Committee Report : JCI- TC091A

Technical Committee on Self-healing / Repairing Technology in Cement-based Materials

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Abstract

Subsequent to the “Technical Committee on Autogenous-healing in Cementitious Materials” from FY2007 to FY2008, we organized a “Technical Committee on Self-healing /Repairing Technology in Cement-based Materials” from FY2009 to FY2010 emphasizing experiments and measurements. Regarding the 2010 Annual Congress of JCI (Saitama), we invited internationally eminent researchers who lead the research field of concrete self-healing and held an international workshop. In addition, to summarize the activities of the Committee, we broadly invite papers, and plan to have a “Symposium on the Self-healing of Cement-based Materials”, in order to have active discussions from various viewpoints.

Keywords: Self-healing, Case studies of self-healing, Mechanism of self-healing, Non/Minor-destructive testing, International workshop

1. Introduction

It has been a long time since efforts to provide materials with autonomic performance for functioning as intelligent materials drew attention worldwide. Autonomic performance includes self-diagnosis, self-control, and self-repair. Research and development of autonomic performance has been progressing on varieties of materials such as metals, non-metals, inorganic materials, organic materials, and composite materials. Also for cement-based materials, based on a background of epoch-making ideas and existing research results, it has become possible to introduce some autonomic functions or their combined mechanisms.

In the above situation, RILEM set up Research Committee TC221-SHC on “Self-healing Phenomena in Cement-based Materials” in 2005 by inviting Professor E. Schlangen of Delft University of Technology (Holland) as Chairman. The Committee has continued to organize activities including holding an international conference which covers all self-repairing materials over a wide range of fields. Research of cement-based materials has shown rapid development making it an independent sector among these fields.

On the other hand, JCI set up JCI-TC075B, the “Technical Committee on

Autogenous-healing in Cementitious Materials" in 2007, two years after the establishment of RILEM's Committee. During its two years of activity, JCI-TC075B aimed to popularize the self-repairing performance of cement-based materials, and issued a report[1)] which reviewed the present state of research and technology in the world to complete its task. It had to be admitted, however, that the Committee did not play a major role on promoting experiments and research on self-repair, and issuing information about detailed research results. The topics covered in the report were limited to the introduction of research results of some members who aggressively promoted research as a leader. Based on a self-appraisal of the research activities of the JCI-TC075B Committee, JCI-TC091A, "Technical Committee on Self-healing /Repairing Technology in Cement-based Materials", was established as its successor in 2009. Its purpose was to involve each member with a different research background in contributions to experiments and research relating to self-repair and self-healing in their respective positions and to hold discussions on the results from various viewpoints, and further provide information about the Committee's activities internationally as far as possible.

Based on the above history, the Committee began activities for two years from FY2009 to FY2010 emphasizing the research in April 2009, and completed the activities in March 2011. During this period, it organized several working groups responding to the research backgrounds of individual members, and conducted detailed research including experiments and in situ measurements. At the 2010 Annual Congress of Concrete Engineering (Saitama), an international workshop was successfully held to have significantly fruitful discussions with a large number of participants. We are now preparing a detailed report of the entire activities in these two years. This paper describes an overview of the activities of the Committee, and details are given in the Report[2)] issued in June.

2. Members of the Committee and Working Groups

Table 1 lists the members of the Committee. The Committee is a relatively large research-oriented committee with 23 members of different research backgrounds in civil engineering, architecture and materials. For actual activities, the Committee was divided into three working groups and three sub-working groups, thus allowing members to join various experiments according to the interest of each member. **Table 2** lists the working groups.

Table 1: Committee Members

Chairman	Shin-ichi IGARASHI	Kanazawa University
Vice Chairman	Toshiharu KISHI	The University of Tokyo
Manager	Minoru KUNIEDA	Nagoya University
Manager	Tomoya NISHIWAKI	Tohoku University
Member	Tae-Ho AHN	The University of Tokyo
Member	Hiroshi INADA	Shimizu Corporation
Member	Kei-ichi IMAMOTO	Tokyo University of Science
Member	Yuichi OTABE	Sumitomo Osaka Cement Co., Ltd.
Member	Yuichiro KAWABATA	Port and Airport Research Institute
Member	Tetsushi KANDA	Kajima Corporation
Member	Kaoru KOBAYASHI	East Japan Railway Company
Member	Yoshinori GONDAI	Sendai National College of Technology
Member	Takahiro SAGAWA	Nittetsu Cement Co., Ltd.
Member	Yoshie SATO	Sumitomo Osaka Cement Co., Ltd.
Member	Madoka TANIGUCHI	Northern Regional Building Research Institute
Member	Sanjay PAREEK	Nihon University
Member	Takayuki HIGUCHI	Denki Kagaku Kogyo Kabushiki Kaisha
Member	Takashi HITOMI	Obayashi Corporation
Member	Akira HOSODA	Yokohama National University
Member	Ippei MARUYAMA	Nagoya University
Member	Haruaki YOSHIDA	Nihon Network Support Co., Ltd.
Member	Takeshi WATANABE	Tokushima University
Associate Member	Jinhwan JEON	Kajima Corporation
Secretary	Yukio FUKUBAYASHI	till August 2010
Secretary	Akihiro KAWAKAMI	from September 2010

Table 2: Working groups and their activities

Name of Working Group	Activities
1. Evaluation of performance	Study of evaluation method for self-healing performance
(1) Water leak	Evaluation of water leak stopping performance
(2) Self-healing	Evaluation of self-healing performance observed on utility poles
(3) Bending crack	Execution of common test for the self-healing of bending cracks
2. Analysis of mechanism	Observation of process of self-healing and kinetic investigation
3. Non/Minor-destructive test	Determination of self-healing characteristics which can be evaluated by non/minor-destructive test

3. Outline of Working Group Activities

3.1 Performance Evaluation Working Group (WG)

The performance evaluation WG surveyed and carried out studies on the mechanism and performance evaluation of self-healing and natural healing of cement-based materials, and on the self-repair of cracks in the cement-based materials using a device, and summarized the latest findings. The major findings are outlined in the following.

(1) Self-healing and Natural Healing of Cement-based Materials

(a) Water Leak Phenomena, and Mechanism of Decreasing Water Leak

There are several studies on water leak through cracks induced artificially in concrete structures. These studies determined the allowable width of a crack from the viewpoint of water leak, or evaluated the performance of self-healing concrete in terms of preventing water leak. In these studies, however, the method of forming cracks was not the same, and the effect of the internal shape of the crack on water leak was not fully understood so that many observed results were disordered.

Taking account of this situation, we developed a method of forming cracks so that both crack faces become nearly parallel each other, and developed a method of maintaining the crack width. The comparison with the conventional method in terms of the crack and the internal shape of the crack quantitatively showed that this method ensures that the crack faces become more parallel than in the conventional method[3, 4, 5, 6] **Fig. 1** shows the results of water leak tests of the method. The vertical axis is the correction factor Cw to the theoretical value of Poisuille's equation which assumes that the water leak rate is proportional to the cube of crack width. Different from the study of Shiire[4] reporting that the Cw value is constant independent of the crack width and from the study of Ito et al.[5] reporting that the Cw value decreases with increase in crack width, in a specimen of mortar where crack shape was best controlled, the Cw value tended to increase up to about 300 μm of crack width.

The study also observed the variations of water leak with time, and also investigated self-healing concrete containing a clinker fine aggregate. The results are described in a Committee report.

