Maintenance-free Sewage Facilities by Using Sulfuric Acid-Resistant Concrete

耐硫酸コンクリートによる下水道施設のメンテナンスフリーの実現



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1. Introduction

Construction of the Japanese sewage system began in the 1880s, and by the end of 2018, about 2,200 treatment plants and 480,000 km of sewer lines had been constructed. However, now that the development of sewage facilities is almost complete, the number of these facilities exceeding the standard service life of 50 years is increasing.

It is known that concrete used in sewage facilities tends to corrode because of sulfuric acid produced by sulfur-oxidizing bacteria (**Fig. 1**). Corrosion of concrete occurs mainly above the water level in a facility because hydrogen sulfide (H_2S) generated underwater is released into the air and is converted to sulfuric acid (H_2SO_4) in water droplets that condense on the walls and ceilings in the air phase. In the environment with a high H_2S concentration of 50 ppm or more, the corrosion rate of ordinary concrete is said to be 7 mm or more per year.

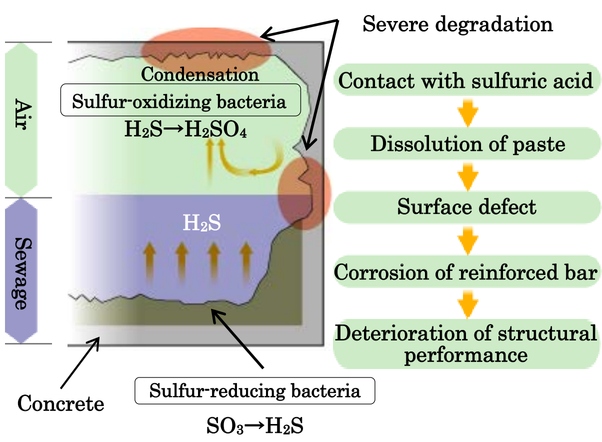


Fig. 1 Degradation of concrete in sewage facilities by sulfuric acid

As a countermeasure, a surface coating technique is widely used to prevent contact with sulfuric acid by covering the concrete surface with resins. However, because the standard service life of the coating materials is about 10 years, it is necessary to renew them several times during a facility lifetime of more than 50 years. Moreover, pinholes in the coating and cracks in the concrete may cause the coating to swell and peel off at an early stage, which may require short-term maintenance. During the repair work, it is necessary to stop the operation of the facility, prepare backup equipment for the water treatment, and dry the facility for coating, all of which is often costly and time-consuming.

With the aim of realizing maintenance-free sewage facilities and extending the service life of the concrete therein, the authors have developed and begun to apply sulfuric acid-resistant concrete (SARC) which has resistance to sulfuric acid 10 times that of conventional concrete [1]-[3]. Because the deterioration of concrete due to sulfuric acid proceeds in proportion to time, if its sulfuric acid resistance is 10 times higher, then 10 times the operational life can be achieved. SARC is expected to contribute to long-term maintenance-free operation without surface coating.

2. Development of SARC

(1) Material Properties

SARC is characterized by the use of a special chemical admixture (organic admixture), limestone aggregates,

Table 1 Example of mix proportion of SARC

Slump flow (mm)	W/C (%)	Unit weight (kg/m^3)					
		W	C	LSP	LSS	LSG	Ad
700 ± 50	51.7	160	310	290	802	767	9.6

Symbols: W: water; C: Portland cement; LSP: limestone powder;
LSS: limestone fine aggregate; LSG: limestone coarse aggregate; Ad: special chemical admixture

and limestone powder for improved sulfuric acid resistance[1]. An example of the mix proportions is given in **Table 1**. Although the type of aggregate is not limited, the use of limestone aggregate is standard because it improves sulfuric acid resistance.
SARC is a high-fluidity concrete that fills every corner of the formwork without compaction in construction works, and its strength is 24–40 N/mm^2, which is a common strength level for civil engineering work.

