Journal of Ceramic Processing Research. Vol. 19, No. 2, pp. 105~110 (2018)

J O U R N A L O F
Ceramic Processing Research

Development of sulfuric acid resistant concrete sewer pipes using waste glass powder and meta-kaolin

Hee Seok Lee[a] and Kwang Ho Sho[b,*]
[a]*KISAN C&M Consulting CO., #301, Daeyoung Building, 10-15, Bangbae-ro 6-gil, Seocho-gu, Seoul 06705, Korea*
[b]*Department of Architectural Engineering, Wonkwang University, Iksan 54538, Korea*

Performance deterioration of concrete has recently been recognized as a significant problem, and is mainly due to corrosion and crack formation, leading to reduced load carrying capacity of reinforced concrete structures. Particularly, the durability of concrete structures built in seawater, groundwater, and waste water treatment facilities are significantly reduced when subjected to chemical erosion by acid and sulfate, and require countermeasures to increase their lifespans. Thus, this study was conducted to evaluate the performance of sulfate-resistant concrete treated with metakaolin and waste glass powder as a binder to improve sulfate and chemical resistance performance for the development of sulfate-resistant sewer pipes. Concrete sewer pipes were successfully developed with excellent sulfate resistance and high strength of 50 MPa or higher.

Key words: Waste glass powder, Meta-kaolin, Blast furnace slag sand, Sulfuric acid resistant.

Introduction

The performance deterioration of concrete structures produced in the rapid growth period of the 1980s has recently been recognized as a pressing issue due to their aging-related deterioration including cracks and reduced chemical durability and load carrying capacity. When concrete structures are located in seawater, ground water, and soil, or constructed in acidic river basins, chemical plants, wastewater treatment facilities, and sewer systems, they are exposed to chemically challenging environments. Chemical attack by acid and sulfate can significantly deteriorate the durability performance of concrete structures, which require countermeasures to maintain structural integrity [1-3].

Although it is difficult to monitor the degradation of sewer pipes due to the surrounding geology, underground construction, and heavy rainfall, sulfate generated in sewage containing a large amount of organic matter has been identified as the main cause of sewer pipe deterioration. The deterioration of concrete sewer pipes by sulfuric acid occurs primarily from diffusion and penetration of the sulfuric acid through the concrete surface or pores. The rate and extent of deterioration depend mostly on the watertightness, absorptive capacity, and permeability of the concrete material, and the propagation path is determined by the extent of surface diffusion. Secondary damage can also occur due to microcracks caused by the direct penetration of deterioration factors such as CO2, chloride, sulfate, and moisture. The deterioration factors diffuse to the interior of the concrete causing corrosion of the reinforcing bars, accelerating the deterioration of the concrete, particularly by moisture penetration. To resolve these problems, it is necessary to form dense interiors in the concrete and to use sulfate-resistant materials.

Waste glass is a common industrial byproduct which is largely disposed of in landfills. Currently, approximately 780,000 tons of waste glass are generated annually, 70% of which is recycled into bottles, tiles, blocks, and fibers. The remaining 30% is sent to landfills, which takes up space and is unnecessary and wasteful. The waste glass powder is composed of approximately 60% SiO2, 10% Al2O3, and 5% CaO, making it potentially useful as a concrete binder in a pozzolanic reaction admixture. Accordingly, studies have been conducted on the use of waste glass as an aggregate and binder, but thus far have shown poor results [4-6].

Therefore, this study aimed to evaluate the performance of sodium sulfate resistant concrete incorporating metakaolin and waste glass powder as a binder to improve sulfate and chemical resistance performance, and to develop a sodium sulfate resistant sewer pipe.

Experimental Plan and Method

Experimental Plan

Table 1 shows the mixing of the sulfate resistant concrete at the laboratory and on-site. W/B was selected as 35% and S/a 39.1 based on a target strength

*Corresponding author:
Tel : +82-63-850-6707
Fax: +82-63-843-0782
E-mail: ar2000@wku.ac.kr

Table 1. Mixing proportions of the concrete.

Kind	W/B	Weight (kg/m^3)						
		Cement	Meta-Kaolin	waste glass powder	SP	AE	Blast Furnace slag Sand	Blast Furnace slag aggregate
Laboratory	35	546.8	62.8	18.8	3.7	0.6	532	836.3
Field	35	435	50	15	3.5	–	620	965

Table 2. Physical properties of cement.

