SERVICE LIFE PREDICTION OF BASALT FIBER REINFORCED CONCRETE UNDER SALT FREEZE-THAW CYCLES

Wenjie Xu,and Zhirui LI

*School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou 450046, China; 1542315987@qq.com, * 97410419@qq.com*

ABSTRACT

To address the reduced durability of concrete structures under salt freeze-thaw erosion in Northwest China, basalt fiber reinforced concrete and common concrete with different mixing amounts were selected to predict their service life in three freeze-thaw conditions. Results showed that the damage on concrete under fresh water freeze-thaw condition is lower than that caused by salt freeze-thaw erosion, the addition of basalt fiber can effectively slow down the degradation of mechanical properties of concrete under salt freeze-thaw erosion, and the lowest degradation rate is reached when the content of basalt fiber is 0.15%. Fiber hinders the expansion of cracks and reduces the pores, and in turn improves the frost resistance durability of concrete. The service life prediction results obtained with Gray Model and Weibull Model are roughly similar, among which, Gray Model needs less sample volume, while Weibull Model presents more accurate prediction results.

KEYWORDS

Basalt fiber reinforced concrete, Mechanical property, Weibull Model, Gray Model, Service life prediction

INTRODUCTION

Aging is a common phenomenon of concrete materials with passage of time, and freeze-thaw damage is one of its main reasons. Affected by environmental temperature change, free water in concrete materials produces expansion pressure and permeability pressure. The combination of the two causes denudation, internal and external crack expansion, and internal structural looseness of concrete materials, reducing their fracture performance and flexural toughness. In Northwest China, because of large amount of salt ions and acid group anions in the soil, most concrete structures' surface layers peel off or crack before expiry due to salt freeze-thaw erosion, impacting its normal functions. Therefore, it is of great practical significance to research the mechanical property attenuation rules and damage mechanisms of concrete materials in simulated environment.

Basalt fiber (BF) is a kind of natural green fiber with superior performance. Scholars at home and abroad have done a lot of research on its properties and applications recently. Li Weimin[1] et al. studied the impact compression properties of basalt fiber reinforced concrete (BFRC), and drew a conclusion that BF can improve the mechanical properties of concrete and the degree of improvement is concerned with the mixing amounts. Feng Zhongju [2] et al. predicted the service life of concrete with different mix proportions on the basis of local temperature and Gray Theory. Xie Liyun [3] et al. established a linear and polynomial damage degradation model based on relative dynamic elastic modulus and strength as damage variables, which can accurately predict the degree of freeze-thaw damage and degradation of fiber recycled concrete. Ahmet B.Kizilkanat [4] et al. compared the mechanics and fracture properties of BFRC with glass fiber reinforced concrete, and came to a conclusion that the extensibility, bending resistance and crack resistance of BFRC are superior to those of glass fiber reinforced concrete. Boxin Wang et al. [5] re-searched the

durability of concrete under the erosion and freeze-thaw action of carbonate and sulfate ions, and established new logical function models on concrete freeze-thaw damage. R. Ralegaonkar et al.[6] proposed the mix proportions of short-cut BF that strengthens the mortar performance and evaluated its advantages and disadvantages in application. Audrius Vaitkus [7] et al. densified the concrete mixture and found that its design performance can be significantly improved by adding silicon powder, steel or polypropylene crude fiber. At present, most research focus on the performance improvement of fiber concrete at early stage, but mechanical attenuation rules and damage mechanisms of BFRC in actual service have not been elaborated.

There is few research on the damage mechanisms of BFRC after salt freeze-thaw erosion so far, thus the present paper studies the mechanical properties of BFRC under the action of freeze-thaw cycles with basalt fiber mixing amount and freeze-thaw media as variables, and compares the analysis results with common concrete (PC). On this basis, Weibull Model and Gray Model are used to predict the frost resistance durability of BFRC with four mixing amounts under the environment of Gansu Province. The variation rules of parameters as the freeze-thaw cycles and fiber contents change are analyzed to lay the theoretical and experimental foundation for fracture mechanics research of concrete.

EXPERIMENT OVERVIEW

## Materials and mix proportions

Tab. 1 - Basalt fiber performance index

Fiber length （mm）	Diameter （μm）	Density （kg/m³）	Fracture ductility rate （%）	Elastic Modulus （GPa）	Tensile strength （MPa）	Moisture content （%）
18	7-20	2 650	3.2	90~110	3 000~3 500	≤0.1

Tab. 2 - Concrete mix design

Species	Cement kg/m3	Water kg/m3	Fine aggregate kg/m3	Coarse aggregate kg/m3	Fly ash kg/m3	Sand rate /%	Fly ash /%
PC	265	180	640	1 200	115	35	30
BFRC	265	180	640	1 200	115	35	30

Po42.5 cement was adopted in the experiment. Fine aggregate was natural river sand, with fineness modulus of 2.9, water-binder ratio of 0.45 and mud content of 1.8%. Continuous grading coarse aggregate with particle size of 5mm-20mm was adopted, and no needle flake particles were allowed. The 19.45g/m3 JDU-1 high performance concrete air-entraining agent was used as additive, accounting for 0.005% of the specimen. This study applied fresh water and 18mm short-cut BF, whose main performance indexes were shown in Table 1. In addition, BFRC with fiber contents of 0%, 0.05%, 0.1%, 0.15% and 0.2% was selected, with mix proportions shown in Table 2.

