Research on the Influences of Resistivity for Steel Fiber Reinforced Concrete

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Keywords: Resistivity; Steel fiber reinforced concrete (SFRC); Orthogonal test

Abstract: In the subway engineering, increasing the resistivity of main structural material can improve the corrosion resistance to the stray current and the durability of structure. It is greatly significance to increase the resistivity of concrete by optimizing its mix proportion and realizing the influence of raw material on resistivity. Furthermore, it can also extend the service life of structure. This paper presents orthogonal experimental results from tests conducted on 9 groups of 27 specimens to evaluate the influence of three parameters such as steel fiber content, fly ash content and corrosion inhibitor content on the resistivity of steel fiber reinforced concrete (SFRC). Experimental results analyzed with range analysis and variance analysis indicate that fly ash content has a significant effect on the resistivity of SFRC, while both of steel fiber content and rust inhibitor content have not obvious. Analytical results provide an evidence for the application of SFRC in subway environment.

Introduction

In the last few years, several measurement methods used for concrete resistivity have been widely concerned by researchers. The resistivity value of concrete can be measured by using a simple test method, which can be taken as an indicator to evaluate the material performance and quality of concrete or the durability of concrete structure [1]. Several experimental studies have been conducted to investigate the resistivity of concrete [2, 3, 4]. These studies have shown that: (i) the measurement of resistivity can provide a basic reference for the durability evaluation of existing concrete structure, and (ii) the resistivity of SFRC is larger than that of reinforced concrete, and (iii) the stray current corrosion resistance of SFRC is better than that of reinforced concrete.

In the subway operating environment, the rebar is prone to be corroded due to the existing of stray current, which will affect the durability of main structure and shorten its service life [2]. The corrosion of steel fiber and rebar caused by stray current reduces when the resistance value of SFRC increases, therefore the durability of main structure is better. It is exceedingly significant to extend the service life of concrete structure, which will come true by improving the resistivity of SFRC with an appropriate design of concrete mix proportion. In this paper, orthogonal experiments on the influence of steel fiber content (SF), fly ash content (FA) and corrosion inhibitor content (CI) on the resistivity of SFRC was carried out. Both the variance analysis and range analysis are used to analyze the results. Analytical results provide an evidence for the application of SFRC in subway environment.

Design of Orthogonal Experiment

Parameters. The method of orthogonal experiment can fully reflect the inherent law of test by as little test number as possible and consider as more the factors as possible at the same time. It's a scientific method to found out the optimum levels and main factors [6]. Therefore, this method is adopted in this experiment. A total of 9 groups (27 specimens, as shown in Figure 1) with three parameters such as steel fiber content (A-SF), fly ash (B-FA) content and rust inhibitor (C-CI) content are designed to investigate the influence of resistivity for SFRC. All the three parameters are divided into 3 levels (as shown in Table 2) with percentage by weight.

Table 1 summarizes the factors, levels and experimental results for orthogonal experiment.

Table 1 L9 (3^4) The orthogonal experiment design and result

Specimens	A-SF [%]		B-FA [%]		C-CI [%]		Resistivity [Ω•m]
	Column	Levels	Column	Levels	Column	Levels	
1	1	0.50%	1	0%	3	4%	220
2	2	1%	1	0%	1	0%	253.3
3	3	1.50%	1	0%	2	2%	305
4	1	0.50%	2	15%	2	2%	410.8
5	2	1%	2	15%	3	4%	441.7
6	3	1.50%	2	15%	1	0%	436.7
7	1	0.50%	3	30%	1	0%	569.2
8	2	1%	3	30%	2	2%	513.3
9	3	1.50%	3	30%	3	4%	668.3

Figure 1 Specimens of SFRC

Mix Proportion. The concrete grade is C40 with the water-cement ratio of 0.41. Table 2 summarizes all the mix proportions of SFRC.

Table 2 All the mix proportions of SFRC

Specimens	Steel fiber [kg]	Water [kg]	Cement [kg]	Fly ash [kg]	Sand [kg]	Coarse Aggregate [kg]	Water reducer [kg]	Corrosion inhibitor [%]	Slump [cm]
1	39.25	166	405	0	717	1075	7.29	16.2	18
2	78.5	168	410	0	750	1035	8.2	0	9
3	117.75	170	415	0	781	995	9.13	8.3	12.5
4	39.25	166	344	61	717	1075	8.1	8.1	10
5	78.5	168	349	61	750	1035	8.61	16.4	17
6	117.75	170	353	62	781	995	9.96	0	16
7	39.25	166	284	122	717	1075	8.12	0	13
8	78.5	168	287	123	750	1035	8.61	8.2	19
9	117.75	170	291	125	781	995	10.83	16.64	17

Note: Size of specimen is 100mm×100mm×100mm, as shown in Fig. 1.

