Committee Report: JCI- TC121A

Technical Committee on the use of sea water in concrete

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Abstract

The Committee has collected information on the use of seawater, such as for mixing and curing concrete, investigated problems and remedies via experiments and reference studies, and surveyed technologies for using seawater for manufacture and curing of concrete by interviews and literature searches. Based on the results, issues surrounding the use of seawater and its possibilities are proposed.

Keywords: Effective use of seawater, mixing water, curing water, case study, property evaluation, performance improvement, production and construction methods

1. Introduction

Effective use of resources is a pressing concern. Particularly, water resources for drinking are predicted to be in serious shortage in 2050 due to increases in population and rapid urbanization throughout the world. In the field of concrete, billions of tons of freshwater is consumed annually for mixing, curing and washing concrete. Seawater, which exists in abundance on the globe, is presently not permitted to be used for these purposes. Active use of seawater in the field would help more effective use of freshwater resources.

The Committee aims to: 1) collect information on use of seawater, such as for mixing and curing concrete, and investigate problems and remedies via experiments and reference studies, 2) survey technologies for using seawater in manufacture and curing of concrete by interviews and literature searches, and 3) summarize and investigate the results, and propose various possibilities, etc., for effective use of seawater.

To achieve these goals, five working groups were formed under the Committee: Survey WG (WG1), Evaluation WG (WG2), Performance Improvement WG (WG3), Construction WG (WG4), and English Culture WG (WG5). The activities of the working groups were comprehensively summarized in general meetings. The members of the Committee are shown in **Table 1**, and the activities of each WG are described below.

Table 1: Committee Members

Chairman	Nobuaki OTSUKI	Tokyo Tech.
Vice chair	Hidenori HAMADA	Kyushu Univ.
Secretaries	Toru YAMAJI	Port and Airport Research Institute
	Nobufumi TAKEDA	Obayashi Corp.
	Takashi HABUCHI	Toa Corp.
	Kei-ichi IMAMOTO	Tokyo Univ. of Science
	Takahiro NISHIDA	Tokyo Tech.
WG1: Case studies on existing structures constructed with concrete mixed with sea water /sea sand		
Chief	Hidenori HAMADA	Kyushu Univ.
Members	Nobuaki OTSUKI	Tokyo Tech.
	Kei-ichi IMAMOTO	Tokyo Univ. of Science
	Takahiro NISHIDA	Tokyo Tech.
	Tatsumi OHTA	Shimizu Corp.
	Keisaburo KATANO	Obayashi Corp.
	Kazuya KOGA	Fukuoka Univ.
	Tsuyoshi SAITO	Niigata Univ.
	Takumi SAWADA	Penta-Ocean Construction Co.,Ltd.
	Masashi FUNABASHI	Maeda Corp.
	Yasuhiro DAN	Nippon Steel & Sumitomo Metal Blast-Furnace Slag Cement Co.,Ltd.
WG2: Evaluation of the material properties of concrete using sea water as mixing and/or curing water		
Chief	Toru YAMAJI	Port and Airport Research Institute
Members	Nobuaki OTSUKI	Tokyo Tech.
	Nobufumi TAKEDA	Obayashi Corp.
	Takahiro NISHIDA	Tokyo Tech.
	Yoshikazu AKIRA	Toyo Construction Co.,Ltd
	Yoshitaka ISHIKAWA	Electric Power Development Co., Ltd.
	Tsuyoshi SAITO	Niigata Univ.
	Yasuhiro DAN	Nippon Steel & Sumitomo Metal Blast-Furnace Slag Cement Co.,Ltd.
	Yusuke BABA	BASF Japan Ltd.
WG3: Investigations of durability and reinforcement of concrete mixed with seawater		
Chief	Nobufumi TAKEDA	Obayashi Corp.
Members	Nobuaki OTSUKI	Tokyo Tech.
	Takahiro NISHIDA	Tokyo Tech.
	Yasuhiro DAN	Nippon Steel & Sumitomo Metal Blast-Furnace Slag Cement Co.,Ltd.
	Kazuto FUKUDOME	Ishikawa National College of Technology
	Eiji MATSUO	Kyushu Sangyo Univ.
	Yutaka TADOKORO	Nippon Steel & Sumikin Stainless Steel Corp.

WG4: Investigation on the production and construction methods of concrete mixed with seawater		
Chief	Takashi HABUCHI	Toa Corp.
Members	Nobuaki OTSUKI	Tokyo Tech.
	Takahiro NISHIDA	Tokyo Tech.
	Tadatsugu KAGE	National Institute for Land and Infrastructure Management
	Keisaburo KATANO	Obayashi Corp.
	Kazuto FUKUDOME	Ishikawa National College of Technology
	Hiroshi MINAGAWA	Tohoku Univ.
	Hiroshi WATANABE	Public Works Research Institute
Translation WG: Translation of research report to english		
Chief	Nobuaki OTSUKI	Tokyo Tech.
Members	Takahiro NISHIDA	Tokyo Tech.
	Takumi SAWADA	Penta-Ocean Construction Co.,Ltd.
	Tsuyoshi SAITO	Niigata Univ.
	Yusuke BABA	BASF Japan Ltd.
	Yoshikazu AKIRA	Toyo Construction Co.,Ltd
	Keisaburo KATANO	Obayashi Corp.
Domestic correspondent Members		
	Yasutaka SAGAWA	Kyushu Univ.
	Yutaka TADOKORO	Nippon Steel & Sumikin Stainless Steel Corp.
	Hiroshi MATSUDA	Nagasaki Univ.
	Toshinobu YAMAGUCHI	Kagoshima Univ.
	Yoshitomo YAMADA	Ryukyu Univ.
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	Ronaldo S. Gallardo	Philippines
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	Muhammad Wihardi Tjaronge	Indonesia
	Nurazuwa Binti Md Noor	Malaysia
	Hwa Kian Chai	Malaysia
	Miren Etxeberria	Spain
	Kamran M. Nemati	U.S.A.
	Yutaka TADOKORO	Nippon Steel & Sumikin Stainless Steel Corp.

