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Study on the Durability of Urban Sewage Pipeline Concrete

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ABSTRACT : *Urban sewage pipelines in infrastructures have important factor for urban ecological security and social production development. Based on the investigation and analysis of the concrete corrosion of sewage pipeline in a city, the indoor simulated corrosion test was carried out, and the durability design method of sewage pipeline concrete was proposed. The research shows that the main factor of pipeline concrete corrosion in the city is sulfate erosion. Mineral admixture and polypropylene fiber can effectively improve the durability of pipeline concrete in the corrosive environment, and double mixing fly ash and slag and adding proper amount of polypropylene fiber has the best effect. Compared with the original proportion concrete, the cubic compressive strength and splitting tensile strength of CX group concrete increase by 20.7% and 16.9%. Under the test conditions of this paper, the effect of cement - based crystalline waterproof coating is not obvious.*

KEYWORDS:*sewage pipeline; concrete; corrosion; mechanism; durability design*

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I. INTRODUCTION

Urban sewage pipeline is an important infrastructure, which plays a vital role in urban ecological security and social production development. In recent years, with the rapid development of social economy and the continuous acceleration of urbanization, the urban water consumption and waste discharge volume have continued to increase, and the composition of sewage has become more and more complex, which will undoubtedly aggravate the sewage corrosion of pipeline concrete, which will lead to the deterioration of pipeline durability, shortened service life, etc. Because the sewage pipeline is buried underground, its durability is often ignored by people. If it is not paid attention to, it will bring huge social and economic losses and ecological environment pollution. Therefore, it is of great practical significance to carry out research on the corrosion mechanism and durability of urban sewage pipeline concrete. Most of the existing research reports involve defect detection and health evaluation of sewage pipelines [1-4], and there are relatively few studies on the corrosion mechanism and durability design of concrete in sewage pipelines. In view of this, this paper intends to investigate and analyze the corrosion of sewage pipeline concrete in a city, and on this basis, carry out indoor simulated corrosion test research, and propose a durability design method for sewage pipeline concrete.

1.1 Corrosion Mechanism of Concrete in Sewage Pipeline

In order to find out the corrosion and damage mechanism of concrete in sewage pipelines, sewage samples were extracted from underground sewage pipelines in a city for several times from July to August 2015, and the components were analyzed. The results of water sample analysis are shown in Table 1.

Table 1 Analysis results of water samples from sewage pipes mg/L

Cl^-	SO_4^{2-}	CO_2	CO_3^{2-}	NH_3^-N	COD	$NO^{3-}N$	Na^+	Mg^{2+}	PH
301	204	56	60	106	211	<0.5	254	59	7.6~8.1

Note: The data listed in Table 1 are the peak concentrations of previous sampling.

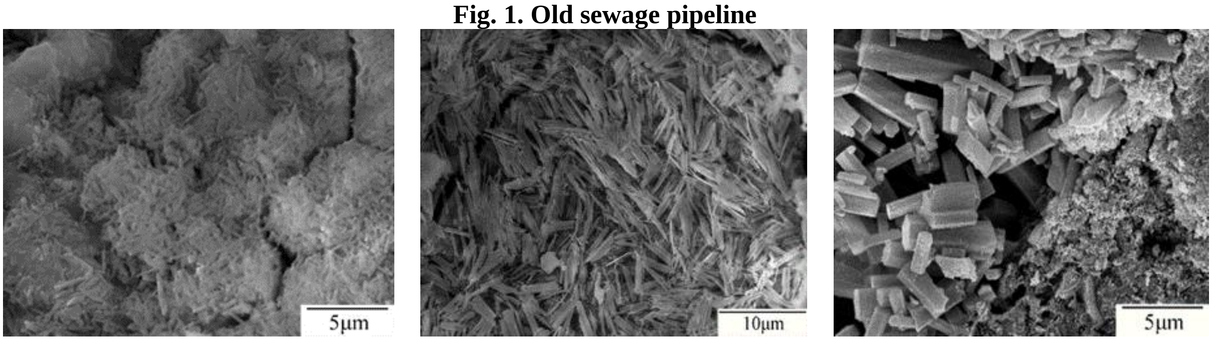
It can be seen from Table 1 that underground sewage contains a variety of harmful ions, if not treated, it will cause adverse effects on the ecological environment. For concrete pipes, the main harmful ions are chloride ions and sulfate ions.

