Development of material technologies for infrastructure maintenance and lifetime extension

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Overview of "Structural materials, deterioration mechanisms, repair and reinforcement technologies"

Research that is being done under this topic relates to extending the lifetime of infrastructure, developing new materials that can contribute to reducing life-cycle costs (LCC), and elucidation of deterioration mechanisms. The National Institute of Advanced Industrial Science and Technology has developed a stress-luminescent material that can be painted onto the surfaces of structures for effective detection of deterioration by cracking, corrosion, etc. Osaka Prefecture University has developed a thermal spraying alloy for corrosion in dents and small end faces, etc. of steel bridges. Development projects at Okayama University include precast floor slabs using highly durable blast furnace slag (BFS) concrete, which has outstanding chloride ion permeation resistance and freezing damage resistance, and is also highly resistant to ASR. Our research team, which consists of the National Institute for Materials Science (NIMS), Kyoto University, and Tokyo Institute of Technology, is investigating the mechanisms of structural deterioration due to salt damage and conducting R&D on damage detection technologies and long-life materials.

Developing a research base on structural materials for infrastructure

A cluster on structural materials for infrastructure has been established at NIMS as a base for research involving collaboration across different fields and different industries.(1) At present, about 40 organizations are participating and providing cooperation in proving tests, and we also offer human resource development activities such as a summer school. The goal is to develop a base for creating long-life material solutions and conducting advanced basic research on structural materials for infrastructure after the end of SIP.

Studying the structural deterioration mechanisms of infrastructure

Salt damage is the most common cause of deterioration in reinforced concrete structures in Japan. To elucidate its mechanism in greater detail, corrosive environment sensors and internal environment sensing technologies are being developed in order to understand the environment where structures are installed and the internal environment of concrete. In addition, it is necessary to clarify how corrosion products such as Fe_3O_4, α-FeOOH, and γ-FeOOH are produced in various environments. Therefore, in addition to performing nanoscale analysis of the morphology and mechanical properties of these products, we have developed a testing method that accelerates rebar corrosion by using a hyperbaric oxygen chamber to increase the supply of oxygen into concrete, focusing on oxygen as a factor that accelerates corrosion.

Development of repair materials, long-life materials, and technologies to detect structural damage due to deterioration

In the future, it will be important to introduce labor-saving technologies and technologies for maintenance by non-experts such as local residents. To make it easy to detect corrosion cracks from a distance, a strain visualization sheet has been developed.(2) The phenomenon of iridescence, or structural color, is used to visualize cracks as changes in color when the sheet is adhered to a structure. In addition, a nondestructive inspection technology that uses electromagnetic waves to determine the degree of rebar corrosion is being developed.

Corrosion-resistant rebar steel has been developed as material that makes it possible to extend the lifetime of reinforced concrete structures.(3) The addition of chromium and silicon has the effect of densifying the corrosion product layers and blocking the transmission of chloride ions. In an exposure test on Miyakojima island, this material showed outstanding corrosion resistance (Fig. 1). In addition, an adhesive biomimetic polymeric surface impregnating material (4) is being developed as a repair material, as well as a cement-based repair material (5) that has chloride fixing capability and crack resistance.