Density (g/cm^3)	Blaine (cm^2/g)	Soundness (%)	Setting time (min)		Compressive strength (MPa)		
			Initial set	Final set	3 days	7 days	28 days
3.15	3 390	0.05	230	345	24.8	39.3	56.9

of 40 MPa, slump of 150 mm, maximum size of the coarse aggregate of 25 mm, and air content of 4.5 or less. In addition, 10% and 3% of metakaolin and waste glass powder were used as binders, respectively, and air-cooled blast furnace slag, whose sulfate resistance performance was characterized by preliminary tests, was used as an aggregate. During the experiment, the compressive and flexural strengths, chloride penetration resistance, and sulfate resistance were measured in accordance with KS and ASTM standards.

Materials

Cement

The cement used in this study was a typical Portland cement, manufactured by a domestic company "H". Its density was 3.15 g/cm^3 and the fineness is 3,390 cm^3/g. The compressive strengths of the cements used in this study were 24.8, 39.3, and 56.9 MPa at 3, 7, and 28 days, respectively. The physical properties of the cement are listed in Table 3.

Metakaolin

Kaolin mineral, the raw material of metakaolin used in this study, was a main component of ceramics in the past. However, the range of applications of metakaolin has been gradually expanded due to its excellent functionality in various industrial fields. The metakaolin used in this experiment was manufactured in China with a fineness of 7800 cm^3/g. The physical and chemical properties of the metakaolin are listed in Table 4.

Table 3. Physical and chemical properties of meta-kaolin.

Density (g/cm^3)	Blaine (cm^2/g)	Chemical composition (%)					
		SiO2	Al2O3	Fe2O3	MgO	CaO	TiO2
2.66	7 800	56.9	38.4	2.7	0.6	34.2	0.9

Waste glass powder

The waste glass powders were collected by a domestic company "D", a company that specializes in the collection and recycling of waste glass. The obtained waste glass was pulverized in a ball mill prior to use. Table 5 lists the physical and chemical properties of the waste glass powder.

Aggregate

The air-cooled blast furnace slag aggregate used in this study was manufactured by a domestic company

Table 4. Physical and chemical properties of wast glass powder.

Density (g/cm^3)	Blaine (cm^2/g)	Chemical composition (%)					
		SiO2	Al2O3	Fe2O3	MgO	CaO	SO3
2.50	4 120	73.2	16.4	0.4	1.0	8.91	0.24

Table 5. Physical properties of blast furnace slag aggregates.

Kinds	Maximum size (mm)	FM	Density (g/cm^3)	Absorption (%)	Unit volume (Kg/L)
Coarse aggregate	25	3.12	2.59	3.42	1.54
Fine aggregate	5	3.01	2.57	3.12	1.54

Table 6. Chemical properties of blast furnace slag aggregates.

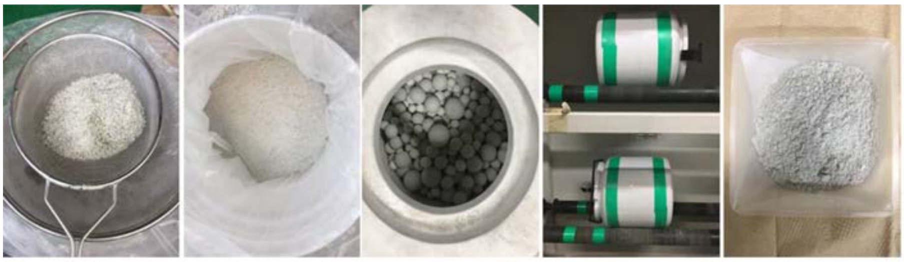
Chemical composition (%)					
SiO2	Al2O3	CaO	MgO	TiO2	S
33.5	13.65	41.8	0.5	1.3	1.0

Table 7. Physical properties of superplasticizer.

Chemical composition (%)					
Chief ingredient	Chief ingredient	Color	Density (g/cm^3)	pH	Alkali (%)
Polycarboxylate-based	Liquid phase	Brown liquid	1.06	5.0	0.01

Low Speed (20rpm)		Medium Speed (30rpm)		Medium Speed (125rpm)		
Cement + Mixed material + aggregate	→	Dry Mixed Concrete + Water	→	Concrete + Superplasticzer	→	Discharge
30 sec.		60 sec.		90 sec.		

Fig. 1. Mixing process of Concrete.



a) Primary waste glass sieve　b) Second ball milling　c) Waste glass powder

Fig. 2. Waste glass pulverization method.

"H" using raw materials from Gwangyang Steelworks. Its physical properties are listed in Table 6 and chemical properties in Table 7.