1.2 Analysis of Corrosion Characteristics of Sewage Pipe Concrete

In order to further clarify the leading factors of corrosion and deterioration of concrete in sewage pipelines, a section of samples was taken from an old sewage pipeline dismantled in a city, as shown in the fig.1. The cement stone was extracted from the concrete of the sewage pipeline and processed into the sample required for the SEM test. The microscopic morphology and composition of the sample were analyzed by the JSM-7500F scanning electron microscope.

(a)Pipe inner wall (b) Pipe section

Fig. 1. Old sewage pipeline



(a) (b) (c)

Fig.2. Microscopic morphology of concrete cement stone sample for sewage pipeline

It can be seen from Fig. 2 that the hydration products in the concrete react with the aggressive ions in the sewage to form expansive products, which are mainly distributed in the pores, crevices and interface areas inside the concrete. The aggregation of corrosion products and the increase of expansion stress will increase the number of micro-cracks in the concrete (Fig. 2(a)), the cohesiveness of the interface between the slurry and the aggregate will decrease, and the concrete will appear loose and peel off. The number of needle-like crystals in the concrete pores is larger and the individual erosion products are larger (Fig. 2(b)). After the concrete is eroded, a large number of short columnar erosion products can be seen in the pores, and there are micro-cracks at the edge of the pores. A large number of short columnar crystals can also be observed in the mortar and aggregate interface zone (ITZ) in the concrete. The short columnar crystals are gypsum (Fig. 2(c)), which, like ettringite, are typical erosion products of concrete during sulfate erosion.

The comprehensive investigation and analysis results show that the main factor causing concrete corrosion and durability degradation of underground sewage pipelines is sulfate erosion.

II. RESEARCH ON DURABILITY DESIGN TEST OF CONCRETE FOR SEWAGE PIPELINE

The production of sewage pipelines usually uses ordinary concrete, and the durability design for the corrosion characteristics of sewage pipeline concrete is relatively lacking. Studies have shown that mineral admixtures can improve the anti-sulfate corrosion resistance of concrete [5-6], while engineering fibers can inhibit early shrinkage cracking of concrete and micro-cracks caused by expansion stress, and improve the impermeability of concrete [7-8]. In addition, waterproof coatings can also improve the impermeability of concrete [9-10], thereby improving its corrosion resistance. Therefore, this paper uses fly ash and slag, polypropylene fibers with good corrosion resistance, and cement-based permeable crystalline waterproof coatings that are environmentally friendly and resistant to acid and alkali to carry out durability design experiments on traditional pipe concrete.

2.1 Concrete Mix Design

The test reference mix ratio is from the sewage pipe concrete produced by a cement products Co., Ltd. in Henan. The concrete design strength grade is C40, the water-to-binder ratio is 0.46, the sand rate is 40%, and the slump is required to be dry slurry, which is formed by roll pressing.The concrete mix ratio for the test is shown in Table 2.

Table 2 Test concrete mix ratio

Symbol	Cement	Fly ash	Slag	Water	Sand	Stone	Gravel	Fiber	Coating
Y	304	0	0	140	644	161	1207	0	0
Y-T	304	0	0	140	644	161	1207	0	1.4~1.7
C	199	45	60	140	644	161	1207	0	0
X	304	0	0	140	644	161	1207	0.9	0
CX	199	45	60	140	644	161	1207	0.9	0

Note: Y-original proportion concrete, Y-T-painted original proportion concrete, C-concrete with mineral admixture added, X-concrete with added fiber, CX-concrete with both mineral admixture and fiber added.