Indoor rapid freeze-thaw experiment
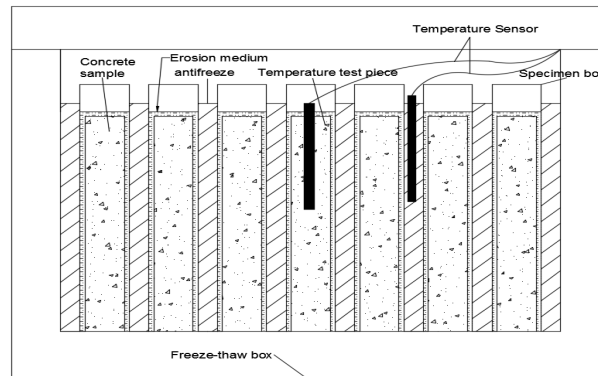
Fig. 1 - Concrete freeze-thaw test design

The specimens were made and maintained in accordance with the Standard for Testing Methods of Concrete Physical and Mechanical Properties [8]. The experiment selected three freeze-thaw solutions, respectively fresh water, 3% NaCl, and 5% Na_2SO_4, and four fiber mixing amounts, and took PC as a control group. In each freeze-thaw environment, 21 cubic specimens and 24 prism specimens were designed. Before specimen production, the inner wall of the test mold was coated with release agent, the dosage of experimental materials was accurate to ±0.5% and the dosage of aggregate was accurate to ±1%. In order to avoid caking effect caused by uneven distribution of fibers during mixing with water, coarse aggregate and fibers were dry mixed for 2min before concrete mixing to ensure the uniform distribution of fibers. Then the mixing and molding of concrete was completed within 15min. The molded specimens were covered with impermeable film and stored at 20±5℃ for 1-2 days and nights. Then the film was removed and the specimens were numbered. The specimens were maintained for 28d, and then the freeze-thaw test was carried out, with 25 freeze-thaw cycles as a period.

HDK-9 rapid freeze-thaw testing machine was used for indoor rapid freeze-thaw test, with test layout shown in Figure 1. The experimental process is as follows:

(1)   The specimens were molded, numbered and maintained for 24d, then taken out and immersed in three different freeze-thaw erosion solutions for 4d, with liquid level 30mm higher than the specimens. The freeze-thaw test began after 28d.

(2)   After 28d, take the specimens into test molds containing different freeze-thaw media with liquid level always 5mm higher than the specimens and number them. Put the specimens into the freeze-thaw machine and make sure that the freeze-thaw liquid level was higher than test molds' liquid level.

(3)   Each freeze-thaw cycle was completed within 2-4h, with thawing time not less than 1/4 of the whole process.

(4)   The center temperature of the specimens was -20℃-7℃, better from -18℃±2℃ to 5±2℃.. The cooling time from 16℃ to 3℃ and heating time from 3℃ to 16℃ were not less than 1/2 of each cycle.

(5)   Specimens in the freeze-thaw machine were always kept at full load to ensure the same freeze-thaw effect.
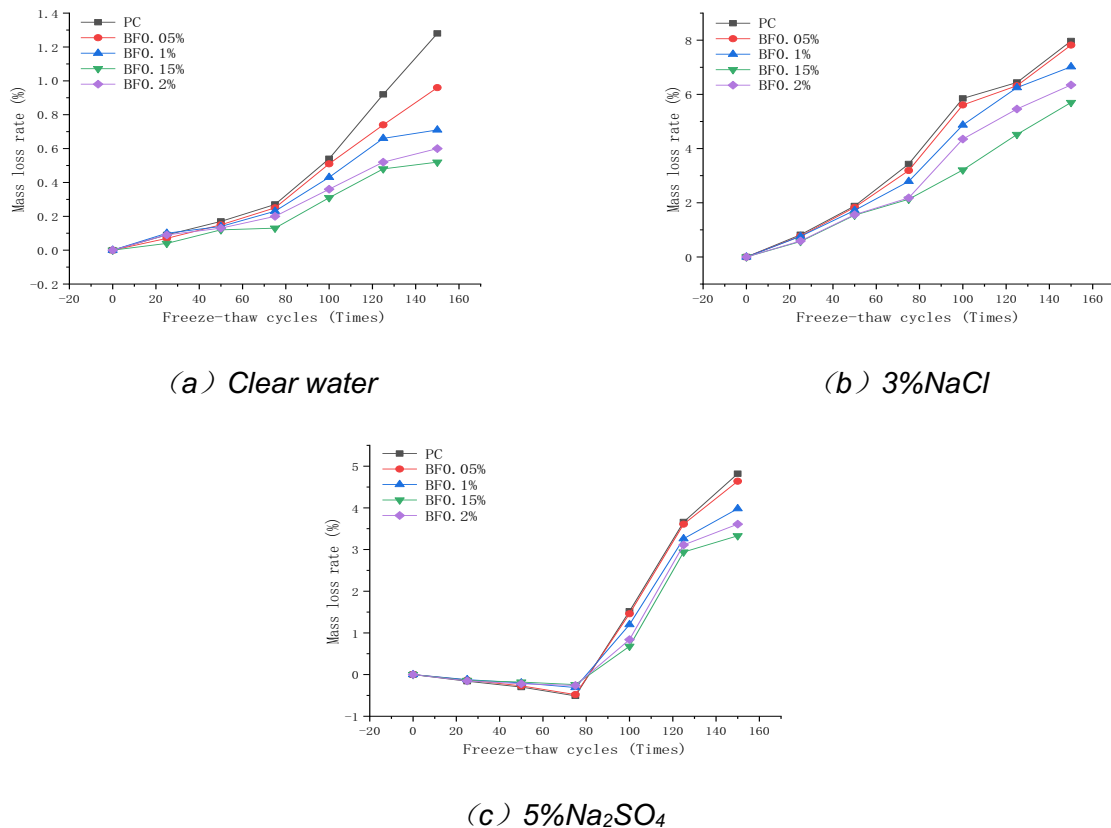
RESULTS ANALYSIS