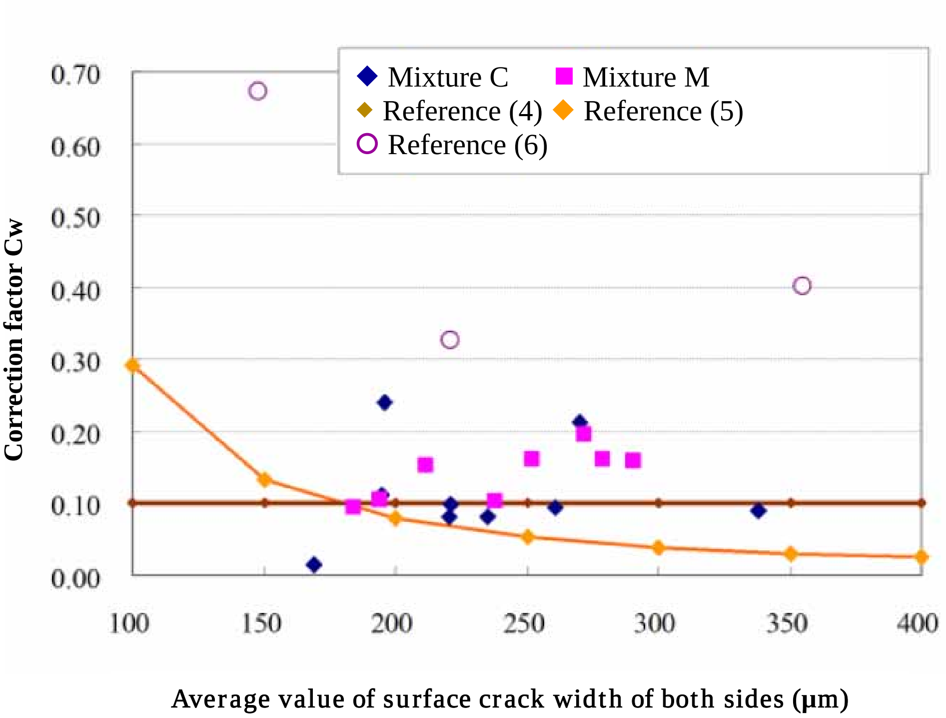


Fig. 1: Effect of crack shape on water leak test [3)]

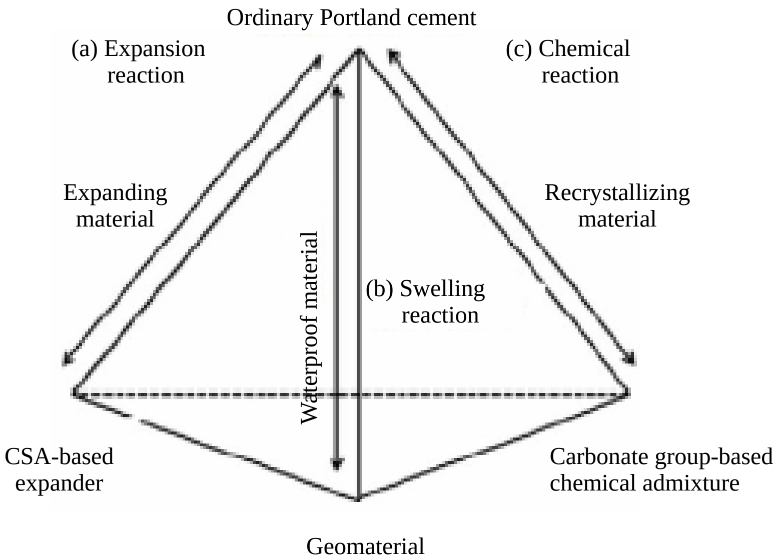


Fig. 2: Design concept of crack self-healing material

(b) Self-healing Concrete Aimed at the Prevention of Water Leak

Several studies for several self-healing concretes aiming to prevent water leak have been carried out, and the results are described in a Committee report.

A new repair method[7)] specifically for the NATM process, which is applied to shotcrete containing a self-healing composition and does not spoil the beautiful appearance or cause the strength of the existing tunnel to deteriorate, has been proposed.

To develop self-healing concrete with high functionality and long-term reliability, a self-healing concrete using a CSA-based expansive admixtures, a geomaterial of a clay-based material, and a carbonate group-based chemical admixture has been proposed[8)] (**Fig. 2**).

A self-healing material[9)] combining an admixture which suppresses the hydration activity of Portland cement and a vinylon fiber has also been proposed. The reported effects of the fiber include the influence of the hydroxyl group on the surface of the vinylon fiber, the role as a deposition site, and the enhancement of ion-migration from inside the cured body.

(2) Natural Healing

A survey was carried out on the latest study results of natural healing of cracks in concrete, not artificial healing.

The longitudinal cracks along a concrete utility pole which was used for 34 years in a frost-damaging environment in Shiga Prefecture showed natural healing. Cores were sampled from the utility pole to be analyzed[10)]. Calcite deposited on the surface of the pole, and as shown in **Photo 1**, propagation of cracks was observed in a pleated pattern outward from the surface layer of the concrete utility pole. An analysis of the internal cracks of the utility pole indicated the deposition of ettringite on the cracks in addition to calcite (**Photo 2**). Since ettringite contains large amounts of bound water and has a large volume occupancy, it is effective in plugging cracks. The survey pointed out that the ettringite enhances plugging of the cracks owing to needle crystals, and that the ettringite presumably functions as a deposition site for calcite.

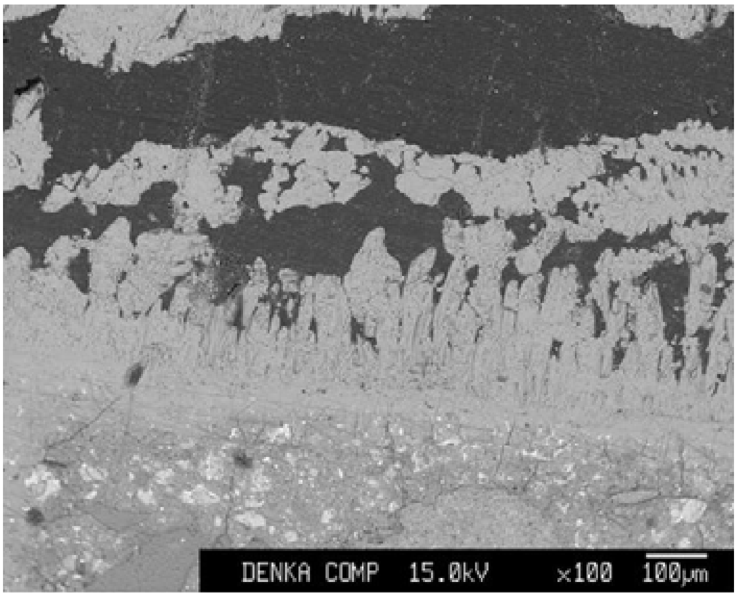


Photo 1: Backscattered electron image of a surface of utility pole

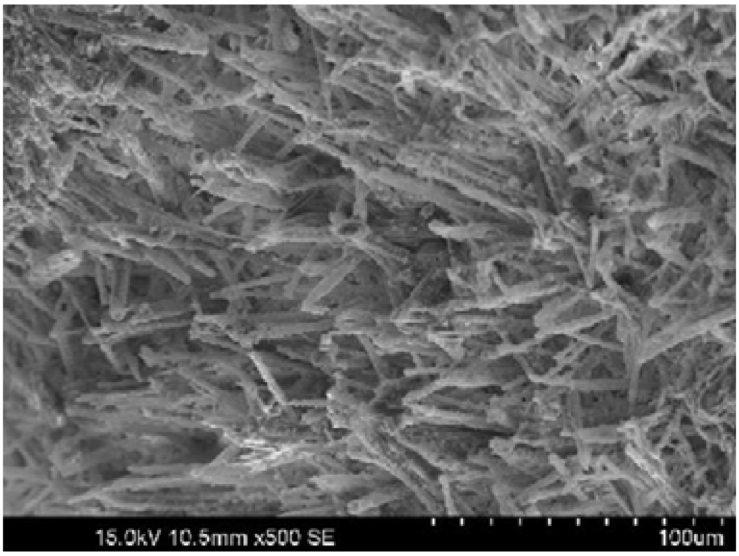


Photo 2: Ettringite on a crack inside the utility pole

A survey was also carried out on the latest findings of natural healing of concrete in an ocean environment. An electrophoretic test was applied to a concrete with marine organisms adhering to it. The test confirmed the effect of decreased diffusion of chloride ions (**Fig. 3**). Increase in the area percentage of organism adhesion tends to decrease the effective diffusion coefficient of chloride ion. An exposure test also showed a long-term decreasing tendency of the effective diffusion coefficient.