The raw materials used in this test are the same as the actual sewage pipe concrete. The cement is P.O 42.5 ordinary Portland cement, the coarse aggregate is crushed stone with a particle size of 5~20mm, and the fine aggregate is river sand with a fineness modulus of 2.8. Stone chips with a particle size of 0~5mm. Mineral admixtures are grade I fly ash and grade S95 slag, the fibers are polypropylene bundled monofilament fibers (see Table 3 for technical specifications), the mixing and curing water is ordinary tap water that meets national standards, and the coating is cement-based infiltration crystallization Type waterproof coating (see Table 4 for technical indicators).

Table 3 Main technical indicators of polypropylene fibers

Diameter mm	Length mm	Tensile Str. MPa	Elastic Mo. MPa	Ulti Elo. %	Melt ℃	Burn ℃	Prop
0.048	19	350	3600	≥15	160	580	0.91

Table 4 Main technical indicators of cement-based permeable crystalline waterproof coating

Initial ≥	Final ≤	7dFlex Str. ≥	7d Elo. Break ≥	Stability	Bond Str.
20min	24h	2.8MPa	12%	Qualified	1MPa

Concrete test blocks (cubic test blocks with a side length of 100mm) are poured according to the design mix ratio, and the standard curing is 28 days. For the concrete that needs to be painted, after the curing of the concrete test block expires, apply a layer of cement-based permeable crystalline waterproof coating on the surface of the test block with a thickness of 1.0±0.05mm.

2.2 Artificial Sewage Preparation

In order to simulate the actual sewage composition and speed up the corrosion test, based on the previous investigation and analysis results and relevant literature reports [11], the sulfate concentration was increased to 10%, and the concentration of other medium ions was formulated according to the peak concentration of the actual sewage test results. The chemical reagents used in the preparation of artificial sewage are $MgCl_2$, Na_2SO_4, Na_2CO_3, NH_4NO_3. The ion concentration of artificial sewage is shown in Table 5.

Table 5 Concentrations of corrosive ions in artificial sewage (mg/L)

Cl^-	SO_4^{2-}	CO_3^{2-}	NH_3^-N	Mg^{2+}	PH
300	67605	750	600	100	8

2.3 Experiment Method

Corrosion of concrete in sewage pipes is a complex physical and chemical process, and the deterioration of its material properties is often the result of the coupling of multiple factors. In the actual environment, the middle area of the inner wall of the pipeline is often the most severely corroded area. This is because the flow of sewage in the pipeline changes all the time, and the inner wall of the pipeline will suffer from dry and wet cycles. Therefore, the experiment will adopt the soaking system of dry and wet cycle to simulate the actual working conditions of the sewage pipeline.

In the concrete sulfate corrosion test, some researchers adopted the test system of soaking and drying cycle [12-13]. Although this method can accelerate corrosion, high temperature drying will affect the deterioration of concrete and the generation of corrosion products. Therefore, this test will use natural soaking for 7 days + natural drying for 8 days, and 15 days as a cycle to carry out the cycle.

The test contents include: concrete apparent quality, cube compressive strength, splitting tensile strength, and mass loss rate. The test time is the initial index after 28 days of curing, and the dry and wet cycle is 2 months, 4 months, 6 months, and 8 months. The mechanical properties test was carried out in accordance with the relevant provisions of GB 50081-2002 "Standards for Test Methods of Mechanical Properties of Ordinary Concrete".

III. TEST RESULTS AND ANALYSIS

3.1 Apparent Mass

The apparent quality of each group of test blocks after 8 months of dry and wet cycles is shown in Figure 3.