Mass loss analysis

（a）Clear water

（b）3%NaCl

（c）5%Na$_2$SO$_4$

Fig. 2 Change curve of concrete mass loss rate

Figure 2 demonstrates the variation curves of mass loss rate of PC and BFRC in three types of freeze-thaw media. The mass loss varies due to different erosion mechanisms of different media. According to Figure 2, with the increase of loads on the specimens, small cracks appear inside the specimens due to freeze-thaw action. The mass loss of specimens tends to increase as the freeze-thaw cycles continue, and such mass loss gradually extends to the surface layer, causing the mortar and aggregate to fall off. As control group, PC shows many small vertical cracks on the surface, while fewer vertical cracks are found on the concrete specimens mixed with BF, indicating that BF prevents the formation of vertical cracks. Finally, PC is seriously damaged, with peeling on the edges, while concrete specimens mixed with BF shows better integrity and less peeling. The tensile strength generated inside the concrete effectively slows down its failure speed. Less BF shows no significant influence, but excessive BF causes more holes and tiny cracks, reducing the tensile strength. When the fiber content is 0.15%, the specimens show the best integrity, with less peeling.

In Figure 2 (a), in the fresh water freeze-thaw test, the mass loss of specimens increases slowly during the first 75 freeze-thaw cycles and begin to accelerate after 75 cycles. Under water pressure effect, only water can enter the surface layer through subtle channels, and no major erosion is generated, thus mass loss of the whole group is relatively small. In Figure 2 (b), in the 3% NaCl freeze-thaw test, the mass loss rates of fiber concrete and PC under the condition of 50 freeze-thaw cycles showed the same trend, and were both less than 2%. After 50 freeze-thaw cycles, the mass loss rate of concrete showed an increasing trend. The increasing trend of BF0.05% was close to that of PC. After 100 freeze-thaw cycles, the 0.05% mass loss of PC and BF has exceeded 5% and met the conditions for stopping the test, the mass loss of specimens increases

rapidly, as NaCl can absorb water, which increases the water retention time of specimens and exacerbates the damage. Furthermore, the existence of permeability pressure aggravates the peeling of aggregate and mud on the surface layer. In Figure 2 (c), in the 5% Na_2SO_4 solution. After 150 freeze-thaw cycles, the mass loss of PC is close to 5%, the curve of BF0.05% mass loss rate is same with that of PC, and the lowest mass loss rate of fiber concrete can reach 3.33%. The mass loss of concrete increases gradually for the first 75 cycles due to SO_4^{2-} crystals sticking to the specimens. With the in-crease of freeze-thaw cycles, cracks on the specimens expand and the parts of specimens begin to fall off, demonstrating a sharp increase of mass loss.
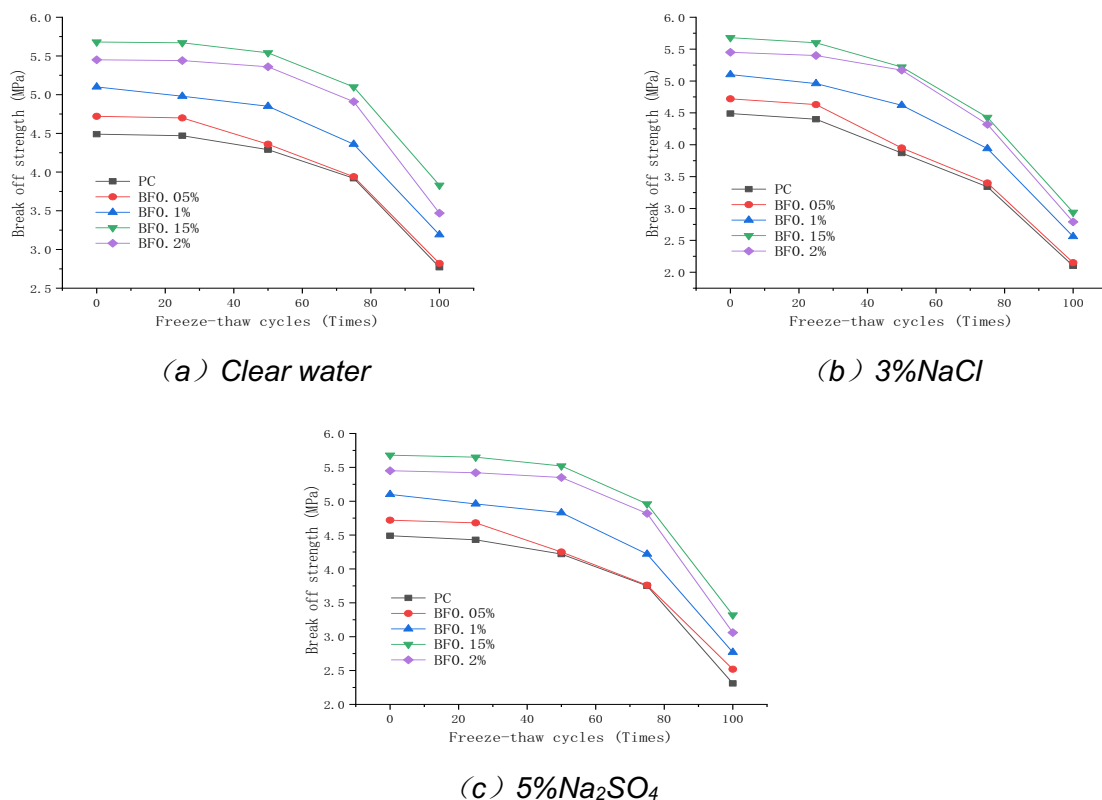
Flexural strength analysis

