel ~crystals increased by L: Ca is shown in Figure 1. This reaction continues repeatedly in concrete or mortar as follows.

L: Ca combined with Ca^{2+} diffuse though the solution in pores and voids of concrete or mortar and within the high density zone of silicic ions, Ca^{2+} of L: Ca combine with silicic ions and precipitate as Calcium silicate CaSiO3 (main gel ~ crystal of cement) due to the difference of solubility products of them. After splitting off Ca^{2+}, the complex ions L^{2-} diffuse in concrete or mortar again. And when L^{2-} ions come into the high density zone of Ca^{2+}, from $Ca(OH)_2$, L^{2-} combine with Ca^{2+} and diffuse as L: Ca again. These reactions occur repeatedly and increase cement gel ~ crystals with passage of time. This is the basic mechanism of cement gel ~ crystals increasing. As the result, these reactions improve the concrete lining itself to be an impermeable concrete and suppress every cause of deterioration.

3.Impermeation Method of Tunnel Concrete Lining by XC

Impermeation effect of concrete by XC exercises as follows. Calcium Complexes L: Ca compounded in XC diffuse through solution in concrete, and with its catalysis function, cement crystals are increased. Therefore, it is the main point of this impermeation method to diffuse L: Ca into concrete effectively. And the basis of this method is to place and to hold XC directly and steadily on the concrete surface. The impermeation method by XC has two basic and concrete methods. One is Coating method and the other is Plugging method, as shown following.

3-1. Coating Method

This is the most basic method and the application process is shown below. After removing dirt, laitance, efflorescence or other impurities which cause to prevent Calcium complexes' permeation into concrete surface by high pressure water blasting, XC mixed with water (W/XC=35%) is applied coating (standard quantity of coating is 1.0 kg/m^2). Before and after XC coating, Curing Agent XG should be sprayed to accelerate crystal increasing. XC mixed with water is like cement slurry. Coated XC slurry needs 10 ~ 12 hours to set. Therefore, plugging method shown as follows should be applied before XC coating to some areas where XC slurry coat may be swept away before it is steadily set, for example, they are water leaking cracks or construction joints.

3-2. Plugging Method

Concrete linings which need to repair are mostly aged long time. They have few Calcium ions (Ca^{2+}) and Silicic ions (SiO^{2-}_{3},.....), inside the cracks and near around the surface. In these cases, it is the preventing factors for cement crystal increasing. This Plugging Method with XC as main material is the method which is devised to decrease such preventing factors and increase the crystal increasing reactions.

In case of applying XC to water leaking cracks, basic point is to make a small chipping slot (standard size of section is 2~3cm wide × 3~4cm in depth) along the crack, and plug it with XC as main material.

According to the size of the crack and degree of water leakage, we should choose to apply double

plugging or triple plugging method.

Basically, triple plugging method as shown in Figure 2, is applied commonly to the cracks with water leakage. Aims of each application process of plugging method to help crystal increasing are explained in Table 3.