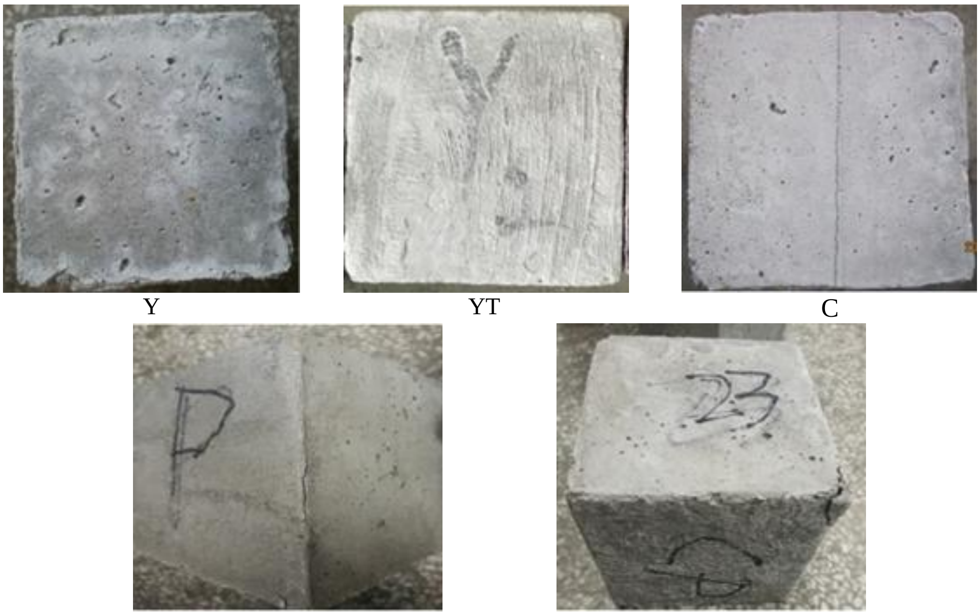


Fig.3. Apparent quality of the test block after 8 months of dry and wet cycles

It can be seen from Fig. 3 that the apparent damage of the concrete in group Y is relatively serious, and its surface has been partially loosened, warped, peeled, pitted, etc., and the edges and corners at the junction of the two sides are incomplete. The appearance of the concrete in the YT group was relatively intact, and the local coating was slightly peeled off. The edges and corners of the two groups of concrete test blocks C and X showed slight expansion cracking, corner drop, etc., but the whole was relatively intact. There was no obvious change in the concrete surface of the CX group, and the corners of the concrete showed a slight angle drop phenomenon, and the overall shape was intact.

3.2 Cube Compressive Strength

The test results of wet and dry cycle concrete cube compressive strength are shown in Table 6, and the time-dependent curve of concrete compressive strength is shown in Fig. 4.

Table 6 Wet and Dry Cycle Concrete cube compressive strength/MPa

Symbol	0 Month	2 Month	4 Month	6 Month	8 Month
Y	52.6	57.0	55.9	56.7	54.6
Y-T	53.6	56.7	58.4	55.4	53.0

C	50.2	60.7	65.8	64.6	63.5
X	47.7	56.6	57.7	60.2	57.8
CX	49.4	59.8	59.7	64.0	65.9

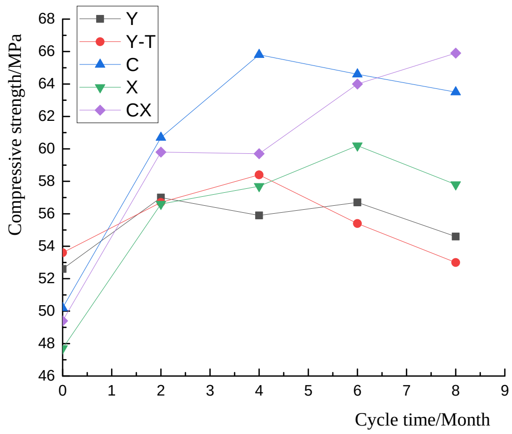


Fig.4. Time-lapse curve of concrete compressive strength

It can be seen from Fig. 4 that in the whole test period, except for the CX group, the compressive strength of the other groups showed a trend of increasing first and then decreasing. The reasons for this result are: (1) the continuous hydration reaction inside the concrete increases the compactness of the concrete; (2) the filling of the concrete pores by the corrosion products enhances the compactness of the concrete; (3) with the increase of the corrosion products with the increase of aggregation and expansion stress, the microcracks in concrete gradually increase, resulting in the decrease of concrete strength.