（a）Clear water

（b）3%NaCl

（c）5%Na_2SO_4

Fig. 3 - Curve of concrete flexural strength change

Figure 3 shows the variation curves of flexural strength of PC and BFRC in three types of freeze-thaw media. The toughness of BF mainly relies on the bridging effect of fibers across the two edges of cracks. Such toughening effect effectively restrains the deformation of concrete matrix, hinders the formation of micro crack zone, and increases the cohesive force of fracture process zone, so as to prevent the expansion of macro cracks and improve the fracture toughness of concrete. The bridging effect of BF can also consume some energy for concrete matrix in the loading process, increasing the energy consuming capacity of concrete in the fracture process and improving its fracture energy. However, according to Figure 3, the flexural strength of BFRC specimens decreases with the increase of BF content when it exceeds 0.15%, as the addition of BF increases the weak transition layers, pores and defects between fiber and concrete matrix while increasing the energy consuming capacity in the fracture process. Too many fibers cause more internal defects of concrete, reducing its fracture toughness and fracture energy. In brief, the flexural strength of all BFRC specimens is higher than that of concrete without BF, so it can be concluded that BF can effectively improve the fracture properties of specimens.

Based on Figure 3(a), Under the action of freezing and thawing of clear water, the curve of BF0.15% and BF0.2% does not decrease significantly after 50 freeze-thaw cycles, and the flexural

strength of BF0.15% and BF0.2% decreases slightly after 75 freeze-thaw cycles. After thawing, the strength began to drop sharply, and the slope of the BF0.2% flexural strength decline curve was the largest, indicating that the BF0.2% concrete specimens were damaged more severely than BF0.15% after 100 freeze-thaw cycles. A certain amount of BF added into the concrete can not only increase the initial flexural strength of concrete, but also effectively slow down the decrease of its flexural strength in the fresh water freeze-thaw condition. Before complete breakage, the flexural strength of specimens mixed with BF is significantly higher than that of PC after the same numbers of freeze-thaw cycles. In Figure 3(b), After 50 freeze-thaw cycles, both the flexural strength of fiber concrete and PC show a downward trend, but the degrees and rates of decline are different. The flexural strength of fiber concrete decreases before 75 freeze-thaw cycles, but the highest flexural strength still meets the relevant requirements of C30 concrete, after 75 cycles, the flexural strength decreases significantly. For common concrete or concrete mixed with fewer fibers, the flexural strength decreases steadily after 25 freeze-thaw cycles, and the decrease rate gradually increases, indicating that BF enhances the frost resistance and salt erosion resistance of concrete to a certain extent. In Figure 3(c), The BF0.05% flexural strength curve of the concrete specimen is close to that of PC after 50 freeze-thaw cycles. The flexural strength of concrete mixed with fiber before 75 freeze-thaw cycles does not change significantly, and it fails after 100 freeze-thaw cycles. The concrete specimens are damaged after 100 freeze-thaw cycles. This is because micro cracks appear inside the concrete as the freeze-thaw cycles continues. The sulfate solution infiltrated into the concrete specimens undergoes physical and chemical reactions, producing physical crystals or chemically expansive products. The addition of fibers inhibits the expansion of micro cracks, but it restrains the crystallization of dilatant generated in hydration reaction, which expands the internal damage. The flexural strength of the specimens suddenly drops when re-straining ability of fiber network structure in the specimens reaches the peak. After 100 freeze-thaw cycles, the flexural strength of fiber concrete is still greater than that of PC, indicating that a certain amount of fiber can effectively inhibit the production of dilatant in the reaction of sulfate and hydration products in the concrete, so as to slow down cracking and peeling and improve the frost resistance of concrete.