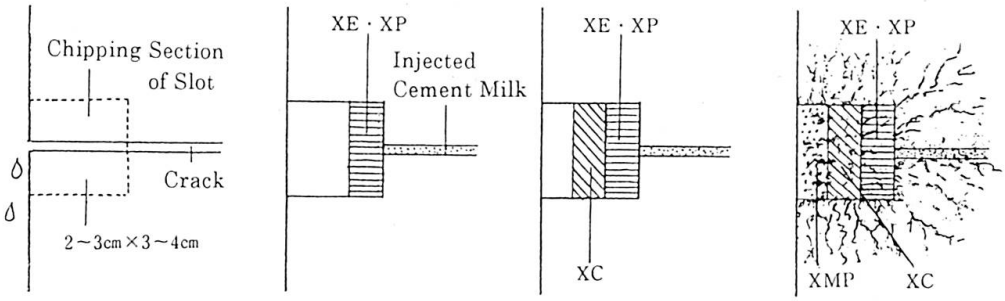


Figure 2. Rough Sketch of Triple Plugging Method

Table 3. Aims of Each Process of Plugging Method

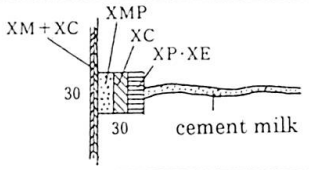
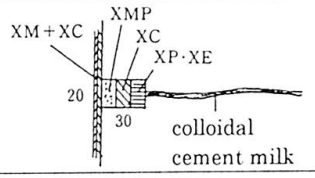
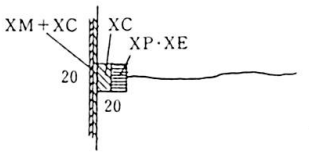
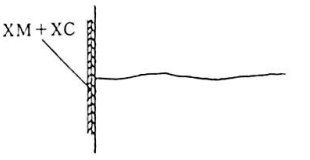
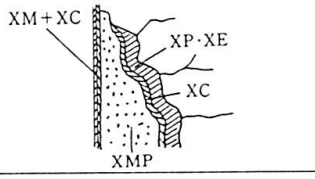
Application Process	How to Increase cement Crystals
Make a chipping slot along the crack	Make a new breakage of section · To increase permeability of L : Ca · To make easy to combine with Ca^{2+}, SiO_3^{2},····
Coat XC srurry on the inside surface of the slot	· To make easy to permeate and diffuse L : Ca earlier from inside the slot
Plug the slot with the mixture of fast setting mortar XP and quick setting mortar XE , as first layer	· To reduce the quantity of water leakage · To fasten the crystal increasing effect by new contact surfaces of chipping slot and plugged XE and XP , instead of the old surfaces of the gap of crack · To make crystals inside of XE and XP.
Plug crystal increasing material XC	· To supply and diffuse L : Ca continuously inside of XE , XP and concrete , and to all contact surfaces of them around XC.
Plug non-shrink mortar XMP as final layer	· Finishing plug to protect XC layer

The main material of this Plugging method is XC itself. Steadily plugged XC increases cement crystals inside of concrete, the other materials and all contact surfaces around XC itself. This is the special feature of this method. In case of big cracks, as shown in Figure 2, inorganic cementitious materials such as cement milk etc. are injected into them. And XC increases crystals inside of such injected materials and in the contact surface between the material and concrete, and impermeate the cracks completely.

4.An Example of Repair of Railway Tunnel

N.Railway Tunnel of JR is located at the northern and mountainous region of Japan, 110m long and was constructed in 1962. The thickness of the concrete lining is 50cm, and with passage of time water leakage through cracks and deteriorated construction joints of the lining have been increased, in addition, it is located in such cold region that the damages of the lining have been accelerated in winter by freezing damage by water leakage from the cracks. Any repairing method by physical barriers such as resinous materials were unusable no longer for these heavy damage by freezing. Therefore, 1993 repairing work was conducted by applying XC as main material to suppress water leakage and freezing damage, deterioration of lining. Repairing methods applied according to the degree of the damage of the lining are shown in Table 4.

Table 4. Repairing Method of Lining

Degree of Damage	Application Method	
crack (more than 5mm in wide) with water leakage	·inject cement milk ·3 plugging method ·coating method	
crack (5mm~0.3mm wide) with water leakage	·inject colloidal cement milk ·3 plugging method ·coating method	
crack (less than 0.3mm wide) with light water leakage	·2 plugging method ·coating method	
crack (less than 0.3mm wide) no water leakage	·coating method	
sectional caving damage (10cm or thereabouts in depth)	·3 plugging method ·coating method	

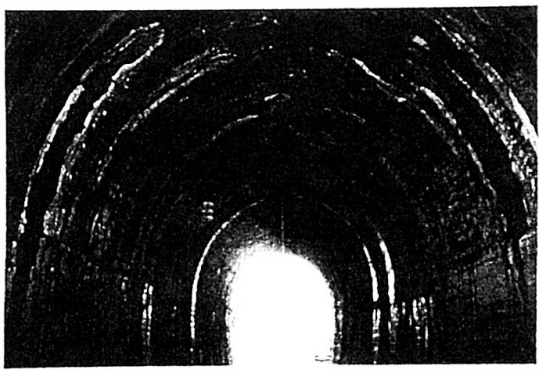


Figure 3. The surface before repair

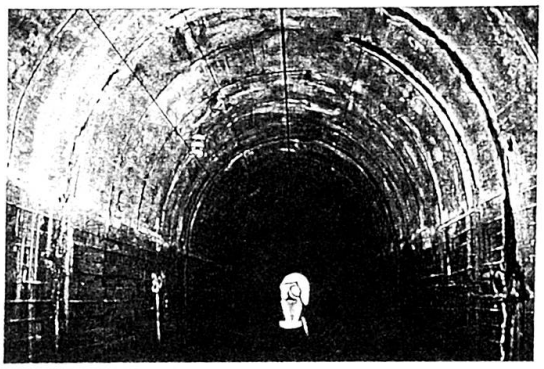


Figure4. The surface after repair

The final process of coating on the whole surface of the lining was double coating method which applied XM on XC coating.