The peak strength of group C concrete is the largest. In addition to the above reasons, because this group of concrete uses fly ash and slag to partially replace cement, the secondary hydration effect and physical filling effect of admixtures play a positive role. The reduction reduces the Ca(OH)2 involved in the sulfate corrosion reaction, delaying and reducing the degree of concrete corrosion. The CX group concrete is mixed with mineral admixtures and polypropylene fibers at the same time. The addition of fibers will inevitably bring more interfaces, which will have a certain negative effect on the compressive strength of the concrete. However, when the concrete is attacked by sulfate, it will cause swelling When cracks occur, the uniformly distributed polypropylene fibers can effectively inhibit the generation and development of cracks, and have a positive effect on the compressive strength of concrete. Taking the test results of dry-wetting cycles for 8 months as an example, the cubic compressive strengths of the three groups of concretes C, X, and CX are 1.16 times, 1.06 times, and 1.21 times that of the original concrete, respectively. The concrete of group Y-T coated with cement-based permeable crystalline waterproof coating performed poorly, and there was no significant difference compared with the concrete of group Y.

3.3 Splitting Tensile Strength

The test results of wet and dry cycle concrete splitting tensile strength are shown in Table 7, and the time-dependent curve of concrete splitting tensile strength is shown in Fig. 5.

Table 7 Wet and Dry Cycle Concrete splitting tensile strength/MPa

Symbol	0 Month	2 Month	4 Month	6 Month	8 Month
Y	3.17	3.41	3.49	3.46	3.37
Y-T	3.30	3.43	3.52	3.56	3.57
C	3.31	3.43	3.52	3.54	3.72
X	3.41	3.50	3.54	3.61	3.80
CX	3.65	3.70	3.73	3.86	3.94

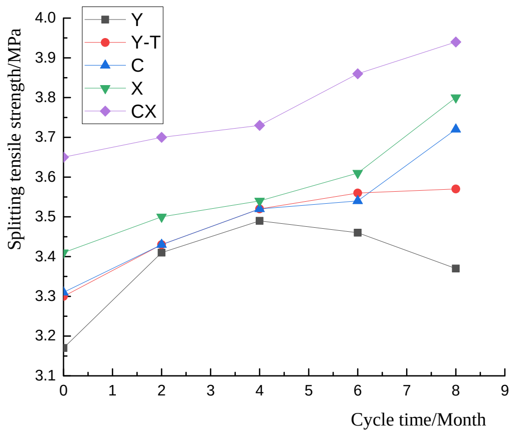


Fig. 5. Time-dependent curve of concrete splitting tensile strength

It can be seen from Fig. 5 that the splitting tensile strength of concrete in group Y showed a trend of increasing first and then rapidly decreasing, while the splitting tensile strength of concrete in group Y-T first increased slowly and then tended to be stable. Significantly different. The splitting tensile strength values of the three groups of concretes C, X, and CX are all greater than those of the other two groups of concrete of the same age, and have always shown an upward trend during the 8-month test. Among them, CX has the highest intensity, followed by X. On the one hand, polypropylene fibers enhance the split tensile strength of concrete; on the other hand, the secondary hydration reaction makes the connection between the active admixture particles and the cement hydration products continue to strengthen, which is conducive to promote the strength of cement-based materials. Growth played an important role. Taking the test results of dry and wet cycles for 8 months as an example, the splitting tensile strengths of the three groups of concretes C, X and CX are 1.10 times, 1.13 times and 1.17 times that of the original concrete, respectively.