Compressive strength analysis
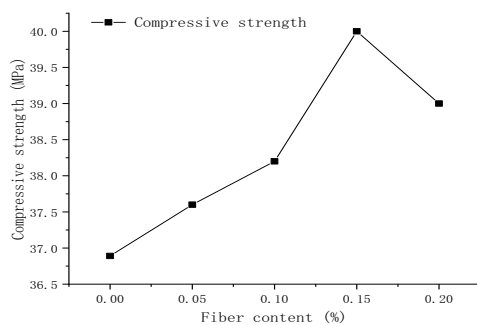
（a）Relationship between fiber content and compressive strength when not frozen and thawed

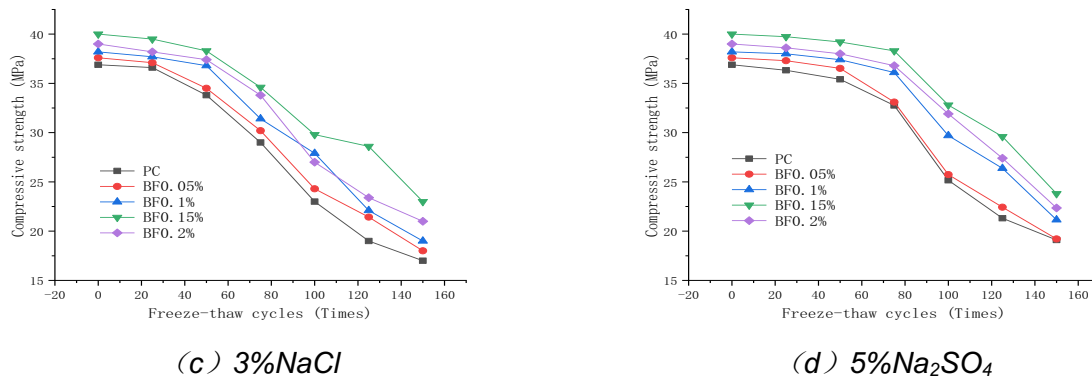（b）Clear water

（c）3%NaCl

（d）5%Na$_2$SO$_4$
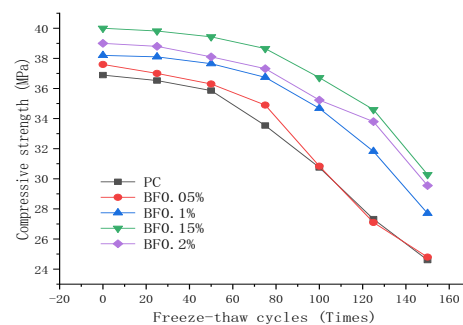
Fig. 4 - Change curve of concrete compressive strength

Figure 4 shows the variation curves of compressive strength of PC and BFRC in three types of freeze-thaw media. Essentially, internal damage resulting from freeze-thaw cycles is responsible for the compressive strength decrease. All the four mixing amounts of BF enhance the compressive strength of concrete after 28d, and such enhancement effect first increases and then decreases with the increase of fiber content. BF forms a network structure inside the concrete, and most fibers are in an oblique and slightly lateral position. Single fiber bonded to the cement matrix enhances the bonding strength and inhibits the lateral expansion of concrete. The fiber network structure strengthens the integrity of concrete, facilitating the integration of aggregate and cement and effectively improving the compressive strength of specimens.

According to Figure 4, the descent speeds of compressive strength of BFRC in the three types of media are lower than those of PC. One reason is that, due to disorderly distribution of BF in the specimens reduces the stress concentration, which changes the trends and ex-tension paths of cracks, and increases the fracture energy. In addition, the three-dimensional frameworks formed by BF inside the matrix support the aggregate settlement and relieve the shrinkage and deformation of concrete, improving the compressive strength of concrete. With the increase of basalt fiber content, the fiber in concrete matrix tends to cake, resulting in other defects. As the freeze-thaw cycles continue, the relevant products increase and expand, after the service capacity of the fibers reaches the maxi-mum value, the compressive strength of concrete gradually decreases.

Based on Figure 4(a), the addition of BF before freeze-thaw test can increase the compressive strength of concrete, and it reaches the optimal value when the content of BF is 0.15%. In Figure 4(b), After 75 freeze-thaw cycles, the compressive strength has shown a significant downward trend and it decreased to 90% of the initial strength. After 100 freeze-thaw cycles, the compressive strength has dropped to 83.3% of the initial strength. However, the strength of BF0.1%, BF0.15%, and BF0.2% did not decrease significantly before 75 freeze-thaw cycles, and the strength decreased after 75 freeze-thaw cycles, but the decline was not significant. The compressive strength of BFRC drops significantly after 100 freeze-thaw cycles in fresh water, and the whole decline curve is relatively gentle. In Figure 4(c), After 25 freeze-thaw cycles, the strength of the specimen has decreased significantly, and with the increase in the number of freeze-thaw cycles, the rate of decline has continued to increase. After 100 freeze-thaw cycles, the strength has dropped to 23 MPa, which is only 62.3% of the initial strength. However, the strength of BF0.15% and BF0.2% began to decrease significantly after 75 freeze-thaw cycles, and the decline rate of BF0.2% became larger. After 100 freeze-thaw cycles, the strength of BF0.2% was less than BF0.1%. After 100 freeze-thaw cycles, the decline rate of BF0.2% slowed down, and the decline rate of BF0.1% increased. The decline rate of BF0.15% decreased significantly after 50 freeze-thaw cycles. After 75 freeze-thaw cycles, it increased, and the rate of decline rate slowed down after 100 freeze-thaw cycles. After 150 freeze-thaw cycles damage has occurred. In Fig. 4(d), Fiber concrete and ordinary concrete have little change in strength under the first 75 freeze-thaw cycles. PC and

