Experimental Study of Fiber Reinforced Concrete Based on Freeze-Thaw Environment

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Abstract: The ordinary concrete has a poor frost resistance. It is often destroyed in the practice of low temperature engineering. By means of investigating the influence of different fiber on the durability of concrete, based on different number of freeze-thaw test block, combined with the concrete water-cement ratio, also the relative dynamic elastic modulus, mass lose rate and the relative compressive strength. It is concluded that when the parameter of the C40 concrete fiber is about 10%, it has the most engineering significance.

1 INTRODUCTION

In the engineering projects in recent decades, large volume of concrete has been widely used, including house building, tunnel construction, road and bridge construction, etc.. With basalt as impact factor, the reference [1] researches the properties of concrete under various environmental conditions. Scholars Mu Ru [2] et al. studied the durability of concrete by different freeze-thaw tests and analyzed the mechanism of freeze-thaw test in detail. Scholars Liu Weidong [3], et al. studied the impact of fiber content upon concrete damage and deterioration by building the freeze-thaw cycle damage constitutive relationship of concrete. Scholars Zhou Zhiyun [4] et al. reflect the frost resistance of concrete indirectly by its dynamic elastic modulus. Scholars Wei Qiang [5] et al. analyzed the damage of freeze-thaw environment upon concrete more visually by magnifying concrete test block residue after freeze-thaw with Scanning Electron Microscope (SEM). Scholars Chen Sijia [6] et al. studied the influence of different mix ratios of reinforced concrete upon frost resistance of structure under freeze-thaw environment.

Most buildings are exposed to natural environment and contact with the atmosphere. Rainwater, sandstorm, etc. in the atmosphere causes irreversible damage to buildings. The difference of climates and geographical locations directly influences the durability difference of large-volume concrete structure, and however, frost is the main factor in north area. Freeze-thaw damage are caused to concrete structure in cold north area, thus the large-volume concrete has potential safety hazard and even is damaged before the end of its service life, which causes directly economic loss to the country. In the Code [8], the environment is divided into five types, including freeze-thaw environment. This shows that the influence of freeze-thaw environment upon the construction industry is enormous. Shenyang is in North China and in almost half a year its temperature is below zero, and thus, the requirement for the frost resistance of construction materials is more rigorous. The scheme taken in this test is adding man-made mineral fiber in the aggregates of concrete test block to research the intensity change of concrete under freeze-thaw environment and reflect the durability of concrete structure under lower temperature in actual projects.

2 FREEZE-THAW TEST AND TEST METHOD

2.1 Freeze-thaw Test

The two freeze-thaw test methods often used are rapid freeze-thaw technique, one is air freeze-thaw technique, and the other is water freeze-thaw technique. This test used water freeze-thaw technique. The freeze-thaw temperature in the test is -20℃-20℃, and the freeze-thaw time is two hours with an interval of one hour. The test instruments used include JCD freeze-thaw machine, TM-II dynamic elastic modulus measurement instrument, electronic scale, etc. the test block was freeze-thawed for 200 times and test data was acquired every 40 times for comparison and analysis. Total 6 groups of test blocks were prepared (1 group for backup), each group had 6*4 standard concrete test blocks, 144 in total. Before preparation of test blocks, inspections shall be done to check if all materials conform to the test standards, if cements are hydrated, and if gravel particle diameter conforms to the standard, etc.

What needs to be noted is that, because it is a water freeze-thaw cycle test, to make sure the test blocks are fully immerged in water, the influence of air upon the freeze-thaw test was avoided by immerging concrete test blocks 3mm under the water before the test.

2.2 Test Material and Model Preparation

Water used in this test was the domestic drinking water in Shenyang, 425# ordinary Portland cement was used, with the density of 3.12g/cm3. The particle size of the gravel used was 7-18mm, and the medium coarse river sand and ordinary man-made mineral fiber were used. According to the Code [7], the concrete test blocks prepared for this test were 150mm*150mm*150mm cubic blocks and 100mm*100mm*400mm cuboid blocks. The designed strength of ordinary concrete was C40. Table 1 shows the mix ratios of concrete test blocks with different proportions of fiber contents and corresponding slump degrees. The concrete test blocks were cured under standard conditions for 28d in standard environment.