WG1 surveyed examples of concrete structures mixed with seawater or/and unwashed sea sand (structure investigation, literature search). WG2 evaluated the physical properties of concrete mixed and/or cured with seawater via experiments and literature searches. WG 3 investigated the effects of seawater on performance improvement of concrete, and anticorrosion measures for reinforcing materials by studying references. Based on the results, WG4 investigated manufacturing and casting methods for concrete mixed with seawater, and their advantages and cautions. The results of the four working groups were comprehensively studied, the problems of using seawater in concrete and committee reports were summarized, and various proposals were made regarding the possibilities of using seawater. WG5 translated the committee reports into English.

2. Survey on examples of concrete mixed with seawater and unwashed sea sand

In this section, findings from case studies (investigation, literature search) of concrete structures mixed with seawater and unwashed sea sand are summarized.

2.1 Overview of the survey

Today, it is deemed taboo to mix concrete with seawater, but in the past many structures were built by mixing seawater in areas where it was geographically difficult to acquire freshwater. Some of the structures are still sound and in service, which is very promising. On the other hand, there are also structures and buildings that have suffered serious salt damage because unwashed sea sand was carelessly used, suggesting the need of using technically correct methods. Aiming to collect information and learn lessons from the viewpoint of using seawater, the working group surveyed existing structures, literature, standards, and cases in oversea countries under the following three items:

(1) Survey of examples (good and bad examples, and examples in overseas countries),
(2) Surveys of standards (specifications in the past, and in overseas countries), and
(3) Views in the past on using seawater.

In (1), the group surveyed, as examples built with concrete mixed with seawater or unwashed sea sand, Ukujima lighthouse (Nagasaki Prefecture, **Fig. 1**), foot protection concrete for exposed rocks on Okinotorishima Island, pre-packed concrete harbor structure mixed with seawater, pre-packed concrete structure mixed with sea water in Tajiri Port (Tottori Prefecture, **Fig. 2**), concrete structures and concrete shore protection on Gunkanjima Island (also known as Hashima Island, Nagasaki Prefecture), concrete structures in Okinawa Prefecture that were built by mixing unwashed sea sand, and concrete mixed with seawater manufactured during WWII on Bikini Atoll by studying literature or/and examining the actual structures. In (2), past standards related to civil engineering, building standards and overseas standards were surveyed on use of seawater as well as technologies for using Cl^- in concrete manufacture. In (3), views were surveyed on a lighthouse built from concrete mixed with seawater, the opinion of Dr. Neville on concrete mixed with seawater, the opinion of Dr. Yuzo Akatsuka on concrete mixed with sea water, and general views toward concrete mixed with seawater in and outside Japan.

Fig. 1: Ukushima lighthouse (Nagasaki prefecture)
-Concrete structure mixed with seawater-

Fig. 2: Tajiri port (Tottori prefecture)
-Pre-packed Concrete structure mixed with seawater-

2.2 Results of examination of actual structures

The lighthouse, which was built 60 or more years ago from concrete mixed with seawater, was found to have no abnormality on the concrete surface and was in sound condition (**Fig. 1**).

The construction records for Okinotorishima Island showed that no special materials or measures were needed for using seawater to mix concrete to be used for underwater structures, and that the use of seawater did not affect the performance of the special underwater concrete (strength and workability). Seawater caused no problem in strength development or setting time of the concrete, and no loss of flowability was observed.

The manufacture of pre-packed concrete structures by using seawater did not cause any abnormality in the casting process or the concrete after completion. Moreover, no condition was found in which clean seawater was particularly defective compared to freshwater. On the other hand, it was found that seawater reduced the setting time of grouting mortal and increased the expansion coefficient compared to freshwater, suggesting the need of noting these points in controlling grouting work.

For the structures on Gunkanjima Island, no conclusive evidence was found, but possibilities were suggested that seawater was used for mixing the concrete. Although the concrete contained a large amount of chloride ion, there were sections where reinforcements were little corroded, suggesting room for investigating the relationship between salt content and corrosion. The survey of the concrete shore protection on the island did not reveal conclusive evidence, but suggested that seawater may have been used to mix the concrete. There are few concrete shore protection works other than the one on Gunkanjima Island in Japan that have been used under severe conditions of open sea for such a long period of time. The main damage to protection works were cracks in concrete, forward inclination of the bank, space between the damaged bank and bed rock, and settlement and suction of the sediment behind the bank, which were not attributable to deterioration of the concrete.

The survey of buildings that suffered salt damage due to use of unwashed sea sand on Okinawa Island revealed that, for those with unwashed or insufficiently washed sea sand, parts of relatively shallow cover depth suffered cracks accompanying corrosion of steel and/or exfoliation of the concrete cover. However, the relationship between steel corrosion and the conditions of mix proportion, such as water cement ratio, were not clear.

A survey of the concrete manufactured during WWII on Bikini Atoll showed that the concrete, which was mixed with seawater and contained coral aggregates, manifested strength over a long time as long as the mix proportion was appropriate. On the other hand, the external environment, concrete cover depth, and cracks on the surface contributed significantly to early deterioration. The findings suggest that concrete mixed with seawater that is durable over a long time can be prepared by correctly understanding the environmental action to take, using appropriate materials and casting appropriately.

2.3 Results of the survey of standards

In the Standard Specifications for Concrete Structures of the Japan Society of Civil Engineering, it is a principle not to use seawater for mixing reinforced concrete. However, the statements on winter concreting and their revisions suggested the possibility of mixing concrete with sea water for plain concrete of specific quality.

In the architectural field (JASS5), the first regulation on salt appeared in 1933, which banned the use of seawater. This regulation has led to the salt content limits in fine aggregates, and limits on the total amount of salt in concrete. In general, salt regulations seem to be stricter in architectural standards than in civil engineering standards. This is probably because most buildings have a shallower cover depth and a larger water cement ratio than civil engineering structures.