IV. DURABILITY MECHANISM ANALYSIS

In this test, a cylindrical sample with a diameter of 15mm and a height of 15mm was drilled from a concrete test block with a dry-wet cycle for 6 months. The Micro XCT-400 testing machine was used to carry out XCT test research, and the Avizo software was used to test the XCT of the concrete sample. The scanned image is 3D reconstructed, as shown in Fig. 6.

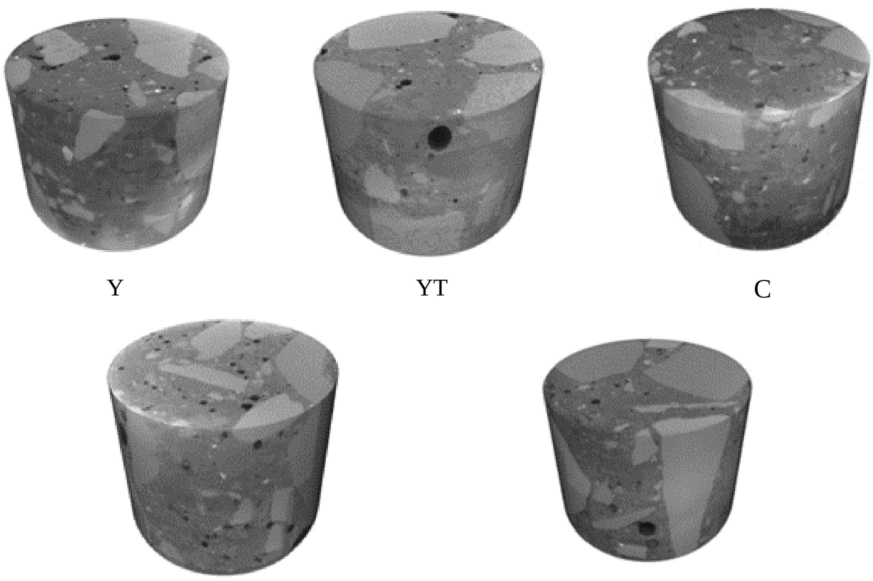
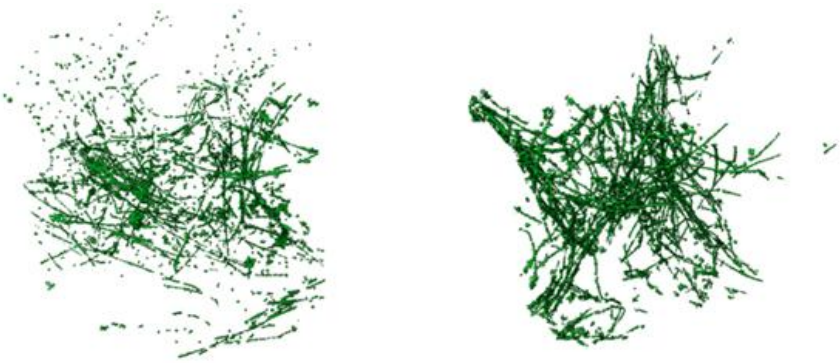


Fig.6. 3D reconstruction map

It can be found from Fig. 6 that the reconstructed graph accurately restores the actual condition of the concrete sample, and there is no dislocation phenomenon, and the restoration degree is high. From the image, not only the distribution of aggregates can be clearly seen, but also the pores on the surface of the sample can be observed. In order to further understand the internal information of the concrete sample, more detailed decomposition and quantitative calculation of the three-dimensional reconstruction map are required.