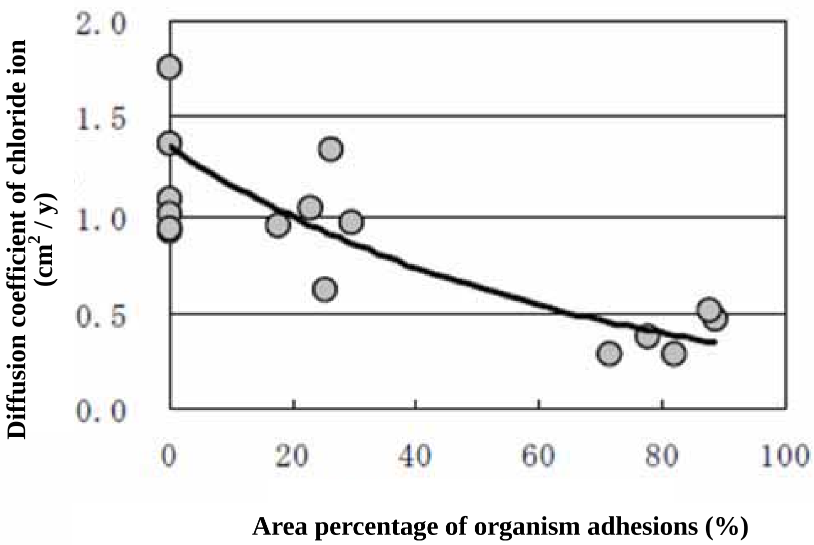


Fig. 3: Area percentage of organism adhesions and effective diffusion coefficient of chloride ion

The effect of the organism adhesion layer on the suppression of corrosion of a reinforcing bar was also confirmed (**Fig. 4**). A survey of corrosion after an exposure test showed the effect of suppressing corrosion of the reinforcing bar.

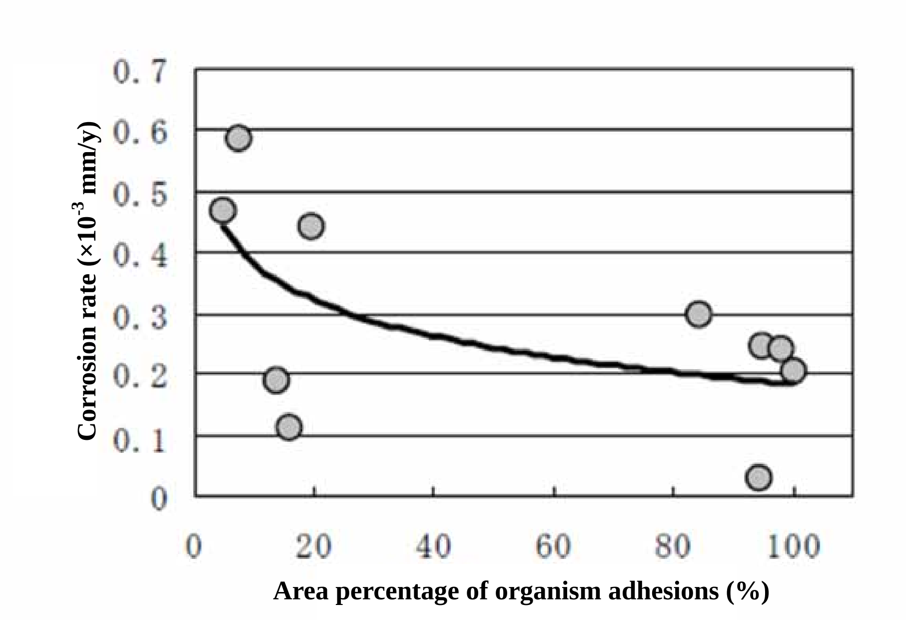


Fig. 4: Relation between the area percentage of organism adhesions and the corrosion rate of reinforcing bar

(3) Recovery of Damage of Fly Ash Concrete at a Short Material Age

To confirm the effect of autonomic healing of a concrete containing fly ash, a common test was conducted for concretes of 8 mixture compositions supplied by 5 organizations. The experimental conditions were: water to cement ratio (W/C) of 0.45, unit water content of 170 kg/m^3, fly ash of JIS A6201 Grade II equivalent, with the addition of fly ash at 20% to the cement volume (percentage of the sum of cement and fly ash) (replacing fine aggregate). At 28 days, cracks were introduced in accordance with JCI-S-001 (2003) “Method of test for fracture energy of concrete by use of notched beam”, followed by curing the concrete under two kinds of conditions: 7 days in warm water at 40˚C or 63 days in water at 20˚C.

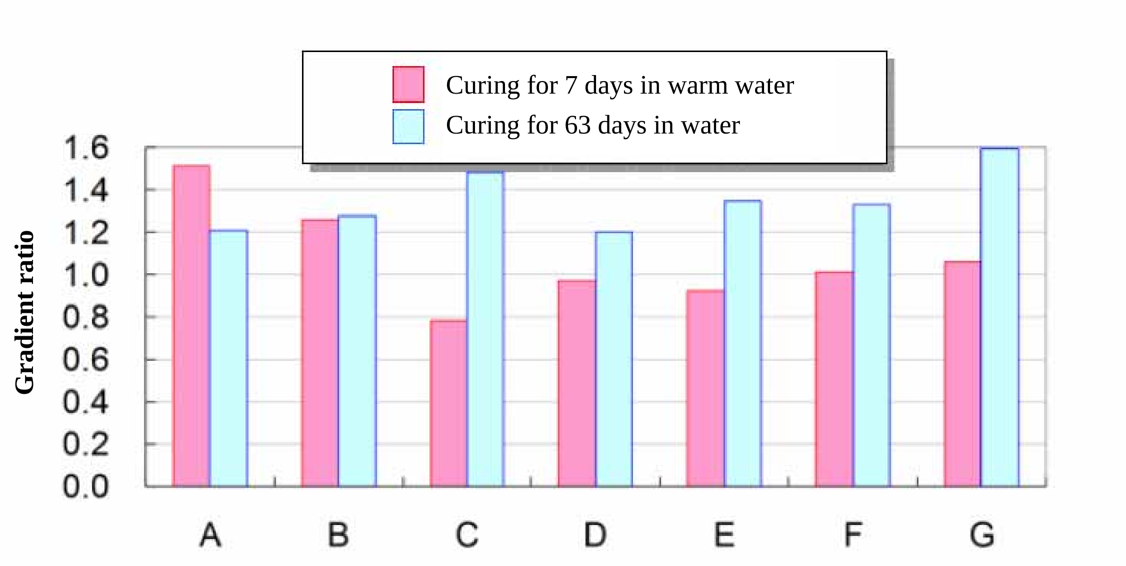


Fig. 5: Variations of rigidity of 8 types of concrete (gradient ratio)

Fig. 5 shows the ratio of the rigidity immediately after creating cracks to the rigidity after re-curing ("gradient ratio"). A gradient ratio larger than 1.0 means that the apparent rigidity becomes higher than that at the point of creating cracks owing to re-curing, suggesting a correlation with healing of the crack portion. In total, many gradient ratios exceeded 1.0, indicating that self-healing recovered the apparent rigidity.