BF0.05% will produce less strength loss after 75 freeze-thaw cycles. After 75 freeze-thaw cycles, the strength loss rate will increase and the strength will decrease. Fast-er, after 150 freeze-thaw cycles, the compressive strength has dropped to 19MPa, which is only 50% of the initial strength. However, the compressive strength of BF0.1%, BF0.15%, and BF0.2% did not change significantly after 75 freeze-thaw cycles, and the slope of the curve was small. More than 75 freeze-thaw cycles increased the slope of the curves of BF0.1%, BF0.15%, BF0.2% and decreased the compressive strength significantly. The strength decrease rate of BF0.1% and BF0.15% is greater than that of BF0.2%. After 100 freeze-thaw cycles, strength decline of BF0.1% and BF0.15% has slowed down, but the BF0.2% strength still declines at a relatively large rate. In salt solution, the internal gaps of specimens are filled with a series of products generated in physical and chemical reactions of salt ions penetrated into the specimens, so the compressive strength in the early and medium stage changes slightly. As the freeze-thaw cycles continue, cracks in the concrete expand and new cracks appear due to chlorine salt erosion and ice-crystal pressure effect, aggravating internal defects and reducing the compressive strength.

FREEZE-THAW CYCLE ACTION MODEL AND SERVICE LIFE PREDICTION

Based on analysis of mechanical properties of PC and BFRC after freeze-thaw action in the last chapter, it is concluded that a certain amount of fiber can enhance the frost resistance of concrete. Therefore, three comparatively optimal mixing amounts of BFRC, respectively 0.1%, 0.15% and 0.2%, were selected for service life prediction, and Weibull Model and Gray Model were used for analysis.

Service life prediction based on Weibull Model

At present, there are three common probability distribution models used for service life prediction of concrete, respectively Normal Model, Lognormal Model and Weibull Model. Normal Model and Lognormal Model show less applicability and flexibility in reliability analysis, thus failure states of concrete cannot be actually simulated [9]. The Weibull Model is relatively simple and flexible, applicable to various situations. It presents fewer requirements on sample size compared with the Normal Model and Lognormal Model. Capable to provide relatively accurate prediction results with a small amount of data, it is widely used in mechanical property analysis of concrete materials [10].

Tab. 3 - Weibull Distribution of Concrete with Different Fiber Contents in NaCl Solution

Experimental conditions	Number of freeze-thaw cycles (n)	Survival rate R(n)	$X=ln(n)$	$Y=ln(ln(1/Rn))$
BF0.1% NaCl	25	0.991	3.2189	-4.7060
	50	0.9741	3.9120	-3.6404
	75	0.8843	4.3175	-2.0959
	100	0.7411	4.6052	-1.2052
	125	0.6547	4.8283	-0.8590
	150	0.4826	5.0106	-0.3167
BF0.15% NaCl	25	0.992	3.2189	-4.8243
	50	0.9752	3.9120	-3.6844
	75	0.9031	4.3175	-2.2835
	100	0.7928	4.6052	-1.4602
	125	0.721	4.8283	-1.1174
	150	0.5649	5.0106	-0.5602
BF0.2% NaCl	25	0.9918	3.2189	-4.7995
	50	0.975	3.9120	-3.6762
	75	0.892	4.3175	-2.1690
	100	0.7533	4.6052	-1.2613
	125	0.6872	4.8283	-0.9805
	150	0.5132	5.0106	-0.4048

Tab. 4 - Weibull Distribution of Concrete with Different Fiber Contents in Na$_2$SO$_4$ Solution

| Experimental conditions	Number of freeze-thaw cycles (n)	Survival rate R(n)	$X=ln(n)$	$Y=ln(ln(1/Rn))$
BF0.1% Na$_2$SO$_4$	25	0.997	3.2189	-5.8076
	50	0.9894	3.9120	-4.5416
	75	0.9362	4.3175	-2.7192
	100	0.7988	4.6052	-1.4932
	125	0.7122	4.8283	-1.0806
	150	0.5636	5.0106	-0.5562
BF0.15% Na$_2$SO$_4$	25	0.9972	3.2189	-5.8767
	50	0.9926	3.9120	-4.9026
	75	0.9423	4.3175	-2.8229
	100	0.8276	4.6052	-1.6648
	125	0.7846	4.8283	-1.4164
	150	0.603	5.0106	-0.6815
BF0.2% Na$_2$SO$_4$	25	0.9971	3.2189	-5.8416
	50	0.9924	3.9120	-4.8758
	75	0.9317	4.3175	-2.6487
	100	0.8082	4.6052	-1.5467
	125	0.7312	4.8283	-1.1613
	150	0.571	5.0106	-0.5792