A survey of overseas standards on chlorides revealed that the regulation value varies greatly by country. Some countries impose restrictions on chloride content even for plain concrete. Concrete mixed with seawater contains about 3kg of chloride ions per cubic meter of concrete. This value exceeds the regulation values of all countries. Therefore, it seems necessary to make adjustments to the regulation values in order to use concrete mixed with sea water for reinforced concrete.

2.4 Results of the survey on existing information about using seawater

Many lighthouses on isolated islands have been constructed from concrete mixed with seawater. From existing structures, the following knowledge was acquired and lessons learnt:

- Many such lighthouses have suffered almost no deterioration over decades. There is no inconvenience in using seawater for mixing plain concrete.
- The amount of cement needs to be increased to make solid concrete.
- Some reinforced concrete mixed with seawater has been sufficiently durable, while some others were destroyed. Possible factors are insufficient cover depth, poor mix proportion, and defective casting. There is no reason to prohibit the use of seawater if sufficient considerations are taken into account, such as using a rich mix proportion to increase water tightness, ensuring sufficient cover depth, and carefully casting the concrete.

・ Curing concrete by removing the form late and spraying seawater does not have any specially harmful effect as long as a good mix proportion is used and the concrete is well cast.

At the time when most of these lighthouses were constructed, it was common to use Portland cement. However, because mixed cement was already recognized to be appropriate for seaside structures, many of the lighthouses were built using Portland blast-furnace cement.

The opinions of Dr. Neville and Dr, Akatsuka on concrete mixed with seawater were reconfirmed. The basic idea of Dr. Neville is to not mix concrete with seawater, with two exceptions. The two exceptions are 1) concrete in perfectly dry condition throughout its service period, and 2) concrete placed in the sea or completely immersed in seawater. Dr. Neville mentioned that concrete can be mixed with seawater only in such cases. In the last, he stated that the prohibition does not apply to plain concrete. On the other hand, the opinion of Dr. Akatsuka is as follows. He does not recommend to mix concrete with seawater, but mentioned that there is no reason to absolutely ban its use. According to him, considerable cautions and measures are needed such as designing and casting concrete so as to have sufficient cover depth, an especially water-tight mix proportion, and sufficiently compacting the concrete during casting. He mentioned that it is practically wiser to undertake careful construction by noting the aforementioned points than paying a huge sum for transporting freshwater.

2.5 Summary of the surveys

The results of the surveys are summarized below. Although it is deemed taboo to use seawater for concrete manufacture today, past experience shows that seawater can be used to construct concrete structures with no performance deficiency. However, it is crucial to use correct manufacturing technologies, and technologies for using seawater should be systemized by fully organizing the experience and knowledge acquired in the past. Establishment of guidelines is also awaited.

3. Physical properties of concrete mixed with seawater and/or cured with sea water

In this section, existing information on the properties of concrete mixed with seawater and/or cured with seawater is summarized.

3.1 Effects of seawater on the hydration reaction mechanism of cement

The reaction mechanisms of ordinary Portland cement (OPC), blast furnace slag (BFS) and fly ash (FA) in concrete mixed with seawater were studied by investigating the time-historical changes in the reaction rate of each constituent mineral, and the time-historical changes in the phase constitution of the hydration product. The following new knowledge was obtained.

1) The experimentally determined reaction ratio of each clinker[1)] is shown in **Fig. 3** for concrete mixed with seawater. Compared to distilled water, seawater accelerated the reaction of the silicate (mainly C_3S) phases in the early stages, and stagnated the reaction in the late stages. The reaction between interstitial phases, i.e. C_3A and C_4AF, was more apparently affected by seawater than the reaction between the silicate phases of C_3S and C_2S from the early stages, and the stagnation in the late stages was also more apparent.

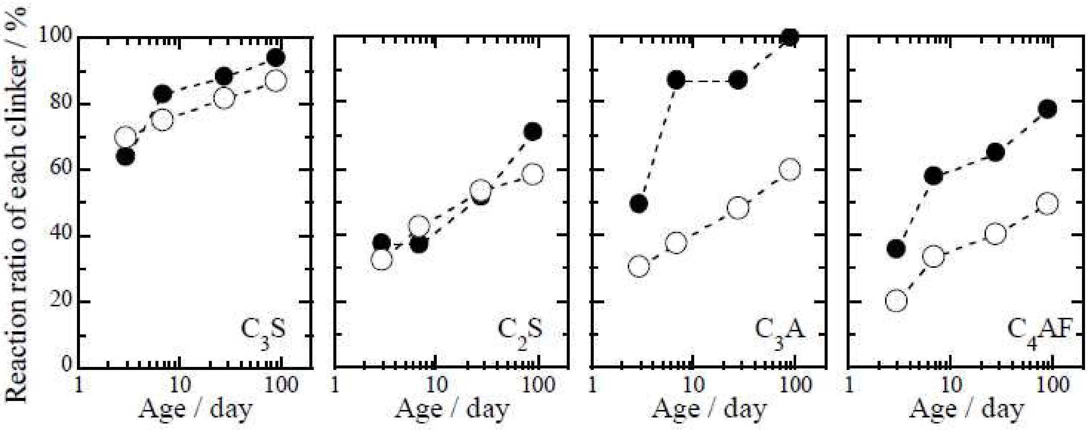

Fig. 3: Reaction ratio of each clinker in OPC paste specimens. ●: DW, ○: SW [1)]

2) Experimentally determined changes in phase constitution[1)] are shown in **Fig. 4**. In the specimen mixed with distilled water, ettringite was converted into monosulfate as it aged. On the other hand, in the specimen mixed with seawater, the generation of ettringite and monosulfate was small, and Friedel's salt was generated most.