Admixture

The high-performance water-reducing agent used in this experiment as an admixture was a polycarboxylicfif acid system (PC system) manufactured by a domestic company "B". The physical properties of the admixture are listed in Table 7.

Experimental Methods

Concrete mixing

Concrete mixing was performed according to the order shown in Fig. 1 using a forced fan type mixer.

Waster glass powder pulverization

The pulverization process of the waste glass powders is shown in Fig. 2. The primarily pulverized waste glass was sieved with a 1 mm sieve. Next, approximately 800 g of waste glass was added into a ball mill and pulverized to prepare the waste glass powder.

Strength test

The tests for compressive and flexural strength of the concrete was conducted as follows. After curing the specimen prepared in accordance with KS F 2403 "Specimen preparation method for concrete strength test", the compressive strength was measured in accordance with KS F 2405 "Standard compressive strength test method for concrete". The tensile strength was measured in accordance with KS F 2408 "Method of test for flexural strength of concrete". The measurements were obtained using 3 GN UTM at the designated age.

Chloride permeability test

Chloride ion penetration resistance was measured using a specimen with 100 × 50 mm dimensions in accordance with KS F 2711 "Testing method for electrical indication of concrete's ability to resist chloride ion penetration". A 3.0% NaCl solution and 0.3 N NaOH solution were added into each cell, and the current was measured at 60 V in 30 min intervals. The measurement was completed after 6 h, and the total amount of passing charges was determined.

The chloride ion penetration depth was evaluated by spraying a 0.1 N AgNO3 solution on the surface of a split specimen after testing the chloride ion permeation resistance. The site with no chlorine ions turned brown, while those with penetrated chlorine ions turned silver by precipitating AgCl. The chloride ion penetration depth was determined from the surface of the concrete to the silver-colored site, and the average depth of five spots was measured.

Chloride ion permeability according to charge amount.

Coulombs	Chloride ion permeability
> 4000	High
2000 ~ 4000	usually
1000 ~ 2000	Low
100 ~ 1000	Very low
< 100	Negligible

Sulfate resistance test (mass change)

The mass change was measured according to ASTM C 267 : 2001 "Standard test methods for chemical resistance of mortars, grouts, and monolithic surfacings and polymer concretes". The mass change test was conducted as follows. After curing the specimen in water for 28 days, the immersion test began. The specimen was immersed in the immersion tank, and was removed at 0, 3, 7, 14, 28, 56, and 84 days to measure the mass reduction. To remove precipitates on the surface, the specimen was washed with a chemical fiber brush, and its surface moisture was then removed with a cotton towel. After the specimen was dried in a drying oven at 20 ± 3 °C for 30 min, its mass was measured using an electronic balance with a working range of 40 gf to 10,000 gf. The mass change rate was calculated from the average value of three specimens using Equation (1).

$$\text{Mass change rate (\%)} = \frac{\text{W-C}}{\text{C}} \times 100 \qquad (1)$$

Here, "C" refers to the mass (g) of the specimen before immersion, and "W" refers to the mass of the specimen after immersion according to its age.

Sulfate resistance test (compressive strength)

The sulfate resistant compressive strength was determined according to ASTM C 579 "Standard Test Method of Chemical-Resistant Concretes". The immersion solution was prepared by mixing first-grade magnesium sulfate with water to a final concentration of 10%. The immersion was started immediately after form removal, and the amount of solution was fixed to an immersion solution (L)/volume (V) ratio of 5, and the temperature was maintained at 23 ± 2 °C. The compressive strength was measured and compared after 28 days of immersion.

Results and Discussion

Strength Performance Evaluation

Fig. shows the compressive and flexural strength test results of the sulfate resistant concrete incorporating waste glass powder and metakaolin. The flexural strength and compressive strength were 5 MPa or higher and 59 MPa, respectively, at 28 days, with the compressive strength exceeding the target compressive strength of 40 MPa by approximately 30%. This suggests that the long-term strength was improved due to pozzolanic reaction and the pore-filling effect of the waste glass powder and metakaolin with fineness of 4000 cm^2/g or higher [7, 8].

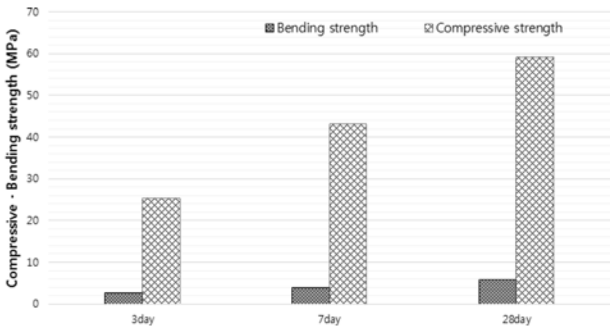


Fig. 3. Compressive strength according to age.