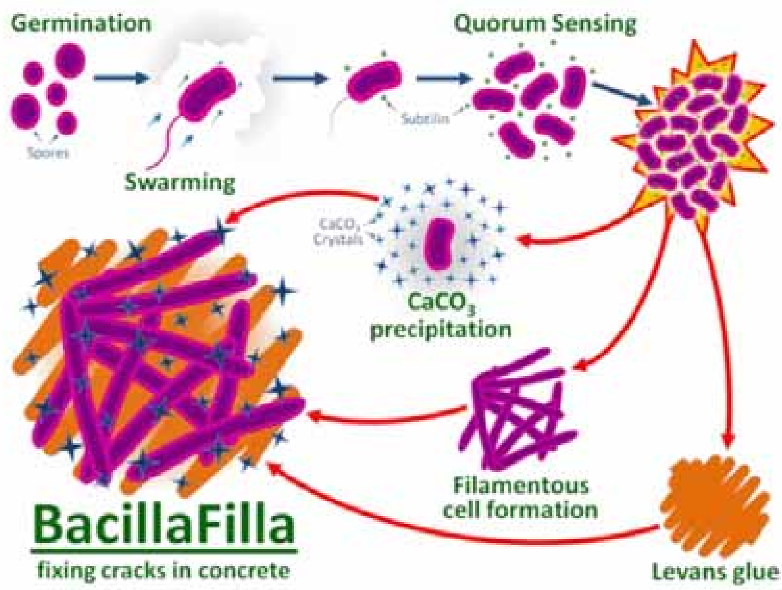


Fig. 6: Concept of self-healing of cracks by Bacilla Filla

(4) Autonomic Healing Using Bacteria

There is a study of repairing cracks on concrete using bacteria. Historically, Jonkers et al.[11)] proposed a method utilizing the deposition of calcium carbonate accompanying the metabolism of bacteria, and the effect was experimentally confirmed. In recent years, a research team of Newcastle University (U.K.) confirmed that bacteria named Bacilla Filla which were created by gene manipulation of Bacillus subtilis mainly found in soil can be used to repair the cracks in concrete structures[12)]. **Fig. 6** illustrates the concept of self-healing of cracks using bacteria.