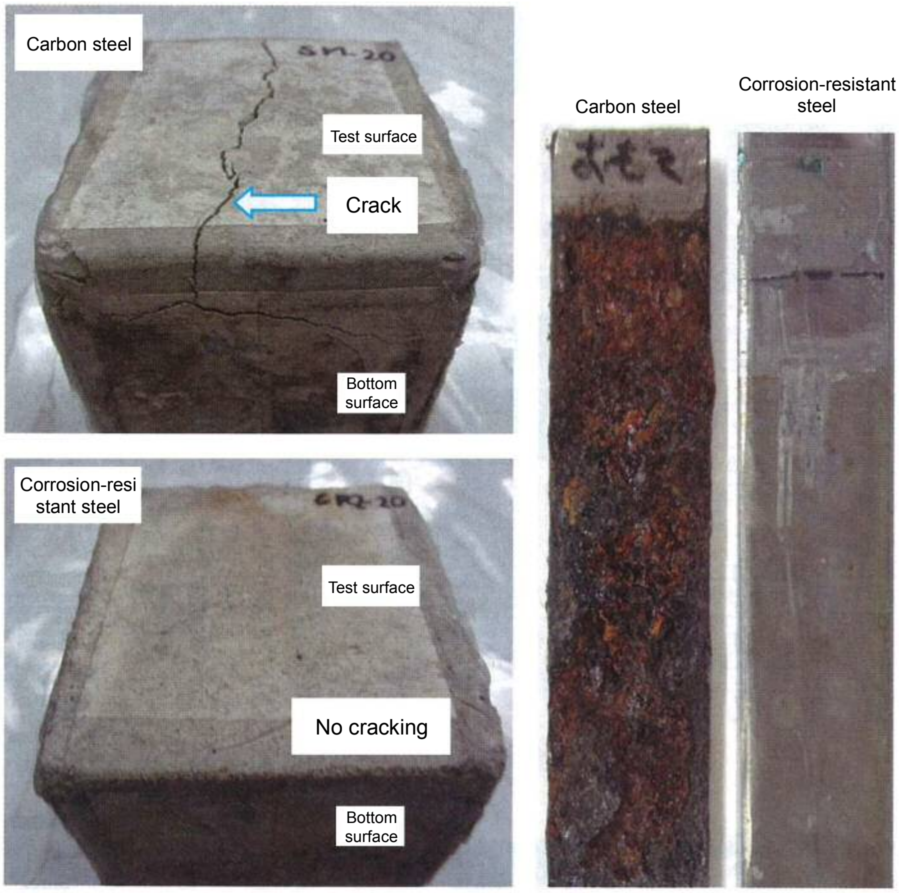

Fig. 1. The results of exposure testing of concrete specimens with corrosion-resistant rebar at Miyakojima for two years. Corrosion cracking occurred in the concrete that contained ordinary carbon steel, but no cracking was observed in the concrete that contained corrosion-resistant rebar.

Development of technologies to improve maintenance efficiency

For reinforced concrete beam and pillar members subject to chloride ion induced corrosion, we are studying a method to evaluate load bearing capacity in terms of primary screening based on corrosion and cracking information obtained from close visual inspection. The width of corrosion cracks is affected by corrosive environments in addition to the rebar arrangement and cover thickness. With consideration for fluctuation in corrosion due to such factors, the amount of rebar corrosion is estimated based on the width of corrosion cracks, and this is used to obtain a rough estimate of load bearing performance. This method is less dependent on the skill of an engineer because it provides easier quantification of the amount of corrosion than grading methods where the performance of a structure is judged from apparent deterioration or damage, which tend to depend on the engineer's experience. The goal is for this to be included as one method for inspection and performance evaluation of reinforced concrete structures with corrosion in the maintenance section of the Standard Specification for Concrete Structures, which is to be revised in FY 2018.

Also, for more efficient maintenance of reinforced concrete slabs, AE tomography [(6), (7)] is developed to evaluate internal fatigue damage, which cannot be confirmed based on the external appearance; and this is used in determining if it is necessarily repaired or not, and moreover to decide the area of repair. In the AE tomography method, the elastic waves generated from existing cracks induced by traffic loads is measured, and the distribution of elastic wave velocity inside the slab is estimated (Fig. 2). The final goal of this method is to automate the damage evaluation and incorporating this into the flow of maintenance programs. Accordingly, the index for decision-making methods that do not require highly experienced engineers would be proposed, yielding the standard for nondestructive evaluation method of road slab damage, which potentially assess the remaining life.

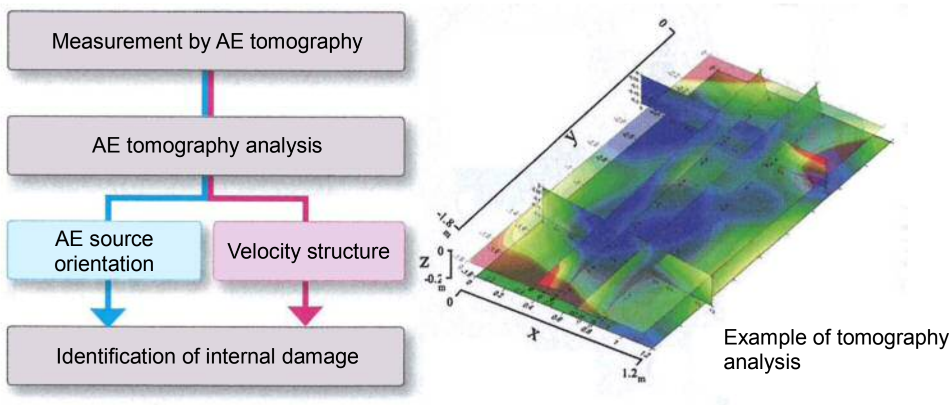

Fig. 2. Example of internal damage evaluation in reinforced concrete slabs using AE tomography

References

(1) http://www.nims.go.jp/KO-ZO/about-topas/dkud7m00000013ad.html

(2) Fudouzi. H., Tsuchiya, K., Todoroki, S., Hyakutake, T., Nitta, H., Nishizaki, I., Tanaka, Y., Ohya, T. : Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2017, ed. Jerome P. Lynch, Proc. of SPIE Vol. 10168, 1016820., 2017.

(3) Nishimura, T. : Proceedings of East Asia Structural Engineering and Construction (EASEC14), pp. 261-265, 2016.

(4) Payra, D., Fujii, Y., Das, S., Takaishi, J., and Naito, M. : Polymer Chemistry, 8, pp. 1654-1663, 2017.

(5) Shinsugi, T., Arata, O., Higuchi, T., and Sakai, E.: Collected papers on cement and concrete, Vol. 70, pp. 162-168, 2017.

(6) Shiotani, T., Okude, N., Momoki, S., and Kobayashi, Y.: Proposal of damage evaluation technique for infrastructures by means of AE tomography, Proceedings of the 18th National Conference on Acoustic Emission, Japanese Society for Non-Destructive Inspection, pp. 39-42, 2011. (in Japanese)

(7) Kobayashi, Y., Shiotani, T. : Computerized AE Tomography Innovative AE and NDT Techniques for On-Site Measurement of Concrete and Masonry Structures, Springer, pp. 47-68, 2016.