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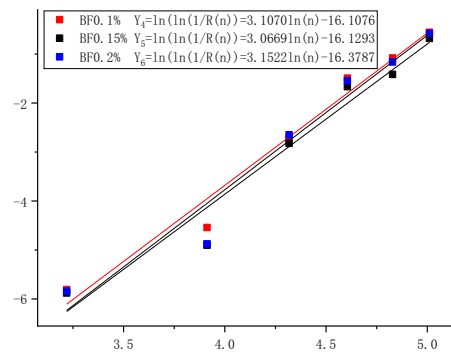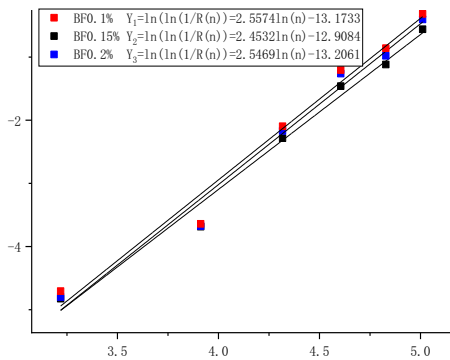
Fig. 5 - Linear regression diagram of durability life in NaCl

Figure 6 - Linear regression of durability life in Na$_2$SO$_4$

Tab. 5 - Weibull linear regression results of durability life in NaCl

Basalt content	Durable life	b	c	R2
0.1%	N1	2.5574	-13.1733	0.9729
0.15%	N2	2.4532	-12.9084	0.9810
0.2%	N3	2.5469	-13.2061	0.9754

Tab 6 - Weibull linear regression results of durability life in Na$_2$SO$_4$

Basalt content	Durable life	b	C	R2
0.1%	N4	3.1070	-16.1076	0.9694
0.15%	N5	3.0669	-16.1293	0.9492
0.2%	N6	3.1522	-16.3787	0.9477

Substituting the obtained parameters into function Y=bx + C, the Weibull distribution life prediction models of specimens with three mixing amounts under the freeze-thaw action of Na$_2$SO$_4$ and NaCl can be obtained respectively. Taking various parameters of Weibull distribution model into consideration, this paper uses two parameters to predict the durability of BFRC. Taking D(n) as the damage degree of concrete after n freeze-thaw cycles, the reliability function R(n) = 1 - D(n) is obtained based on the calculation formulas of concrete related variables, and linear regression analysis is performed by the least square method. The analysis results of BFRC in two kinds of freeze-thaw media are summarized as follows, where Tables 3 and 4 are Weibull distribution values, Tables 5 and 6 are linear regression results, and Figures 5 and 6 are regression curves:

According to relevant specifications, the specimens are considered expired when their relative elastic modulus reaches 60% of the initial value. Substituting R(n) = 0.6 into the above formula, conclusion is drawn as follows: N1 = 132 times, N2 = 146 times, N3 = 137 times, N4 = 143 times, N5 = 154 times, and N6 = 145 times. It can be concluded that the optimum durability is achieved when the content of basalt fiber reaches 0.15%, and damage caused by NaCl to concrete is higher than that of Na$_2$SO$_4$ under the action salt freezing.

Gray Model

Belonging to fuzzy prediction, Gray Model can be used to derive unknown elements in the system, and finally obtain the complete information with ambiguity [11]. Substitute the obtained data into formulas (1) and (2) for verification.

$$C = \frac{S_1}{S_2} \tag{1}$$

Where, S1 is the residual variance, S2 is the original data variance, and C is the posterior error ratio. When C is less than 0.35, the accuracy of prediction results is high, and when C is less than 0.50, the accuracy is qualified. The minimum error probability P is:

$$P = P\left(\left|\varepsilon^0(i) - \bar{\varepsilon}\right| < 0.6745 S_2\right) \qquad (2)$$

Where, $\bar{\varepsilon}$ is the residual mean, and $\varepsilon^0(i)$ is the predicting residual at different times. When P is larger than 0.95, the accuracy of prediction results is high, and when P is larger than 0.80, the accuracy is qualified. The relative dynamic elastic modulus prediction models and accuracy test results of concrete under different working conditions are summarized in Table 7, among which, all the models meet the test requirements and show high accuracy.