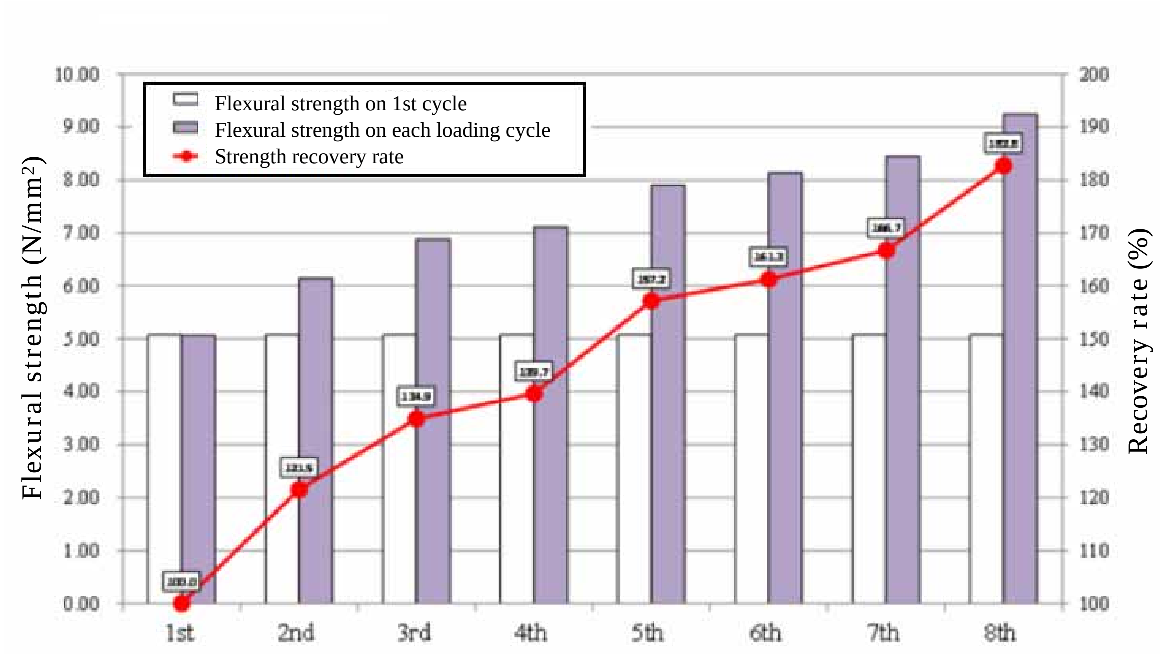


Fig. 7: Recovery rate of strength under repeated loading

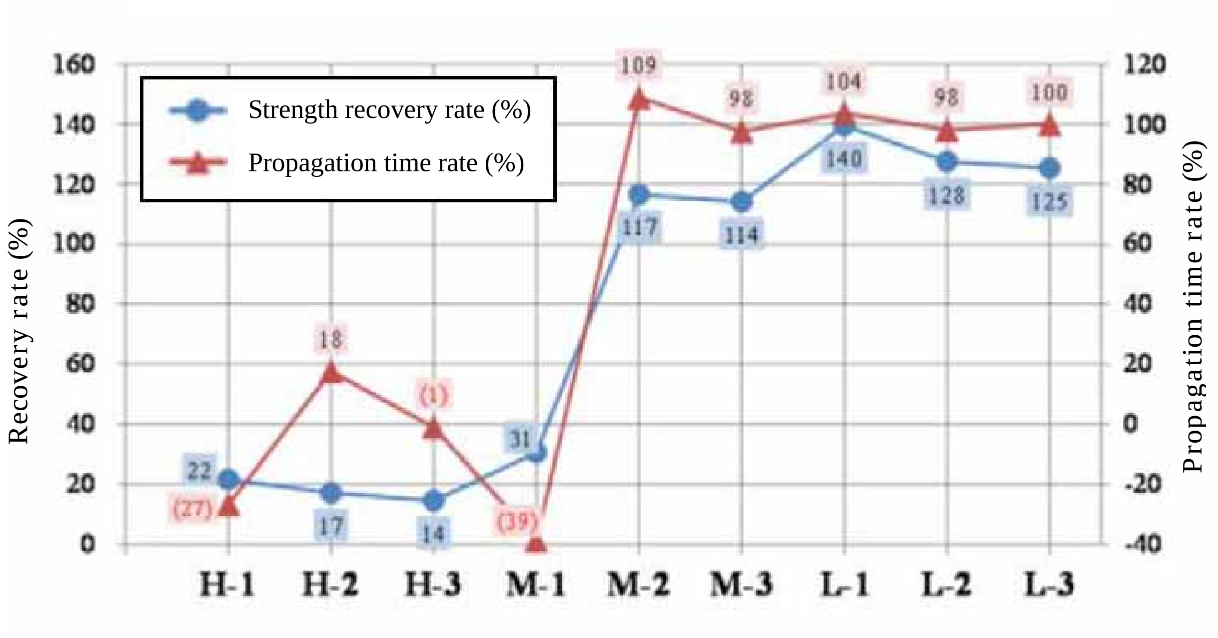


Fig. 8: Ratio of the strength recovery rate and the propagation time rate

(5) Automatic Repair of Cement-based Materials Using a Device

Kumada et al.[13] proposed a method of making pores in a concrete to communicate with external space, called the "intranetwork hollow path", and showed that filling the pores with a repair material can effect automatic repair. In case of cracks in concrete, the repair material filled in the intranetwork hollow path (pores) is released into the cracks to perform self-repair. The authors conducted an experiment using a small mortar specimen to confirm the recovery of flexural strength, and confirmed that the repair material can be held for 28 days by applying surface treatment to the intranetwork hollow path[13]. They also confirmed that the method allows repeat repairs. **Fig. 7** shows the movement of the strength recovery rate through eight repeat loadings. It shows the increased recovery of flexural strength with increased cycles[14]. In addition, an ultrasonic wave test around the crack before and after the repair was carried out to define the recovery rate of the propagation time, and the relation between the recovery rate of the propagation time and the recovery rate of the strength was confirmed. **Fig. 8** shows the recovery rate of the propagation speed and the recovery rate of the strength obtained by using three kinds of repair materials with different viscosities. Both recovery rates obviously have a close correlation with each other.

3.2 Mechanism Analysis WG

The WG developed a method of experimentally evaluating self-healing functions, and conducted a self-healing test with example cases of an ordinary Portland cement paste specimen and a fly ash-containing cement paste specimen. With small specimens, the changes in crack shape before and after the test, the recovery of strength by self-healing and the substances generated in the crack portion were observed. The test method, as a method of evaluating concrete self-healing, is presented below.

(1) Specimens for Self-healing Evaluation Test

Hardened cement paste specimens were used. The mix proportion is given in **Table 3**. Hereinafter the specimen of ordinary Portland cement is abbreviated to N, and the specimen of fly ash cement is abbreviated to N+FA. The N+FA specimen is an autonomic healing concrete[15] which is under investigation led by Northern Regional Building Research Institute.

Table 3: Mix proportion of cement paste

Sample	W/B (%)	Binder(%)	
		N	FA
N	50	100	0
N+FA		85	15

After mixing all the materials, the mixture was poured into a cylindrical mold, cured in water at 20˚C, and then at 56 days, the mixture was formed into a self-healing specimen (hereinafter referred to as the “specimen”). The specimen was in a disk shape of 50 mm diameter and 30 mm height with cracks created on the circumference. At the center of the side of the cylinder, a notch of about 5 mm depth was cut (left photograph of **Photo 3**), and the disk was compressed by inserting wedges from top and bottom using a compression machine, thus splitting it to create cracks (right photograph of **Photo 3**). The section of a crack was measured for surface roughness by a confocal microscope. The crack width was set to about 0.2 mm. To fix the crack width, a wire was placed on the side face of the crack, and then fixed by an epoxy resin.

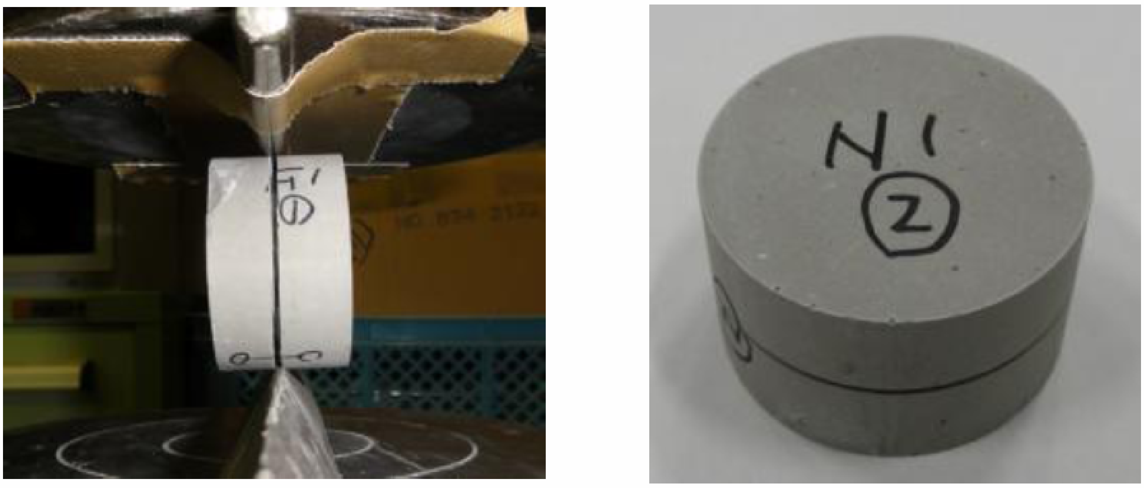


Photo 3: Preparation and appearance of the specimen

(2) Test Method and Analysis Method

a) Immersion Test

The specimen was placed in a wide-mouthed bottle, and the bottle was filled with ion-exchange water. The specimen was then cured to a prescribed age. Four specimens were placed in a single bottle, and the bottle was filled with 1000 ml of water. The curing temperature was 40˚C, and the curing period was 56 days (112 days of material age).

b) Test for the Self-healing State

Validation test of strength recovery in the self-healing portion

A tensile load was applied to the crack in the vertical direction.

Test for the shape change caused by the deposit on the crack surface

The surfaces of the crack generated by the tensile test were observed by a confocal microscope.

(3) Analysis to Grasp the Self-healing State

a) Analysis of Hydrate

The reaction rate of cement and of fly ash was determined by the XRD/Rietveld method, the selective dissolution method, and SEM. Furthermore, the hydration product formed on the interface of the cracked specimen was analyzed by XRD and SEM.

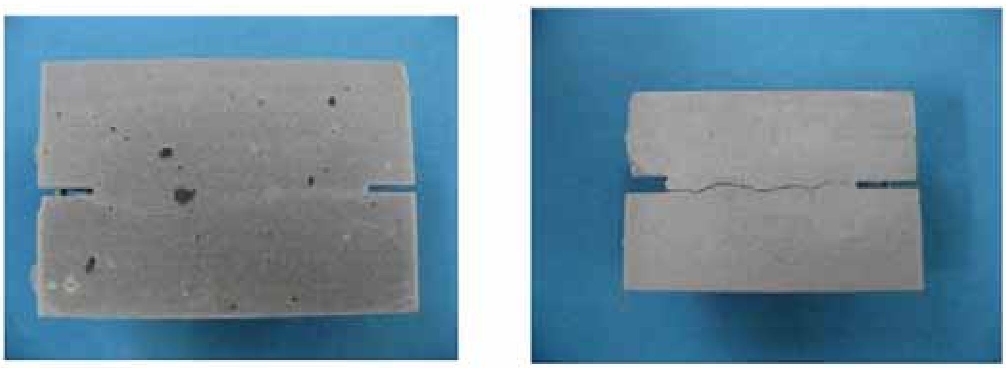
b) SEM Observation

A sample was taken from the surface fractured by the tensile test after the immersion test as a specimen for SEM examination (secondary electron image). Another sample was taken from a separate specimen, and the cross section thereof was used as a specimen for observing under a backscattered electron image.

(4) Result of Test and Analysis

a) Immersion Test

The cross section of a specimen after the immersion test is given in **Photo 4**. In photograph N, an appearance suggesting the plugging of cracks was observed.



(N) (N+FA)

Photo 4: Section of specimen after immersion test

Photo 5: Crack face after immersion test

b) Test for the Self-healing State

Result of tensile test

In the N specimen, a tensile strength of about 0.007 N/mm^2 was obtained. In the N+FA specimen, however, no adhesion between the crack faces was observed.