(2) Sulfuric Acid Resistance

The sulfuric acid resistance of SARC was evaluated via immersion tests into sulfuric acid solution and exposure tests to actual sewage conditions [2]. The corrosion depths of SARC and normal concrete (blank) after immersion in 5% sulfuric acid solution for up to 112 days are shown in **Fig. 2**. In both mixtures, the corrosion depth increased in proportion to the immersion period. The slope of the regression line indicates the corrosion rate of SARC was 1/27 that of the normal concrete.
Although the ratio fluctuates depending on the quality of the normal concrete, from multiple tests the corrosion rate of SARC is 1/10 or better of that of normal concrete without exception.
Exposure tests were conducted at three sewage plants for up to 4.4 years. In each facility, the corrosion of SARC was inhibited drastically compared with normal concrete (**Fig. 3**).
Photo 1 shows the appearance of specimens after exposure in storage tank 1 for 4.4 years. The normal concrete corroded severely, whereas SARC suffered only minor deterioration near the surface.

(3) Mechanism of Sulfuric Acid Resistance

The mechanism of the superior resistance to sulfuric acid is thought to be that when sulfuric acid comes into contact with concrete, normal concrete dissolves and forms putty-like (loosely packed) gypsum on the surface, whereas SARC forms densely packed gypsum that covers the whole surface [1] (**Fig. 4** and **Photo 2**). Because the dense gypsum layers prevent penetration by sulfuric acid, the resistance to sulfuric acid is improved considerably. This mechanism is due to the special chemical admixture and limestone materials.

3. Application in Repair Work

(1) Construction Method

To make full use of the sulfuric acid resistance of SARC, defect-free concrete construction is indispensable. In particular, a form-and-pump technique

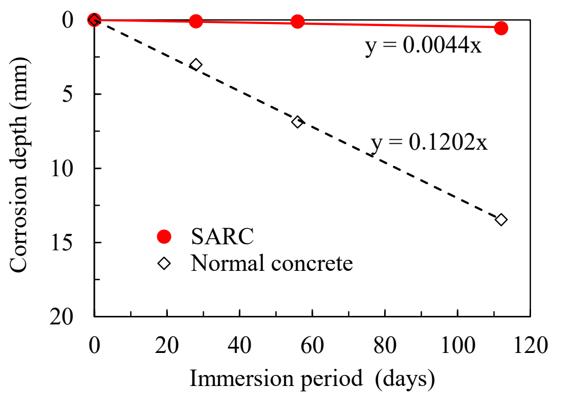


Fig. 2 Resistance to sulfuric acid by immersion test

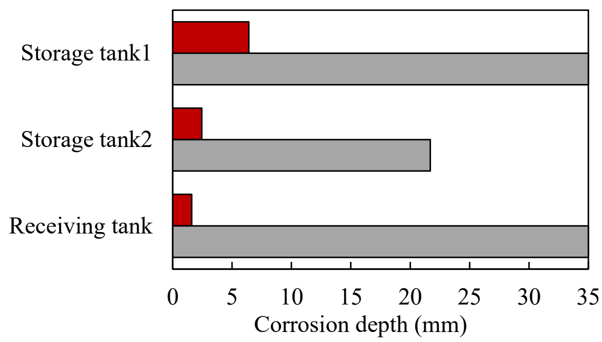


Fig. 3 Resistance to sulfuric acid by exposure tests in sewage facilities

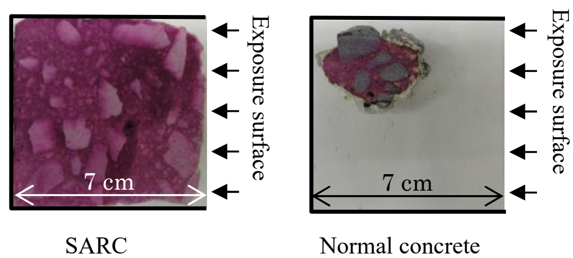


Photo 1 Resistance to sulfuric acid by exposure test in a sewage facility (storage tank 1)