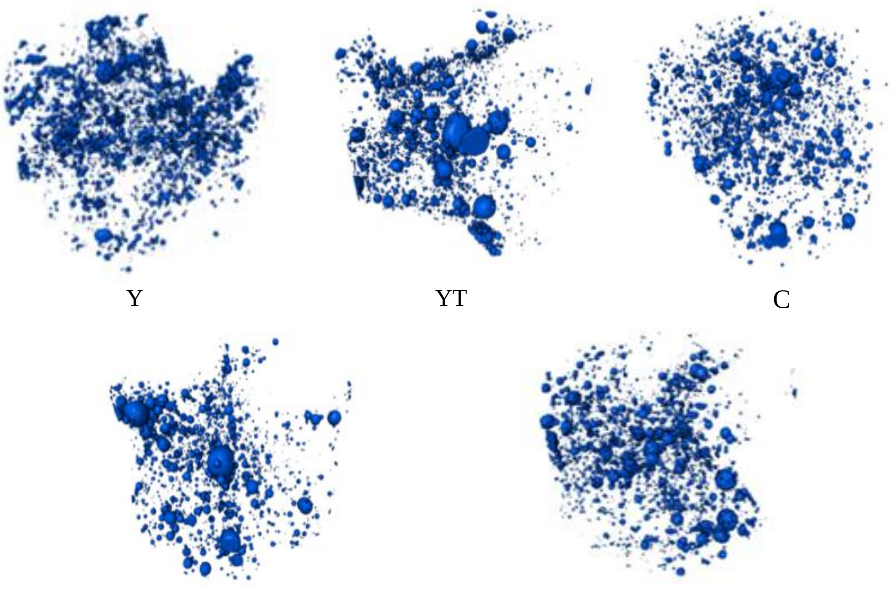
The fiber distribution inside the X and CX concrete samples is shown in Fig. 7. It can be seen that polypropylene fibers have good dispersibility in concrete, and are distributed in a three-dimensional and disorderly manner, and there is no clustering phenomenon. This feature ensures that polypropylene fibers can play a better role in strengthening and crack resistance, and improve the corrosion resistance of concrete materials in sewage. Durability in the environment. At the same time, polypropylene fiber itself also has good corrosion resistance, which is more suitable for corrosive environment than steel fiber.



X CX

Fig.7. Spatial distribution of polypropylene fibers

The distribution of pore structure in each group of samples is shown in Fig. 8. Due to the randomness of sampling, the volume proportion of aggregates in the samples ranged from 23.1% to 58.7%, resulting in differences in the volume proportion of cement stone in each sample. In order to eliminate this difference, the pore volume percentage was converted to the volume ratio of pores in the cement stone, and the results are shown in Table 8.



Y YT C

X CX

Fig.8. Spatial distribution of pore structure

Table 8 Pore volume percentage/%

Y	Y-T	C	X	CX
1.655	3.01	1.487	2.763	2.295

It is not difficult to see from Fig. 8 that the pore distribution in the concrete samples of group C is uniform and the pore size is small. It can be seen that the secondary hydration effect and physical filling effect of the active admixture can optimize the pore structure of the cement-based material. It can be seen from Table 7 that the pore volume percentage of the concrete samples in group C is the smallest. After adding polypropylene fibers, the pores in the cement stone will increase. The pore structure of the concrete samples in the Y-T group is relatively poor, the pore size is larger and the pore volume percentage is higher, which is consistent with the test results of mechanical properties. The results show that an appropriate amount of mineral admixture has the best effect on improving the pore structure of concrete, while the effect of cement crystalline waterproof coating is poor.

V. CONCLUSIONS

This paper investigates and analyzes the corrosion of sewage pipeline concrete in a city, and on this basis, conducts indoor simulated corrosion test research, and proposes a durability design method for sewage pipeline concrete. The main conclusions are as follows:

(1) The main factor of concrete corrosion and damage of sewage pipelines in this city is sulfate erosion.

(2) The use of mineral admixtures and polypropylene fibers to modify pipeline concrete can effectively improve the durability of pipeline concrete in a sewage corrosive environment. Double-mixing fly ash and slag, and adding an appropriate number of polypropylene fibers have the best effect. good. Compared with the original mix concrete, the cubic compressive strength and splitting tensile strength of the CX group concrete increased by 20.7% and 16.9%, respectively.

(3) Under the test conditions of this paper, the improvement of cement-based crystalline waterproof coating on the durability of pipeline concrete is not obvious.

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