Result of observation of the crack face

Photo 5 shows a crack face. In the N specimen, a crystalline deposit was observed. In the N+FA specimen, however, no deposit was observed.

c) Analysis for the Self-healing State

Analysis of hydration products

Table 4: Degree of hydration

Sample	Temp. (°C)	Degree of hydration(%)			
		C_3S	C_2S	Cement	FA
N	20°C	99.2	51.6	89.6	-
	40°C	100	96.8	99.3	
N+FA	20°C	100	54.0	90.4	9.1
	40°C	100	94.5	98.2	57.9

Table 4 shows the observed reaction rate of cement and of fly ash, determined using a specimen with similar temperature history as a cracked specimen.

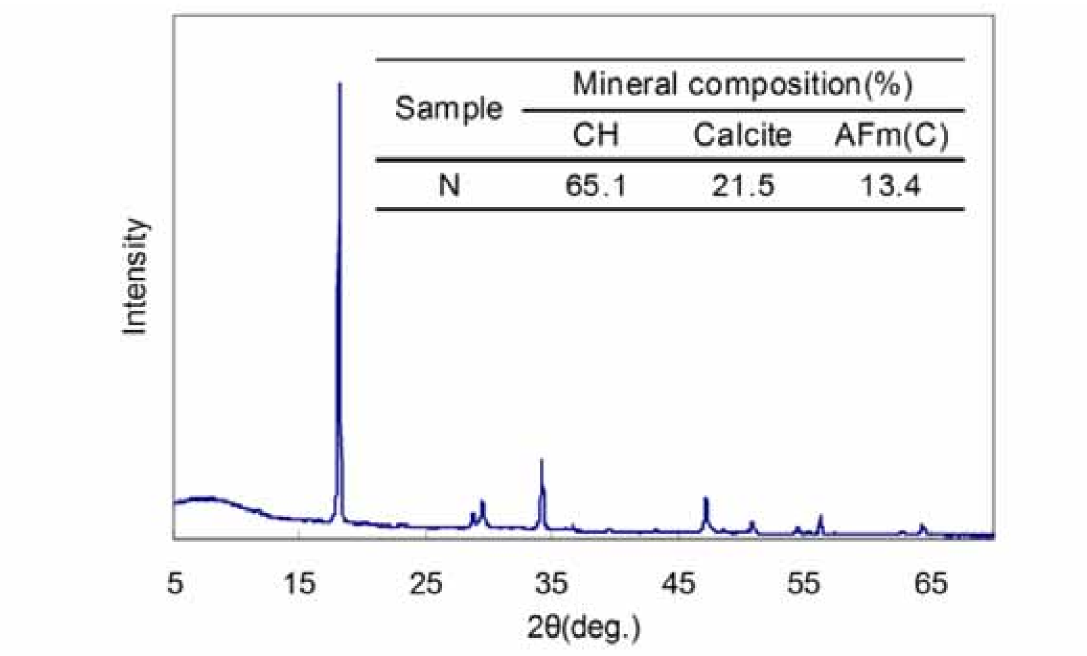


Fig. 9: XRD pattern of hydration products on the surfaces of N specimen

Also, an analysis of the hydration products at the interface of the cracked specimen was conducted using XRD and SEM. As shown in **Fig. 9**, most of the deposits were calcium hydroxide which would have been deposited again. In the N+FA specimen, no distinct deposit was observed.

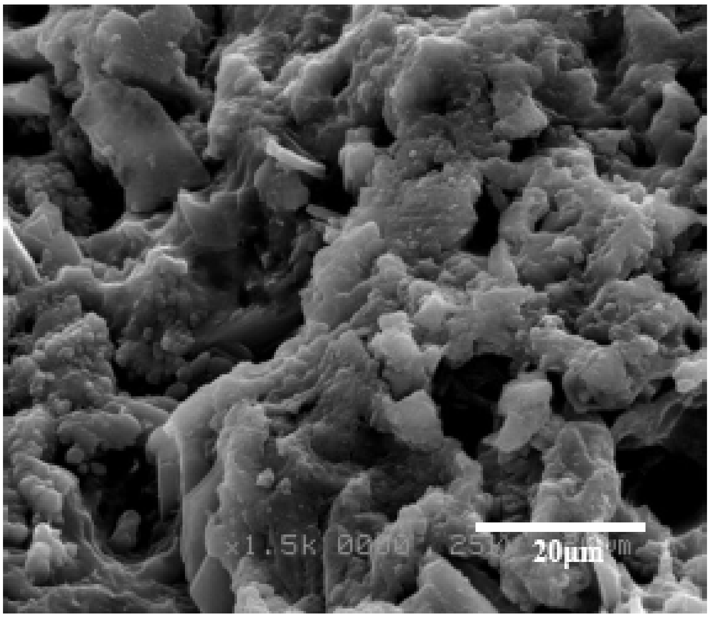


Photo 6: SEM image of N+FA specimen surface

SEM observation

Photo 6 shows an SEM image of a crack face in the N+FA specimen after an immersion test at 40˚C. The entire surface was covered with a reaction product of presumably C-S-H having several micrometers roughness. The C-S-H was presumably formed on the surface in topochemical mode. At many points on the surface, relatively large crystals of calcium hydroxide about several tens of micrometers in size were observed.

(5) Summary of Self-healing Evaluation Test

A self-healing test was conducted on a cracked cement paste specimen. On an ordinary Portland cement specimen, cracks filled with a deposit of calcium hydroxide were observed. On the other hand, on a fly ash cement specimen, although C-S-H formation was observed, the deposit did not fill the cracks. The phenomenon presumably results from the fact that the difference in solubility of calcium hydroxide from that of C-S-H within the microvoids affected the deposition of crystals which contribute to self-healing. For a detailed discussion of the phenomenon, refer to the report[2)]. The method combining multiscale images with chemical analysis and the XRD/Rietveld method, adopted by the WG, is considered to be highly effective not only for observing and analyzing the self-healing of the crack portion, but also in determining the healing mechanism.

3.3 Non / Minor-destructive testing WG

It is important to validate the self-healing (repair) characteristics of concrete in situ at the structural member. A specifically important issue is to evaluate the degree of self-healing of concrete not damaging the structure as far as possible, or by non-destructive means. However, there is insufficient information which answers the questions of “what non-destructive test method can evaluate the self-healing characteristics of concrete?” and “what is the level of self-healing that can be evaluated by existing non-destructive test methods?” The WG therefore applied various non-destructive test methods to full scale simulated concrete members provided with self-healing characteristics, exposed for about three years in Northern Regional Building Research Institute and tried to evaluate the characteristics. In winter, the exposed concrete was susceptible to damage under repeated cycles of freezing and thawing. Microcracks caused by frost attack were expected to heal autonomically.

Table 5: List of materials used

Material name	Symbol	Type, etc.	Density (g/cm^3)
Cement	C	Nittetsu Cement Co., Ltd. Ordinary Portland cement	3.16
Fine aggregate	S	Pit sand produced at Nishitappu	2.69
Coarse aggregate	G	Crushed stone (lime stone) produced at Garo	2.71
Fly ash	FA	produced at Atsuma Thermal Power Plant of Hokkaido Electric Power Co., Inc.	2.20
Water-reducing agent	Ad1	Kao Corporation Mighty 150	1.20
AE agent	Ad2	Yamaso Chemical Co., Ltd. N: Vinsol F: Yamaso	1.09

Table 6: Chemical composition of fly ash (%)

SiO_2	Al_2O_3	Fe_2O	CaO	MgO	Na_2O	K_2O	SO	TiO	MnO
66.6	18.6	3.4	1.6	1.0	0.4	1.2	0.2	0.8	0.0

(1) Outline of Full Scale Member

Table 5 lists the used materials and **Table 6** lists the chemical composition of fly ash used. Four kinds of concrete were prepared. Two kinds of self-healing concrete were prepared: F, containing fly ash without air entrainment; and FA, with air entrainment. Two kinds of ordinary concrete were prepared for reference: N, without air entrainment and NA, with air entrainment. **Table 7** shows the mix proportion of concrete.