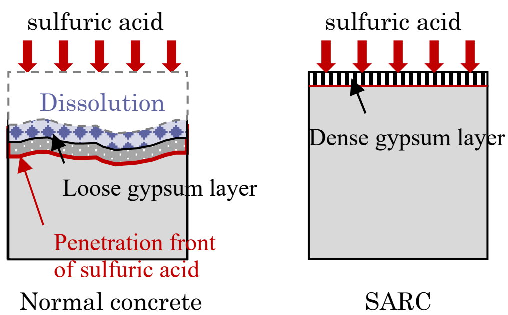
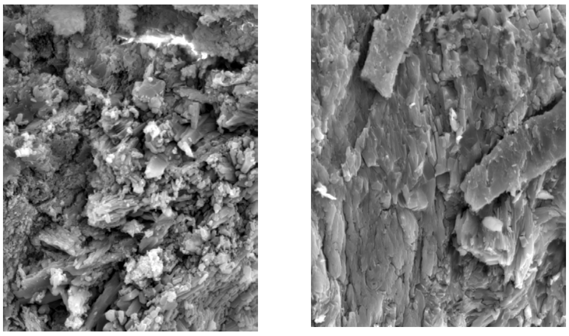


Fig. 4 Mechanism of sulfuric acid resistance



Normal concrete SARC

Photo 2 Secondary electron images of surface gypsum after immersion in sulfuric acid

and a panel technique were developed and applied for the repair work of a deteriorated sewage facility [3].

In the form-and-pump technique, formworks were set with 35-mm gaps to the existing concrete, and SARC was pumped into the gaps (**Fig. 5**). To fill the narrow space, the slump flow of SARC was adjusted to 73.0–75.0 cm, and the maximum size of coarse aggregate was 10 mm. SARC exhibited sufficiently good filling ability to fill the narrow gaps between the formworks and existing concrete (**Photo 3a**). The compressive strength of specimens (∅100 mm×200 mm) of pumped SARC was over 40 N/mm^2 at 28 days.

In the panel technique, prefabricated SARC panels with thickness of 25 mm were arranged at the surface of existing concrete with 10-mm gaps followed by grouting using SARC mortar (**Fig. 5** and **Photo 3b**). A hammering test confirmed that the grout filled the narrow space behind the panels, meaning that the panel technique is reliable. Furthermore, it shortens the work process in comparison with conventional methods. In both methods, the joints in the concrete were sealed with a sulfuric acid-resistant resin.

(a) Form-and-pump technique

(b) Panel technique

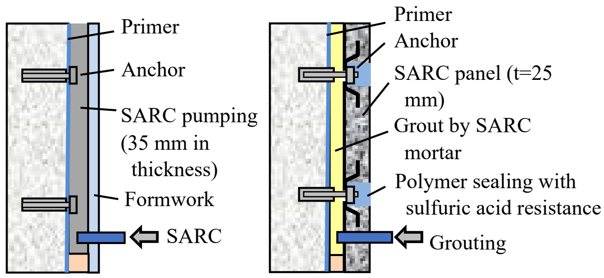
Photo 3 Repair work at the sewage facility

(2) Verification after Construction

After the repair work described in (1) was completed, the facility was in service for 7 years, and the soundness of SARC was investigated. The annual average concentration of hydrogen sulfide measured during service was 40 ppm, which is classified a comparatively severe environment with respect to sulfuric acid attack.

After 7 years, a brown brittle layer had been deposited on the surface; when it was removed by scraping, white hard deposits appeared that were firmly adhered to the surface of SARC (**Photo 5**). This white deposit was gypsum as indicated by an electron probe microanalyzer (EPMA), which showed the high concentrations of sulfur on the surface (**Fig. 6**).