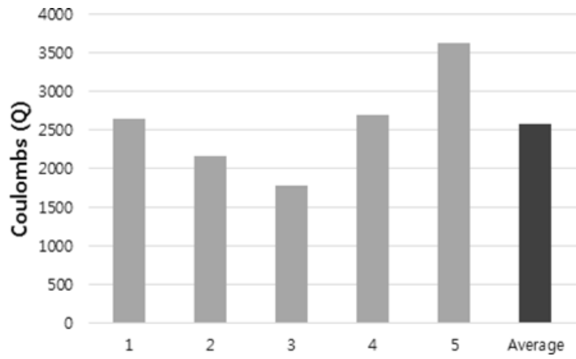


Fig. 4. Chlorine ion penetration resistance.

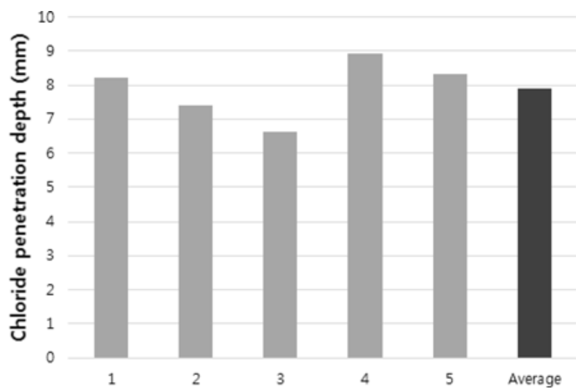


Fig. 5. Chloride penetration depth.

Chloride ion penetration resistance

To measure the chlorine ion penetration resistance of the sulfate resistant concrete incorporating waste glass powder and metakaolin, tests were conducted in accordance with ASTM C 1202, and the amount of passing charge and diffusion coefficient were determined according to the test standard. Fig. 4 shows the chlorine ion penetration resistance from 1700 to 3600 C, which is below average according to the criteria of ASTM C 1202. Furthermore, the chloride penetration depth shown in Fig. 5 was measured as 10 mm or less, indicating good chloride ion penetration resistance. These results show that because the fineness of the waste glass powder and metakaolin in the binder are significantly higher than that of cement, the internal structure of the concrete is densified, reducing the number of micropores and decreasing the penetration rate of chloride ions.

Sulfate Resistance performance evaluation

The sulfate resistance performance of the concrete prepared using waste glass powder and metakaolin was tested in accordance with ASTM C 267 and ASTM C 567. Fig. 6 presents a graph showing a mass reduction rate of -3% or less on average. Furthermore, Fig. 7 shows the compressive strength after immersion in the sulfate solution. Despite slight variation in compressive strength after the immersion of sulfate, it was maintained at 52 MPa or higher on average. This

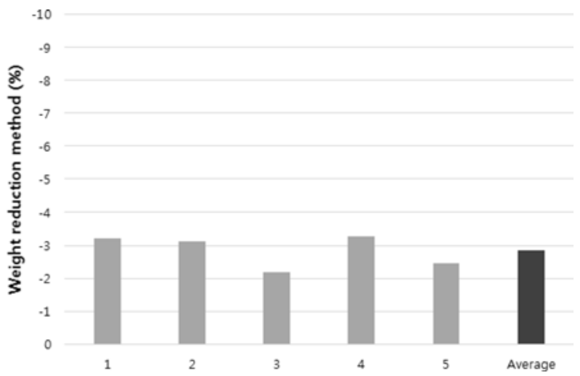


Fig. 6. Mass reduction rate.

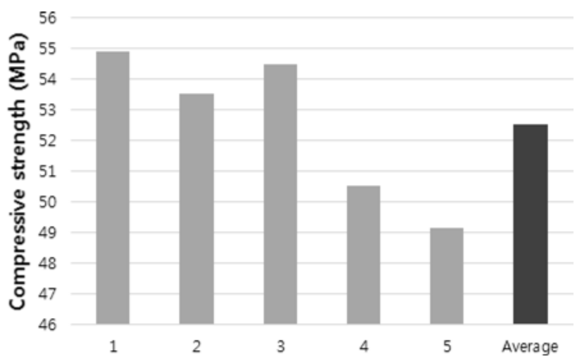


Fig. 7. Compressive strength after sulphate immersion.