Table 7: Mix proportion of concrete

Type of concrete	Symbol	Mass (kg/m^3)					SP	AE	W/C	S/a	W/B	SL	Air	Temp.
		W	C	S	G	FA	C*%	B*%	(%)	(%)	(%)	(cm)	(%)	(°C)
For reference (without air entrainment)	N	151	296	942	1070	—	1.3	0	51	47	—	16.5	4.0	23.0
For reference (with air entrainment)	NA	151	296	880	1038	—	1.1	0.02	51	46	—	17.5	5.5	23.0
Self-healing concrete (without air entrainment)	F	151	296	907	1049	44.4	1.3	0	51	48	44	18	2.6	20.0
Self-healing concrete (with air entrainment)	FA	151	296	823	1038	44.4	1.1	0.09	51	46	44	19	5.1	20.5

The specimen of the full scale member (**Photo 7**) was a box culvert in a square shape of 1500 mm x 1500 mm of 500 mm width and 150 mm thickness. When installing the specimen, a gradient was generated for the top face as the horizontal surface to let rainwater and melted snow flow down to the southern face wall.

Photo 7: Exposure of full scale member

Photo 8: Air permeability tester

(2) Non-destructive Test Method

The non-destructive tests adopted by the survey were the air permeability test (**Photo 8**), the surface moisture sorption test (**Photo 9**), the observation of microcracks by microscope (**Photo 10**), the impact elastic wave velocity method (iTECS method) (**Photo 11**), and the ultrasonic wave method. An example of observation by the iTECS method is given in **Fig. 10**.

(3) Future Plans

Based on the observed results, we will promote investigations on the required performance of self-healing concrete, and on adequate applications of non-destructive testing depending on the healing mechanism.

Photo 9: Surface moisture sorption

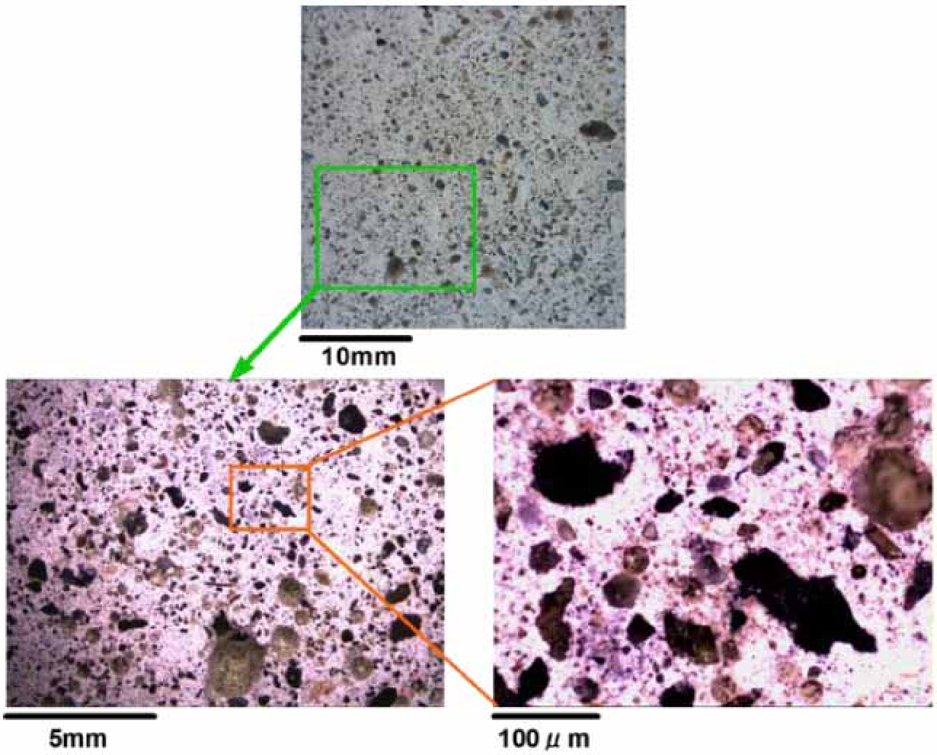


Photo 10: Microscope observation

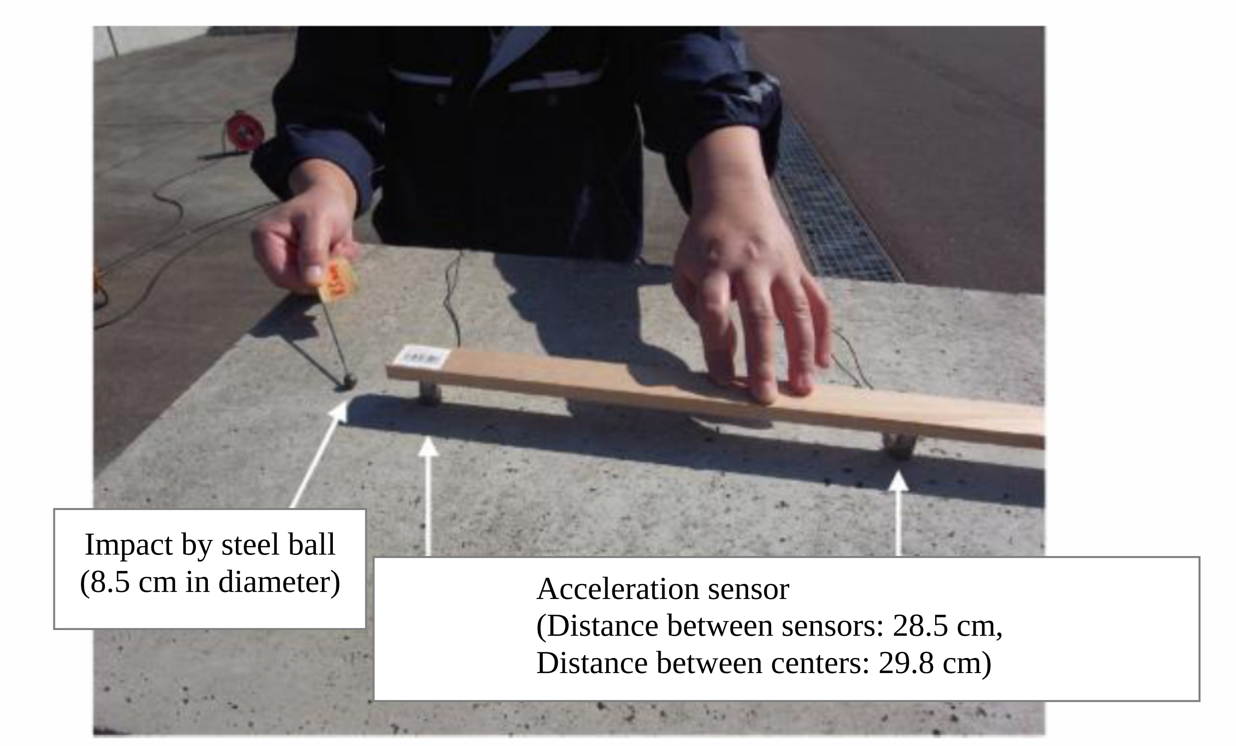
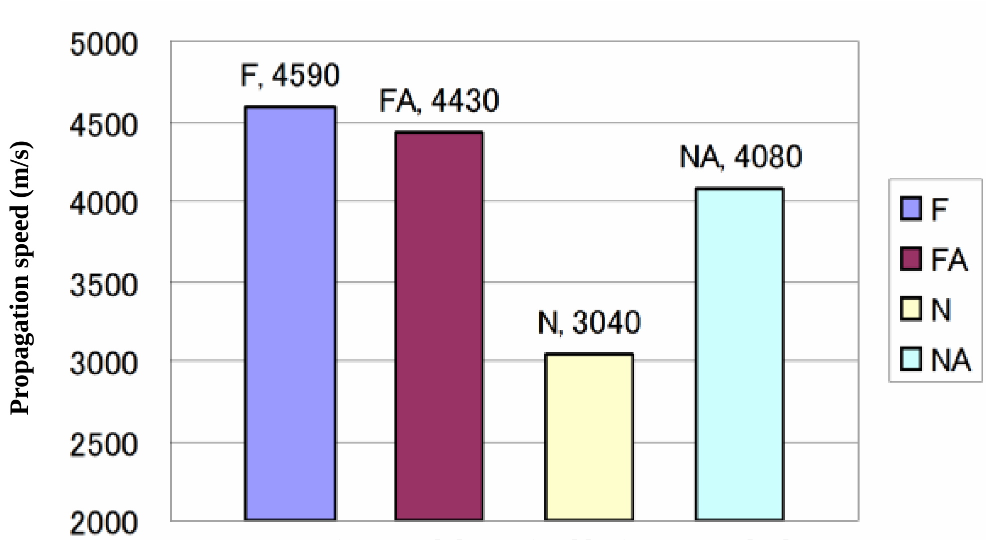