As described in 2.(3), it has been clarified that the gypsum layer works as a barrier layer against sulfuric acid, and this mechanism was also confirmed in this study.



a) Form-and-pump technique b) Panel technique

Fig. 5 Schematic diagrams of repair work

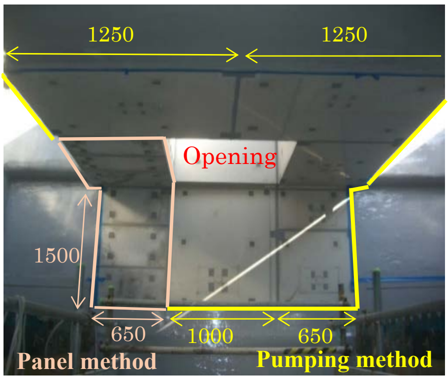


Photo 4 Appearance of the facility after repair

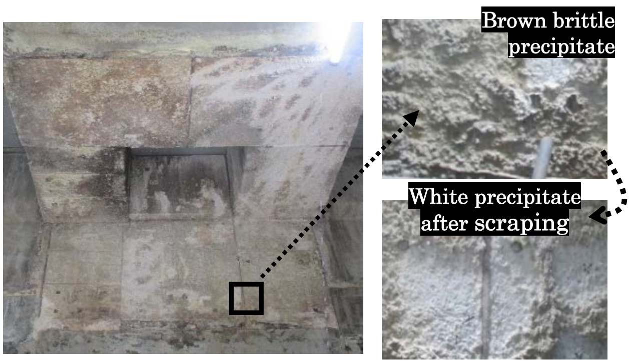
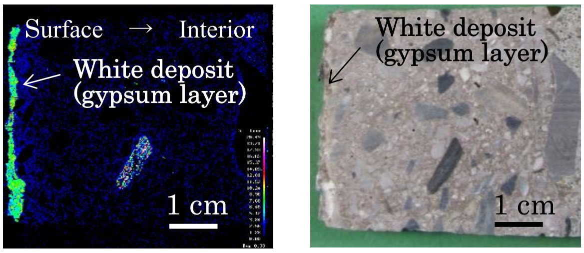


Photo 5 Surface condition of repair site after 7 years of service



(a) Distribution of sulfur (b) Photo of specimen

Fig. 6 Distribution of sulfur by EPMA

The corrosion depth, which is the sum of the dissolution depth of surface concrete and the neutralization depth of remaining concrete, was only 3 mm in a repair thickness of 35 mm. As mentioned above, because the corrosion depth is proportional to time, it is calculated that the facility can be maintenance free for about 70 years if its environment does not change.
In addition, no degradation was observed in the epoxy resin used for the joints. Therefore, 7 years after the repair, the whole repaired area including the SARC and joints remains sound, and the facility is judged as being usable for longer without further protection.

4. Conclusion

Sewage facilities are important social infrastructure, but their aging and early-stage deterioration are becoming more serious. With the aim of realizing maintenance-free sewage facilities and extending the service life of the concrete therein, the authors developed sulfuric acid-resistant concrete (SARC) that has 10 times higher resistance to sulfuric acid than normal concrete. In addition to the sulfuric acid resistance, by its good self-compactability, SARC is suitable for the large-scale repair of existing facilities as cast-in-place concrete with a form-and-pump technique, or as prefabricated panels.
SARC is expected to contribute to the sound operation of sewage systems by realizing maintenance-free and long-lasting facilities.

References

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概　要

下水道施設の整備がコンクリートは，微生物が生成する硫酸により早期に腐食する場合がある。この対策として，樹脂等でコンクリート表面を被覆する防食被覆工法が広く用いられているが，被覆の耐用年数は10年が標準であり，定期的な更新が必要となる。
著者らは，施設のコンクリートの長期のメンテナンスフリーや長寿命化を実現することを目的として，硫酸による腐食速度を通常のコンクリートの1/10以下に低減する耐硫酸コンクリートを開発し，硫酸浸漬試験や下水環境での暴露試験によりその耐硫酸性を検証した。さらに，品質を発揮させる施工技術として型枠充填工法とパネル工法を開発した。硫酸劣化を生じた施設の補修に適用し，厚さ35mm の小断面の施工も欠陥なく確実に行えることを実証した。補修後 7 年における追跡調査により，補修後の耐硫酸コンクリートの腐食は緩やかであり，補修を必要とせずにさらなる長期の耐用が可能であること確認した。