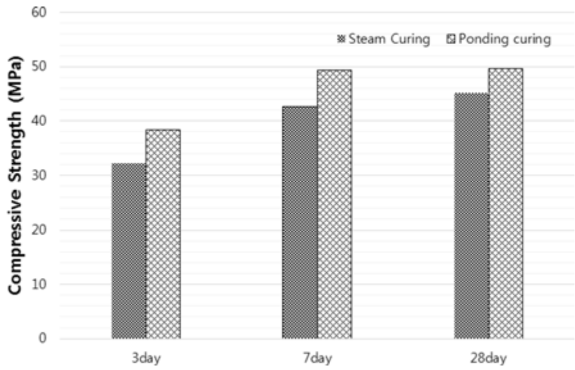


Fig. 8. Compressive strength test results according to curing method.

indicates the compressive strength is 20% greater than the target strength of 40 MPa., and is likely due to the addition of metakaolin with excellent chemical resistance as well as the filling effect by the fine waste glass powder. Moreover, a continuous reduction occurs by sulfuric acid in typical concrete, with cycles of ‘volumetric expansion-peeling of the paste or mortar parts’ due to the formation of calcium sulfate (CaSO4.2H2O) and ettringite. This can be explained by the formation of a thick gypsum layer in the mixture including the air-cooled blast furnace slag aggregate to reduce the precipitation of the sulfuric acid solution [9, 10].

Sewer pipe fabrication

A concrete specimen was fabricated to measure the flow and compressive strength of a sewer pipe test product. Fig. 8 shows the compressive strength according to the curing methods used, and was 40 MPa or higher, meeting the target strength for steam and underwater curing.

Conclusions

Below is a summary of the results of the development of sulfate resistant concrete sewer pipe using waste glass powder and metakaolin.

1) For the chemically resistant sewer pipe prepared using concrete mixed with waste glass powder and silica, the compressive strength at 28 days was 59 MPa, 30% higher than the target strength of 40 MPa. This improvement can be explained by the filling effect of the fine waste glass powder and addition of metakaolin.

2) With respect to the chemical resistance of the prepared sewer pipe, the chloride ion penetration was below average compared to that in the ASTM C 1202 standard. The chloride penetration depth was 10 mm or less, indicating excellent chloride ion penetration resistance.

3) In addition, the mass reduction rate was −3% or less upon immersion in sulfate solution, which is regarded as excellent. The sulfate resistance was superior to typical concrete as evidenced by compressive strength

after the sulfate immersion of 50 MPa or higher.

Finally, it is cost-efficient to use the industrial by-product waste glass powder as a binder, and metakaolin, which is cheaper than silica fume, to ensure high durability and chemical resistance. Furthermore, this product was developed for a special purpose and can be differentiated from existing concrete products by its superior properties.

Overall, the optimal design of sulfate resistant concrete with high durability and high chemical resistance can be produced using waste glass powder and metakaolin with a high degree of fineness. The sulfate resistant concrete is eco-friendly and promising for the fabrication of chemically-resistant concrete sewer pipes.

Acknowledgments

This paper was sponsored by Wonkwang University in 2016.

References

1. S.W. Ha, T.H Ahn, S.Y. Bang, N.W. Yang, J.S. Ryu, KCI Spring Conference. (2015) p. 393.
2. S.W. Ha, T.H. Ahn, S.Y. Bang, J.H. Park, J.S. Ryu, KCI Fall Conference. (2015) p. 737.
3. D.W. Seo, G.H. Jung, Y.D. Lee, N.G. Lym, S.J. Jung, AIK 18 [12] (2002) 75-82.
4. Y.S. Kim, Y.J. Jung, D.W Lee. KSCE 9 [3] (2009) 109-116.
5. T.H. Young, J.H. Yun, J.M. Choe, Y.S. Lee, AIK 13 [2] (1993) 625-628.
6. J.H. Jin, K.T. Koh, G.S. Ryu, J.H. Lee, J.J. Park, KCI (2008) p. 649.
7. H.G Lee, J.Y Jung, J.W Sim, G.S Zi, H.S Oh, J.S Sim, KCI (2014) p. 427.
8. I.H. You, J.W. Sim, T.S. Jang, S.S. Hwang, G.S Zi, KCI (2013) p. 261.
9. G.J. Jang, E.C. Kim, C.M. Lim, G.H. So, KIA (2017) p. 959.
10. J.E. Jung, Y.R. Jang, K.W. Kim, S.C. Heo, J.S. Min, KAS 26 [5] (2013) 340-351.