To confirm the effects of application, one year later after the repair 2 concrete cylindrical cores (core No.1 and No.2) from applied area and another one (core No.3) from untreated area were collected as comparing specimens (the size of each specimen is 86 mm in diameter $\times$65 mm in length), and permeability test (water pressure 5kgf/cm^2) was conducted. The results are shown in Table 5.

Table 5. Results of Permeability Test

Core No.	Collected Area	Coefficient of Permeability(10^{-10}cm/sec.)
No. 1	Applied area	Non - leakage of water
No. 2	Applied area	11.6
No. 3	Untreated area	182.7

The samples for SEM were sheared through 5cm below end surface of cores No.1 and No.3, and structural improvement of the samples was examined by SEM photos. They are shown in Figure 5 and Figure 6. Each photo is 1000 times enlarged photo of inside the pore of thereabout 100 μ m in diameter in size of hardened cement structure of each sample. Figure 5 is the SEM photo of core No.1 and Figure 6 is the core No.3. In Figure 5, increased cement crystals in the pore are observed.

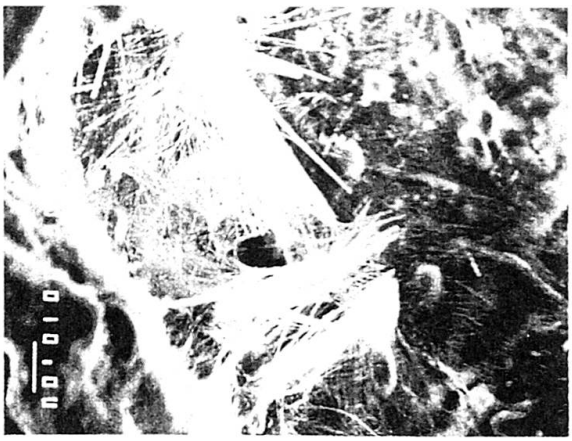


Figure 5. Inside the pore of core No.1

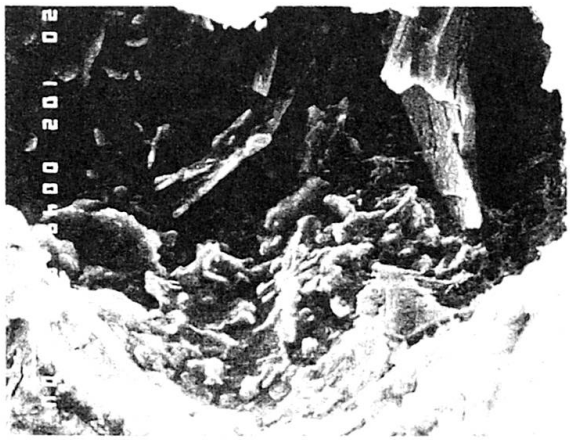


Figure 6. Inside the pore of core No.3

4 years have passed since this repair was conducted, now no water leakage and deterioration by freezing damage are observed, and the result of repair are going on quite satisfactory.

Conclusion

It is confirmed that the structural improvement of concrete by applying XC impermeates the concrete itself not by XC coating onsite as a physical barrier but by the cement crystals increasing function of XC.

It is considered that impermeation of concrete linings themselves by XC suppress not only freezing damage but other causes of deterioration. It is necessary to confirm the effects through further observations and studies of some more concrete lining repairs.

The impermeation effect of XC by increasing cement crystals is an eternally repeating mechanism of chemical reactions. The authors are going to conduct further experimental studies to confirm that the effect would be exercising eternally.

References

- K.Kobayashi, K.Suzuki, Y.Nojiri, Y.Matuoka – Diagnosis of Structural System of Concrete – Morikita Press, Tokyo, 1993

- K.Kobayshi – Carbonation of Concrete – Proceedings of Japan Society of Civil Engineers No.433/V-15,1991

- H.F.W.Taylor, (translated by M.Daimon) – Hydration Products – JME Vol.3, No.3, Portland Cement (Science of Cement), Uchida Rokaku Press, Tokyo,1995

- F.Basolo, R.C.Johnson, (translated by S.Yamada) – Coordination Chemistry, 2nd ed. Kagaku-Dojin Press, Tokyo, 1995