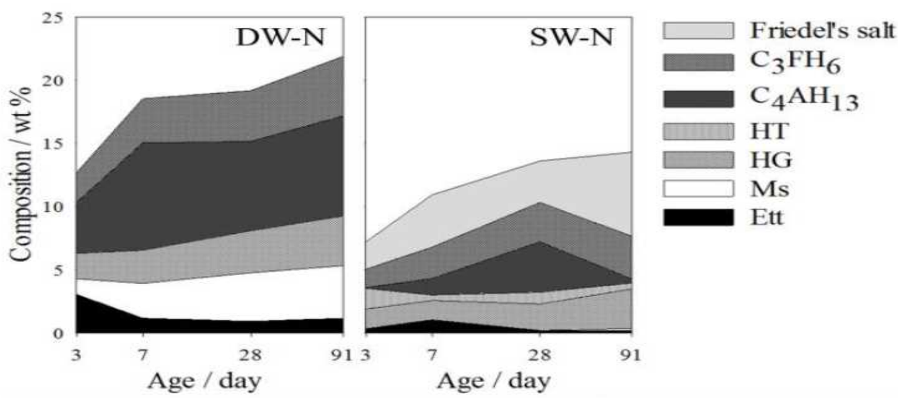

Fig. 4: Phase constitutions of Alumina-Ferrite hydrates in OPC paste specimens. [1)]

3) The reaction ratios of clinkers, phase constitutions, pore structures, and their relationships in concrete with admixture showed similar trends to those in concrete formed only with Portland cement[1)]. However, the reaction ratio between interstitial phases of BFS, particularly C_3A, increased by seawater more notably than in concrete formed only with Portland cement. The increase was more apparent as the substitution rate was larger. This effect of seawater on FA was smaller compared to BFS, but increases in reaction ratio were also observed.

3.2 Physical properties of concrete mixed with seawater

Information was collected and summarized on the following physical properties of concrete mixed with seawater:

(1) Fresh properties

The majority of reports mention that seawater reduced or did not affect flowability from freshwater. Seawater lowered dispersibility in concrete that contained certain kinds of admixture due to effects of inorganic ions in the seawater.

(2) Curing characteristics

Most reports mention that seawater accelerated the development of strength in the early stages, and stagnated strength development in late stages.

3.3 Properties of concrete mixed with seawater and containing a mixture(s)

Information was collected and summarized on the physical properties of concrete formed by adding a mixture(s), and mixing with seawater.

(1) Blast furnace slag micropowder

In fresh concrete, the effects of seawater were small. As in OPC, seawater stimulated strength development in early stages. Compared to tap water, seawater also increased strength development in late stages.

(2) Fly ash

Many references in the literature show that seawater constituents possess the cure acceleration action of fly ash. The action was larger as the substitution rate by fly ash increased. It has been confirmed that NaCl in seawater is mainly responsible.

3.4 Properties of concrete cured with seawater

There is little information, and the properties are not well understood. However, there have been no reports mentioning notable adverse effects.

3.5 Summary

On physical properties of concrete mixed with seawater, many reports mention that seawater stimulated strength development in early stages, and stagnated development in late stages. In this section, the effects of seawater on the hydration reaction mechanism of cement, and the time-historical changes in the reaction ratio of each clinker and phase constitution of hydration products, were investigated and summarized.

4. Durability of concrete mixed with seawater

Information was collected on the durability of concrete mixed with seawater, and is summarized in this section.

4.1 Salt damage

(1) Movement of chloride ions

Most of the literature mentions that seawater does not much affect the movement of chloride ions. Effects of seawater on fixation of chloride ions were not clear. One of the results is shown in **Fig. 5**. No significant difference was observed in the chloride fixing characteristic between the two. It is likely that the effect of mixing water on long-term fixation of chloride ions is small.

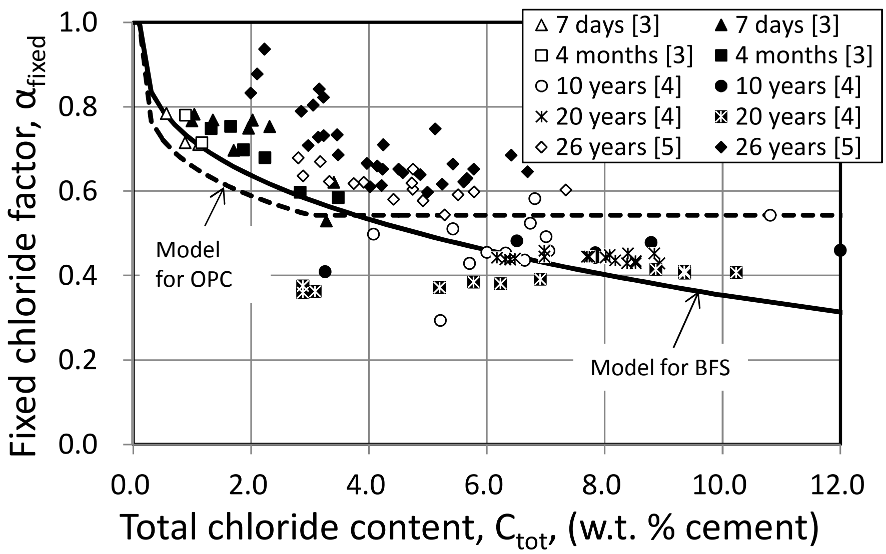

Fig. 5: Relationship between Fix chloride factor and total chloride content in seawater mixed concrete exposed for 10 and 20 years

(2) Steel corrosion

Seawater is likely to accelerate corrosion of steel when used to mix concrete for structures on land and at sea (excluding those under water) compared to tap water. The degree of acceleration varies depending on the quality of concrete and environment. On the other hand, in an environment where oxygen supply is small, such as in the sea, steel corrosion proceeds very slowly, and it has been confirmed that mixing concrete with seawater has almost no effect. **Figure 6** shows the effects of seawater in concrete specimens exposed to a tidal environment (but the specimens were almost always wet) [2]. Even in concrete mixed with seawater, steels suffered almost no corrosion.