Photo 11: Impact elastic wave velocity method (iTECS method)



Propagation speed determined by iTECS method (average value)

Fig. 10: Observation by iTECS method

4. International Workshop

An international workshop "Frontline Technologies of Self-healing Concrete and Their Prospects" was held on July 8, 2010, during the 2010 Annual Congress of JCI (Saitama) (**Fig. 11**). The invited lecturers and the subjects of the lectures are given below. All the invited lecturers were internationally leading experts in the field. Professor Erik Schlangen as Chairman of the above-described TC-SHC gave a lecture on recent advances in self-healing of construction materials in Europe focusing on the activities of the RILEM Research Committee. Professor Victor C. Li gave a lecture about the ECC, a high performance fiber-reinforced cement-based material developed by the Professor, showing that this material, which tends to draw attention only to its mechanical properties, provides significant performance from the self-healing point of view. Professor Hirozo Mihashi positioned concrete as a smart material, indicated the possibilities of adding various autonomous functions, and concluded the lecture by giving the keen message “Don’t give up!”

- Prof. E. Schlangen (Technical University of Delft, The Netherlands)
  Title: Recent advances on self-healing of construction materials
- Prof. V. C. Li (University of Michigan, USA)
  Title: Self-healing in ECC
- Prof. H. Mihashi (Tohoku Institute of Technology, Japan)
  Title: Smart concrete - self-control, self-healing and self-repairing

Fig. 11: Poster of International Workshop

The number of registered participants was about 150. A total of about 200 participants including non-registered members attended the workshop, and paid keen attention to the lectures. In a question-and-answer session after each lecture, many questions were posed from floor participants. The workshop with a strong interest in the self-healing technologies of concrete, thus came to a successful conclusion.

5. Contents of the Report

The “Report of the Technical Committee on Self-healing/Repairing Technology in Cement-based Materials” [2)]issued by the Committee is a binding journal with the papers of the “Symposium of Self-healing of Cement-based Materials” held on June 9 at the Institute of Industrial Science of the University of Tokyo. An outline of the Report is as follows:

[Part 1] Committee Report

Chapter 1 Introduction

Chapter 2 Self-healing technologies for cement-based materials in the world

Chapter 3 Experimental observation of self-healing phenomena of cement-based materials

Chapter 4 Mechanism and evaluation method for self-healing phenomena of cement-based materials

Chapter 5 Non-destructive evaluation of self-healing of cement-based materials

Chapter 6 International Workshop in Saitama

<Attached document> Report of the Technical Committee on Technical Committee on Autogenous-healing in Cementitious Materials (JCI TC-075B)

[Part 2] Symposium proceedings

The symposium proceedings collect 13 papers, and introduce the latest research on self-healing technologies in Japan.

6. Conclusion

It can be said that the understanding of self-healing phenomena of cement-based materials and applying the phenomena as a repair technology have already reached the level of practical use. When observing the movement of various researches, Japanese research and technology are obviously in the front runners’ group, and have reached the nearest position to practical applications.

Research on the self-healing of cement-based materials is still active in the world, and under the current situation where maintenance and sustainability are emphasized, expectations of self-healing are becoming stronger ever. We do expect that the Report will encourage many researchers to take interest in self-healing technologies.

References

1) JCI-TC075B: Technical committee report on autogenous-healing in cementitious materials, JCI, 2009 (in Japanese).

2) JCI-TC091A: Technical committee report on self-healing/repairing technology in cement-based materials, JCI, 2011 (in Japanese).

3) Kohiyama, T., Hosoda, A., and Kurita, Y.: Investigations on control method of crack width and on evaluation method of water leakage decrease, JCI proceedings, Vol.33, No.1, pp.1439-1444, 2011 (in Japanese).

4) Shiire, T.: A few experimental investigations on prevention of decrease of water tightness of concrete due to cracking, AIJ proceedings, No.69, pp.217-220, 1961 (in Japanese).

5) Ito, H., et al., Experimental study on water permeability in concrete crack, CAJ proceedings, Vol.41, pp.217-220, 1987 (in Japanese).

6) Kurita, Y., Hosoda, A., and Kohiyama, T.: An investigation on evaluation method of performance of self healing concrete to prevent water leakage, CAJ proceedings, No.64, pp.160-161, 2010 (in Japanese).

7) Morita, S., Tobe, R., Ahn, T.H., Kishi, T.: Fundamental study on water leakage prevention with self healing constituents, JCI proceedings, Vol.32, No.1, pp.1577-1582, 2010 (in Japanese).

8) Ahn, T. H. and Kishi, T.: Crack self-healing behavior of cementitious composites incorporating various mineral admixture, Journal of Advanced Concrete Technology, Vol.8, No.2, pp.171-186, 2010

9) Sato, Y., Otabe, Y., and Okamoto, H.: Fundamental investigations on self healing mechanism of crack, Concrete Techno, Vol.29, No.9, pp.52-57, 2010 (in Japanese).

10) Higuchi, T., Eguchi, M., Yoshida, H., and Hosoda, A.: Mechanism of natural self healing of crack in utility concrete pole, JCI proceeding, Vol.33, No.1, pp.1415-1420, 2011 (in Japanese).

11) Jonkers, H. M.: Self-healing concrete: A biological approach, Self-healing materials, alternative approach to 20 centuries of materials science, (Ed. Sybrand van der Zwaag), Springer Series in MATERIALS SCIENCE, pp.195-204, 2007

12) http://2010.igem.org/Team:Newcastle

13) Kumada, H., Pareek, S.: A fundamental study on self-repair function for flexural strength of mortar specimens by network systems, JCI proceeding, Vol.32, No.1, pp.11871-1876, 2010 (in Japanese).

14) Kumada, H., Ohira, A. and Pareek, S.: Self-repair performance of cracks by network in self-repair system, JCI proceeding, Vol.33, No.1, pp.1445-1450, 2011 (in Japanese).

15) Fujiwara, Y., Hama, Y., Yamashiro, Y. and Saito, T.: Effect of self-healing of mortar using fly ash, JCI proceeding, Vol.29, No.1, pp.303-308, 2007 (in Japanese).