Tab. 7 - Relative dynamic elastic modulus prediction model and accuracy test

Freeze-thaw solution	Fiber content	Posterior difference ratio /C	probability error /P	Predictive model
3%NaCl	0.1	0.27	1.00	-8.9105e-0.1262t+9.9105
	0.15	0.27	1.00	-10.9392e-0.1004t+11.9392
	0.2	0.27	1.00	-9.60345e-0.1160t+10.6034
5%Na₂SO₄	0.1	0.3	1.00	-10.8542e-0.1029t+11.8542
	0.15	0.34	1.00	-12.7191e-0.0865t+13.7191
	0.2	0.31	1.00	-11.4173e-0.0973t+12.4173

Tab. 8 - The relative dynamic elastic modulus of basalt fiber concrete based on gray. prediction

Number of freeze-thaw cycles	BF0.1%		BF0.15%		BF0.2%	
	3%NaCl	5%Na₂SO₄	3%NaCl	5%Na₂SO₄	3%NaCl	5%Na₂SO₄
0	1.000	1.000	1.000	1.000	1.000	1.000
25	1.056	1.061	1.045	1.054	1.052	1.059
50	0.931	0.958	0.945	0.967	0.937	0.960
75	0.821	0.864	0.855	0.887	0.834	0.871
100	0.723	0.779	0.773	0.813	0.743	0.791
125	0.638	0.703	0.699	0.746	0.661	0.717
150	0.562	0.634	0.633	0.684	0.589	0.651
175		0.572	0.572	0.627		0.590
200				0.575		

Where, t stands for the number of freeze-thaw cycles. At the 25th freeze-thaw cycle, t = 1; at the 50th freeze-thaw cycle, t = 2; and so on. The calculation results refer to cumulative value of dynamic elastic modulus, which is 1 when t = 0; the dynamic elastic modulus at t = 1 is the value at t = 1 minus the value at t = 0; the dynamic elastic modulus at t = 2 is the value at t = 2 minus the value at t = 1, and so on. The prediction results of relative dynamic elastic modulus are shown in Table 8.

According to the specification, the specimens are considered expired when their relative elastic modulus reaches 60% of the initial value, conclusion is drawn as follows: N1 = 125 times, N2 = 150 times, N3 = 150 times, N4 = 175 times, N5 = 125 times, and N6 = 150 times. It can be concluded that the optimum durability is achieved when the content of basalt fiber reaches 0.15%, and damage caused by NaCl to concrete is higher than that of Na₂SO₄ under the action salt freezing.

Service life prediction and analysis of BF

Li Jinyu [12] et al. concluded that the average number of freeze-thaw cycles in different regions around China is as follows: 120 times in Northeast China, 84 times in North China, and 118

times in Northwest China. He also pointed out that one outdoor freeze-thaw cycle is equivalent to 12 indoor freeze-thaw cycles.

Tab. 9 - Life prediction of basalt concrete

WEIBULL	3%NaCl			5%Na$_2$SO$_4$		
	BF0.1%	BF0.15%	BF0.2%	BF0.1%	BF0.15%	BF0.2%
Northwest	13.4	14.8	13.9	14.5	15.6	14.7
North China	18.8	20.8	19.5	20.4	22	20.7
Northeast	13.2	14.6	13.7	14.3	15.4	14.5

Tab. 10 - Life prediction of basalt concrete

GRAY MODEL	3%NaCl			5%Na$_2$SO$_4$		
	BF0.1%	BF0.15%	BF0.2%	BF0.1%	BF0.15%	BF0.2%
Northwest	12.7	15.2	12.7	15.2	17.7	15.2
North China	17.8	21.4	17.8	21.4	25	21.4
Northeast	12.5	15	12.5	15	17.5	15

Based on the environment in Gansu Province, this study takes the annual freeze-thaw cycles in Northeast China, North China, and Northwest China to calculate the frost-resistant durability of BFRC in Gansu Province with two prediction models, as summarized in Tables 9 and 10.

Comparing Weibull Model with Gray Model, it is concluded that the salt-freezing resistance of concrete is optimal when the fiber content is 0.15%, and the damage of 5% Na$_2$SO$_4$ on concrete structures is slightly less than 3% NaCl. In service life prediction, the Weibull Model can use relative dynamic elastic modulus damage as a variable to derive more accurate number of freeze-thaw cycles. The Gray Model can only be used for fuzzy inference based on the present data, and final data refers to data obtained before the relative dynamic modulus of elasticity reaches 60%, thus such results obtained are relatively general.

CONCLUSIONS

(1) This study uses Weibull Model and Gray Model to conduct service life prediction of BFRC under the environment of Gansu Province with three mixing amounts. The prediction results obtained with these two models are similar. With different emphases, the results obtained by Weibull Model are more accurate than Gray Model, and optimum durability is achieved when the content of BFRC is 0.15%. In salt invasion, the damage caused by SO_4^{2-} is less than that caused by Cl^-.

(2) With the increasing number of freeze-thaw cycles, the compressive strength and flexural strength of BFRC in three kinds of media reduce to varying degrees, and the mass loss rate-increases. The influence degree of these three kinds of freeze-thaw media on the mechanical properties of BFRC is: 3% NaCl > 5% Na$_2$SO$_4$ > water.

(3) In the same freeze-thaw environment, the frost resistance capability of concrete first in-creases and then decreases with the increase of BF content. The reason is that BF slows down the expansion of micro cracks in the specimens in the stress process, showing a toughing and anti-cracking effect and slowing down the decline of frost resistance. However, excessive BF causes weaker transition layer between itself and concrete matrix, causing more internal defects and weakening the frost resistance of concrete. As a consequence, optimal frost resistance is obtained when the fiber content is 0.15%.

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