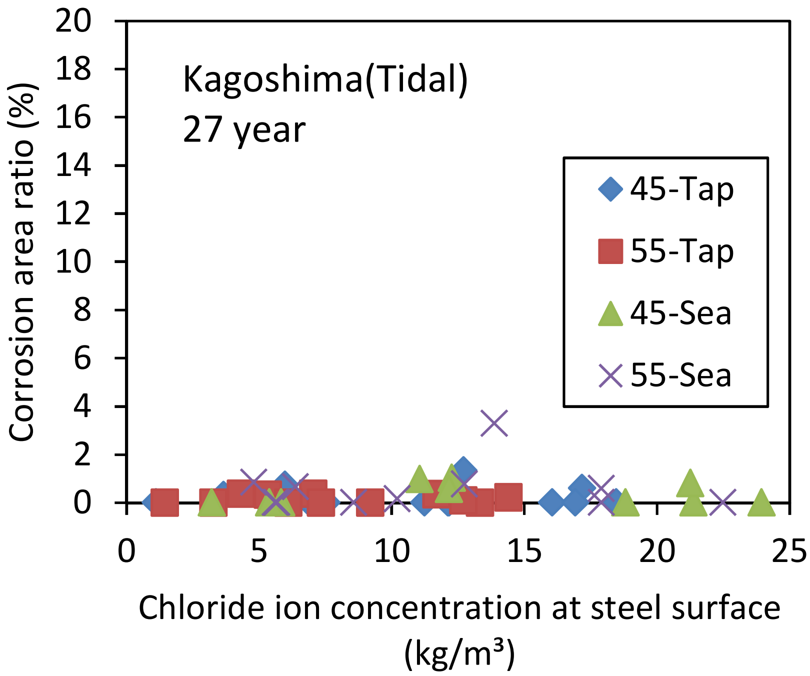

Fig. 6: Relationship between chloride ion concentration at the steel surface and corrosion area ratio

4.2 Seawater resistance

Many reports mention that mixing concrete with seawater did not cause major effects. Changes in compressive strength of specimens exposed for a long time to a marine environment are shown in **Fig. 7** [3]. No effect due to mixing water is observed.

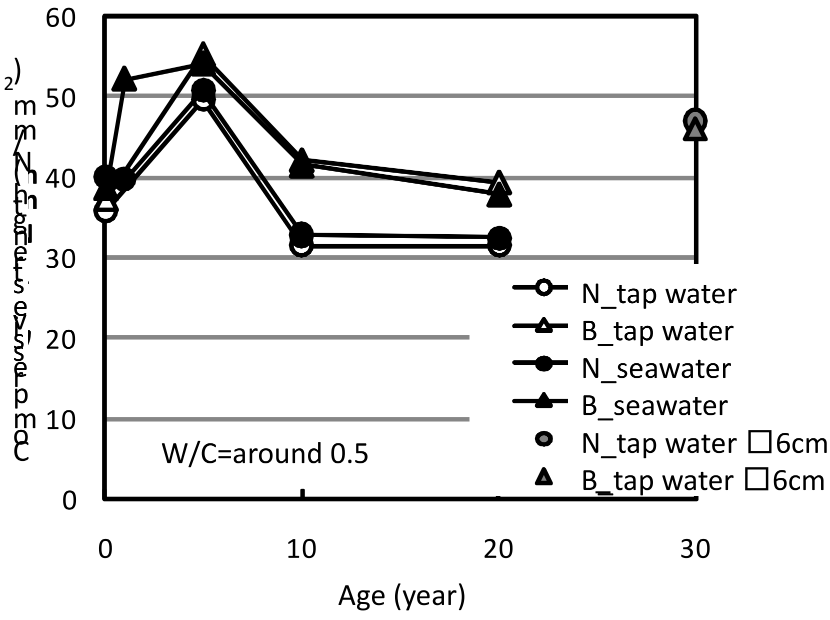

Fig. 7: Compressive strength

4.3 Carbonation

Many reports mention that mixing concrete with seawater does not much affect carbonation.

4.4 Freeze thaw damage

Many reports mention that seawater tends to accelerate the progress of freeze thaw damage. However, it has been confirmed that the progress can be controlled by entraining an appropriate amount of air in the concrete.

4.5 Alkali aggregate reaction

While seawater may accelerate alkali aggregate reactions, no clear information was obtained.

4.6 Summary

Using seawater to mix concrete was found to adversely affect the durability of concrete in terms of steel corrosion and freeze thaw damage. However, it was also confirmed that the corrosion of steel can be controlled by using an appropriate cement and mix proportion, and considering the environment. Freeze thaw damage was confirmed to be controllable by securing a sufficient amount of air.

Use of seawater to mix concrete does not immediately lead to inferior durability. It is likely that necessary durability can be secured by considering the target environment, and selecting concrete of appropriate quality.

5. Performance improvement of concrete mixed with seawater, and rust prevention measures for reinforcement

This section summarizes the existing information on the effects of using seawater in improving the performance of concrete, effects of rust-preventive agents on concrete and their rust prevention effect, and the applicability of various kinds of reinforcement.

5.1 Improvement of concrete performance by use of seawater

Many reports mention that mixing concrete with seawater increased the compressive strength of concrete compared to freshwater. When mixed with seawater, concrete undergoes rapid strength development particularly in its early stages. Also in its late stages of 20 or more years of exposure to a marine environment, the concrete was as strong as that mixed with freshwater [4), 5)], as shown in **Fig. 8**. As these reports suggest, mixing concrete with seawater is likely to have little effect on the long-term strength of the concrete.

Recently, it has been reported that addition of calcium nitrite to concrete mixed with seawater instead of freshwater increased the initial compressive strength as well as the strength after one year. Use of seawater was also reported to increase the initial strength of self-compacting concrete [6)].

The increase in compressive strength by the use of seawater (or salt water) instead of freshwater tends to be larger in concrete formed by adding a binder, such as blast-furnace slag powder and fly ash, than in concrete with Portland cement alone.