Testing Principle. The resistivity of SFRC specimens was measured with the condition of curing period of 28d and moisture content of 100%. The method of two electrodes is used to measure the resistivity in this test, as shown in Figure 2. Two parallel electrodes are set on both sides of specimen. The resistance value between the two electrodes is measured by multimeter (type MT-2017), which is a traditional analogue type and produced by Baogong Co.Ltd in Taiwan, China. The resistivity of concrete can be calculated from the formula shown as the following [4].

$$\rho = R\frac{A}{L} \tag{1}$$

Where ρ is resistivity in Ω•m, A is cross-sectional area in m^2, all the cross-sectional area of the specimens are 0.01 m^2, R is resistance in Ω, L is length of specimen in m.
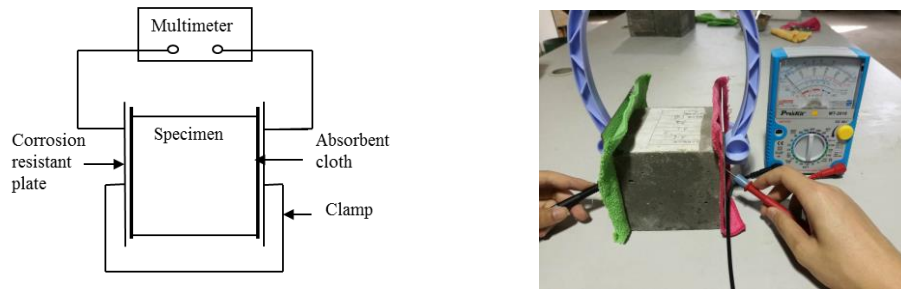
Figure 2 The measure principle of resistivity for method of two electrodes

Result Analysis

The range analysis method is simple and easy to be understood. The major-minor order of test factors and best combination of best factors can easily be obtained by simple calculation and indicators. However, the test results have been influenced by test errors, factors and some interaction between factors. But the range analysis can't estimate the error bound which exists in the test and test data. The errors can't be analyzed. In order to evaluate the influence of the three parameters on resistivity more objectively, both the range analysis method and variance analysis method are used to discuss the test result in this paper. Both the analyzed results calculated by the two methods indicated that the content of FA significantly affect the resistivity of SFRC, while the influence of the other two parameters are not obvious (as shown in Table 3 and Table 4). Compared to range analysis, the results of variance analysis are quantitative with a quantity of 90%, as shown in table 4 noted by (*).

Table 3 The orthogonal experiment result with range analysis method

Indicator	Parameters	A-SF	B-FA	C-CI
Resistivity ($\Omega \cdot m$)	K_1	1200.0	778.3	1259.2
	K_2	1208.3	1289.2	1229.1
	K_3	1410.0	1750.8	1330.0
	k_1	400.0	259.4	419.7
	k_2	402.8	429.7	409.7
	k_3	470.0	583.6	443.3
	Range (R)	70.0	324.2	33.6

Table 4 The orthogonal experiment results with variance analysis method

Sources of variation	Sum-of-squares	Degrees of freedom	Mean sum of square	The value of Fi	Significant level α
A-SF	9428.0	2	4714.0	1.8	No effect
B-FA	157761.0	2	78880.5	29.6 [*]	0.05significant effect
C-CI	1788.8	2	894.4	0.3	No effect
Error	5325. 9	2	2662.9	/	/
Summation	174303.7	8	/	/	/

Note：$F_{0.01}$（2,2）=99， $F_{0.05}$（2,2）=19， $F_{0.1}$（2,2）=9， $F_{0.25}$（2,2）=3

Parameter Analysis

The relative magnitudes of the different parameters are discussed by Range analysis. Furthermore, the results were tested for significance by variance analysis. The variation tendency of resistivity affected by the three parameters is showed in Figure 3.

From Figure 3, it shows that that the resistivity of SFRC has a positive relationship with the content of FA. The resistivity increases with the increasing of content of FA. The filling effect of FA improves the internal microstructure of SFRC and smaller its pore structure. Therefore, the

resistivity of SFRC improves with the increasing of FA by reducing the content of calcium hydroxide in SFRC. The same results have been carried out by Liu & Zan [7] and Hussain [8]. Due to the disordered distribution of steel fiber, the conductivity of SFRC rarely improves compared to normal concrete [9]. Therefore, the variation of steel fiber content has not obviously affected the resistivity of SFRC. The content of corrosion inhibitor adding in the test is lower and its influence on resistivity of SFRC is also not obvious.
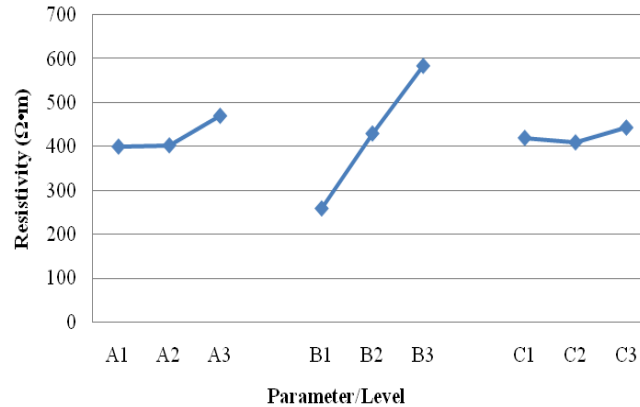

Figure.3 The influence of the three parameters on resistivity of SFRC

Summary

This paper presents orthogonal experimental results from tests conducted on 9 groups of 27 specimens to evaluate the influence of three parameters such as steel fiber content, fly ash content and corrosion inhibitor content on the resistivity of SFRC. Experimental results analyzed with range analysis and variance analysis indicate that: (i) the resistivity of SFRC increases with the increasing of content of fly ash, it can increase the resistivity of SFRC by increasing the content of fly ash in the application of subway engineering, therefore the durability of structure can be better; (ii) both of steel fiber content and rust inhibitor content have not obvious.
In this paper, only the three parameters are discussed. More researches such as the influence of external parameters need to be carried out in future.

Acknowledgements

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