Use of seawater instead of freshwater has also been reported to improve other performance variables, such as reduced water permeability (**Fig. 9**)[7)], reduced drying shrinkage, and reduced mean pore diameter.

After meeting the prerequisite of executing appropriate work, seawater probably may contribute to promoting strength development of late-hardening concrete by using admixture, early removal of precast products from the form, and increasing the watertightness of structures.

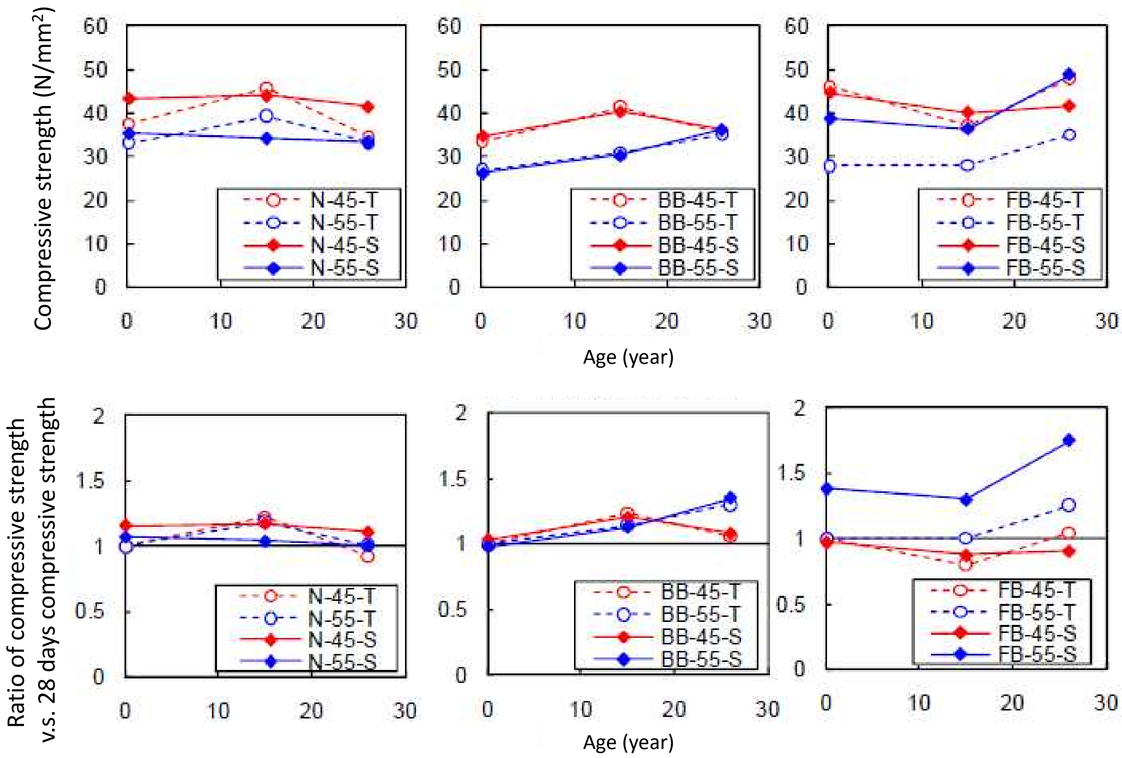

Fig. 8: Change of compressive strength of concrete mixed with seawater [5)]

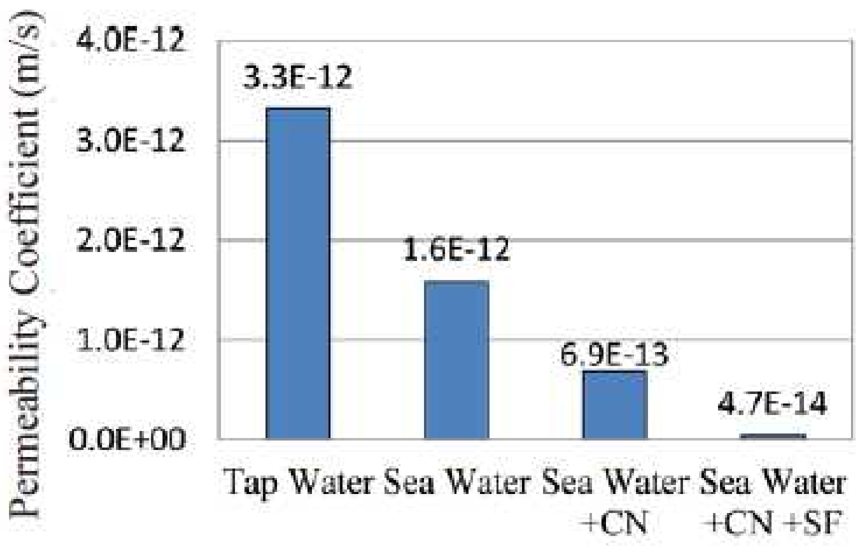

Fig. 9: Water permeability of concrete mixed with seawater [7)]

5.2 Effects of a rust-prevention agent on concrete mixed with seawater, and rust prevention effect

Nitrite rust preventives tend to delay the setting time, and increase the short- and long-term strength of concrete mixed with seawater. Rust-prevention agents have been reported to not adversely affect the freeze-thaw resistance and the progress of carbonization of concrete mixed with seawater, but to prevent rusting of steel.

On the other hand, nitrite rust prevention used in concrete in a marine environment tends to result in elution of nitrite ions, losing the rust prevention effect in the course of time. Therefore, long-term elution characteristics of nitrite ions need to be considered.

5.3 Investigation of reinforcement in concrete mixed with seawater

In corrosion tests and long-term monitoring of stainless steel reinforcement bars and resin-coated reinforcing steels, the bars were confirmed to not suffer corrosion even when the amount of chloride ions in the concrete exceeded a certain level from the initial stage due to use of seawater [8), 9)]. Therefore, it is likely possible to prevent corrosion of steels within concrete mixed with seawater by using these and other reinforcement bars of high corrosion resistance.

It is also likely possible to use noncorrosive reinforcements, such as FRP and bamboo, for concrete mixed with seawater to be exposed to certain conditions.

6. Investigation of manufacturing and casting methods for concrete mixed with seawater

This section summarizes manufacturing methods for concrete prepared by mixing with seawater, casting methods, and their advantages and cautions based on surveys of construction examples and the contents of Sections **2** to **5**.

6.1 Actual water utilization survey of the concrete industry

In order to clarify cautions that need to be taken for using seawater for concrete, the actual state of water use in the concrete industry in Japan was investigated by interviewing relevant organizations

(1) Actual state of water use in concrete manufacture

The actual water utilization state at a ready-mixed concrete mill and a floating mixing plant barge was surveyed. Use of seawater for cement materials was surveyed at a manufacturing plant for coal ash hardened body (hardened body comprising cement, coal ash, various kinds of slag, and seawater) and a solidifying vessel.

The large-scale mill of ready mixed concrete (monthly shipment of about 20,000m^3) consumed 3,500t/month of mixing water to manufacture concrete. At the mill, about 90 to 190kg/m^3 of mixing water and 4 to 11kg/m^3 of washing water were used to ship 1m^3 of concrete (excluding recycled water). In other words, when the water content of concrete is assumed to be 170kg/m^3, 50% to 100% of the mixing water and 2% to 6% of the washing water are consumed for manufacturing concrete. The data shows that concrete manufacture consumes a very large amount of water.

Use of seawater to manufacture concrete (or cement materials) is feared to cause adverse effects on manufacturing facilities, requiring additional maintenance. However, the effects are mostly attributable to corrosion and salt, and based on the interviews, it was confirmed that countermeasures require preliminary investigation and preparation, but are not technically difficult.

(2) Actual state of water use in concrete casting

In the process of casting concrete, procedures that use “water” may include transportation (spraying water on the agitator), formwork (spraying water on wooden forms), jointing (coarse surface processing), curing (wet curing), cleaning (cleaning of reinforcement, forms, inside the feeding pipes, work site, etc.), and spraying water in the working space (dust control).

Although the amount of water used for these procedures may vary depending on the conditions at the site, under ordinary concrete casting conditions, the largest amount of water is likely used for curing. Usually, a larger amount of water is used to cure a horizontal surface (top face) than vertical surfaces. For example, ponding with 3 cm of water requires 30kg/m^2 of water.

Here, the necessary amount of water was calculated for ponding the top concrete of a breakwater caisson with 3 cm of water. Assuming that top concrete (depth: 2 m) of five caissons of standard size (width: 15 m, length: 20 m) is cast per year in a harbor, 30kg/m^2 × 15m × 20m × 5caissons/year = 45t/year of water would be used. This amount of water is 45t/year / 3,000m^3/year = 15kg/m^3 relative to the amount of concrete cast (15m × 20m × 2m × 5caissons/year = 3,000m^3/year), and corresponds to 9% of the water content (assumed to be 170kg/m^3) of the concrete. The amount of water used for curing concrete is so large that cannot be ignored.

6.2 Example of casting concrete mixed with seawater

Casting methods and circumstances which led to its adoption were surveyed in references for some examples of concrete (or mortar) structures mixed with seawater.

The foot protection concrete for exposed rocks on Okinotorishima Island was mixed with seawater for underwater sections because freshwater was difficult to acquire. No record was found mentioning that special materials or devices were needed. However, epoxy resin-coated reinforcing steels were used for horizontal construction joints.

For the reinforced concrete lighthouses and prepacked concrete (plain concrete) that used mortar mixed with sea water, records up to 1954 and 1964, respectively, were confirmed. Seawater was actively used because it was difficult to obtain freshwater, and transport equipment and materials.

Concrete blocks mixed with seawater were manufactured to make effective use of concrete waste produced during the Great East Japan earthquake. During about 3 months of manufacture at the plant, rust developed on an ordinary steel water tank and measuring equipment, but the bath mixer did not corrode because it was washed with freshwater once every day.

Among casting examples of the above coal ash hardened bodies, those that used exclusive plants consisting of rust-proof pipes and measuring equipment did not suffer serious damage other than slight rust at pipe joints, etc. On the other hand, when manufactured in existing mills for ready mixed concrete, new pipes and water tanks were needed to be installed for seawater, seawater needed to be transported on a sprinkler truck, and the shipment of ordinary concrete was suspended during the period, showing that such a manufacturing method makes it difficult to obtain the advantages of mixing concrete with seawater.

6.3 Characteristics of manufacturing and casting concrete mixed with water (cautions to be taken and countermeasures), and production system

While concrete mixed with seawater can in principle be handled like ordinary concrete, the main characteristics (cautions to be taken, and measures to be employed when necessary) are described below.

(1) Materials and mix proportion

The components of seawater and their relative ratios of concentration do not much vary by place (region) or intake depth. However, the seawater concentration may be low at the river mouth. Care should be taken regarding suspended solids for seawater taken along the coast and closed bays.

Ordinary cement, aggregates, admixture and reinforcing materials can be used. Strength development and durability (compactness) can be expected by using mixed cement and admixtures such as blast furnace slag micropowder, fly ash, and calcium nitrite. Admixtures for seawater have also been developed, for which the water reducing effect is only slightly less even when seawater is used. Noncorrosive reinforcing materials are also effective depending on the performance required for the structure and the service environment.

(2) Manufacture and transportation

As manufacturing and transportation facilities are susceptible to corrosion by seawater, it is desirable to use highly rust-resistant water tanks and measuring equipment, and to wash mixers and drums of agitator trucks with freshwater. To cope with slump loss and reduced setting time, it is necessary to investigate transportation methods and admixtures to use. Pumping can be performed as for ordinary concrete.

(3) Placing, compacting, finishing

Concrete mixed with seawater should be cast noting that bleeding is small, and setting time is short. Especially when placed in two or more layers, the allowable time limit for successive placements should be investigated in advance so as to prevent cold joints.

(4) Curing and joints

Curing and joint work can be performed in the ordinary manner. However, when cured by controlling temperature (such as by heating), thermal cracks may develop due to rapid heat generation. Thus it is recommended to investigate in advance.

Concrete blocks mixed with seawater can be immersed and cured in the sea after they are removed from the forms, which prevents the blocks from drying during their early stages. Particularly in winter, seawater is warmer than the air, and has a better curing effect.

On the other hand, it has been confirmed that curing concrete mixed with freshwater in seawater increases the strength. This is particularly advantageous for plain concrete. However, in a cold environment that may cause freeze thaw damage, seawater may accelerate the progress of the damage, and thus its use should be avoided as much as possible.

(5) Reinforcement works and formwork

Reinforcement works and formwork can be executed in the ordinary manner. However, the reinforcement should be assembled carefully and precisely so as to ensure the predetermined cover depth.

Particular attention is needed for epoxy resin-coated reinforcing steels so as to ensure that the coat is free of cracks, pinholes, scratches, etc.

(6) Quality control

It is desirable to carefully check the performance required for the structure, and carefully investigate the quality control method to implement for each step of the casting plan, which is to be drawn up by considering the effects of seawater on quality. It is crucial to control the chloride ion content in the concrete, and cover depth over reinforcement bars.

(7) Measures against cracks

Crack control measures should be taken by duly considering future maintenance work, such as inspection after completion and possibility of repair. Use of steels for crack width control (highly rust resistant steels when necessary) can be investigated depending on the performance required for the structure.

(8) Manufacturing system

Concrete mixed with seawater can in principle be manufactured like ordinary cement. For works in coastal zones and on isolated islands, concrete can be manufactured by installing an in-situ plant by the sea, as shown in **Fig. 10**. Seawater is pumped up, filtered when necessary, kept in a tank, and used. The temperature can be controlled by using a heater and/or chiller. In places where sea sand is available, the sand can be used as fine aggregates, unwashed.

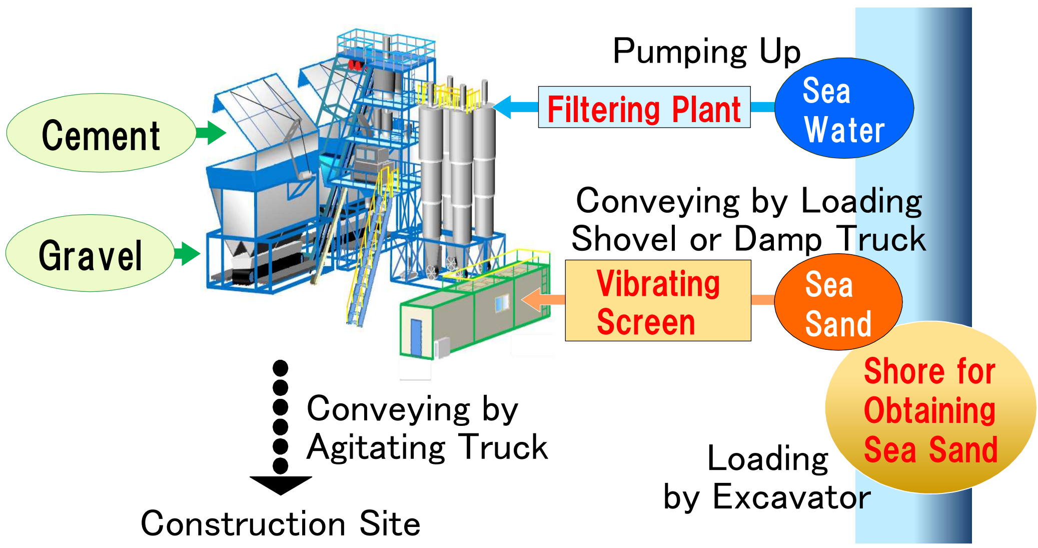

Fig. 10: Example of manufacturing system of concrete mixed with seawater

6.4 Summary

Using seawater in concrete not only contributes to effective use of water resources in the concrete industry, but also improves the quality of concrete if sufficient consideration is given to materials, mix proportion and curing method. It is also expected to improve the efficiency of casting. Many effects can be expected: for example, seawater accelerates strength development (particularly the initial strength), makes the concrete compact (improved durability), enables early removal from the form, prevents cracks when cured with seawater or cured immersed in seawater, and improves the efficiency of work.

For plain concrete, seawater can be used not only to mix concrete, but also to spray on wooden forms, treat joints, and cure concrete wet (such as in mat curing, ponding, and water spraying).

7. Overall summary and future development

(1) Summary

Depletion of freshwater resources is progressing globally. Drinking water will certainly be in short supply. Freshwater that can be used for manufacturing and casting concrete will be limited. Concrete engineers are therefore required to have an attitude of “not thinking why seawater cannot be used, but thinking of a means to use seawater”, and find technologies to reduce the use of freshwater.

Investigations so far by the Committee have shown that 1) using seawater to mix or cure concrete would not cause any disadvantage as long as a certain level of caution is taken regarding the mix proportion, manufacturing and casting methods, and 2) seawater is rather advantageous in certain cases. Use of seawater for plain concrete causes almost no problem. Even for reinforced concrete, measures (devices) are available for meeting the required performance.

Naturally, careless use of seawater, for example with a large water cement ratio and inappropriate casting, leads to conspicuous salt damage. Stepping out from the basic rules of concrete manufacture and casting is something that must not be done.

(2) Future development

Deployable methods of seawater use that have been discussed by the Committee are listed below.

Possible methods include:

1) Use for restoration work at the time of an earthquake and other disasters, and combination with waste produced by the disaster,

2) Use on isolated islands such as Okinotorishima Island,

3) Use in deserts (particularly those adjacent to the sea), and

4) Curing marine and coastal concrete structures under the sea.

The authors hope that, by this report, readers will think about the effective use of seawater in the concrete industry.

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