2.3 Mix Ratio Design of Test Block

Whether the design of mix ratio is reasonable or not directly affects the result of test. The mix ratio should be verified for reasonablity repeatedly in strict accordance with the steps of mix design. The mix ratio design of this test is based on different fiber contents, the mass of each aggregate mixing content in 1 m3 of concrete is 2450kg, see Table 1 for details. According to the steps of mix design for ordinary concrete, the test designed and determined two types of the concrete water-cement ratios: W/C=0.46 and 0.51

3 RELATIVE DYNAMIC ELASTIC MODULUS OF CONCRETE

The performance of concrete after being freeze-thawed is usually evaluated by two standards in the Concrete Code [7]. The first method is to measure with relative dynamic elastic modulus, only when the dynamic elastic modulus ranges from 60% to 100%, it is deemed that the concrete has not been destroyed in the freeze-thaw damage environment. The second standard is to take whether the mass loss rate of concrete test block after the freeze-thaw cycles exceed 5% as a measure to evaluate the concrete. Due to the loss and crack of concrete after freezing and thawing, the concrete may has water in some parts. Such factors may cause errors in the mass of concrete. Therefore, sometimes the mass loss ratio may increase on the contrary, which may influence the test result. Considering such factors, the water on concrete should be removed when acquiring the concrete mass data after freezing and thawing. In this test, the test blocks were preliminarily treated with fan and absorbent paper, which was weighed, and analyses were made by combining relative dynamic elastic modulus data of concrete. From Table 2, it can been found that the compressive strength of concrete decreases as freeze-thaw cycles increase, and comparing ordinary concrete with the test blocks with different fiber contents, the concrete strength is damaged more obviously as the freeze-thaw cycles increase. As fiber content in the concrete increases, the compressive strength of concrete under the same low temperature environment is better, and test blocks with approximately 10% fiber content are more suitable for projects. As freeze-thaw cycles increase, especially after 120 cycles, whether the concrete contains fiber or not, the concrete strength decreases to 50% of that under standard curing environment, and after freeze-thaw cycles increase to above 160, the strength of test block will be fluctuating at 25% of that under standard curing environment. This proves that after approximately 120 freeze-thaws, the concrete has basically lost its strength, and freeze-thaw is the most important factor that damages concrete strength.

Table 1：Concrete mix ratios with different fiber contents.

	W/C	Unit：1m³/kg					Slump
		Cement	Water	Gravel	Sand	Fiber	Degree/mm
Ordinary concrete	0.46	371.7	171	1354.2	553.1	0.0	165
5% fiber concrete	0.51	335.3	171	1256.6	564.6	122.5	140
10% fiber concrete	0.51	335.3	171	1172.1	526.6	245.0	125
15% fiber concrete	0.51	335.3	171	1080.7	485.5	377.5	120
20% fiber concrete	0.46	371.7	171	1006.3	411.0	490.0	95

From the data in Table 2 and curve in Figure 1 it can be found that the relative modulus of each fiber test block is above 60% when freeze-thaw cycle ranges from 0 to 120, while the relative modulus of ordinary test block has already decreased to below 60% after 160 or more freeze-thaw cycles and that of the 5% and 10% fiber test blocks has also dropped to below 60% after 160 freeze-thaw cycles. Only the relative dynamic elastic modulus of 5% and 10% fiber test blocks is above but close to 60% after 200 freeze-thaw cycles. This shows that concrete durability can be improved by fiber, but after the concrete is freeze-thawed for enough times, its durability can still be damaged. From the entire curve in Figure 1, it can be found that the freeze-thaw cycle and relative dynamic elastic modulus of concrete have a linear curve relation, namely that the relative modulus of concrete decreases as concrete freeze-thaw cycles increase.

In Figure 1, the change of the relative modulus of fiber test blocks tends to slow down after 120 freeze-thaw cycles. The probable reason is that when the freezing and thawing just starts, the initial defects of the test blocks and materials are fully developed in the freezing environment, thus leading to the quick decrease of relative modulus of concrete. When the defects in the concrete material develops to a certain extent, the change of relative dynamic elastic modulus of concrete slows down as the curve of freeze-thaw count goes down.

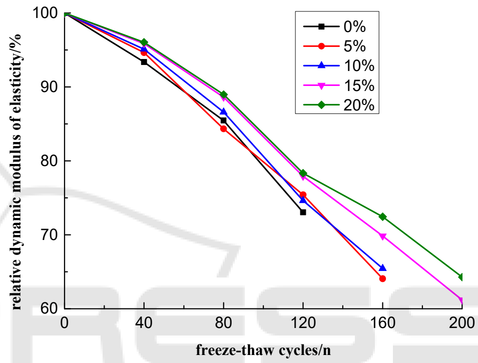

Figure 1：Curve of relation between freeze-thaw cycle and relative dynamic elastic modulus of concrete with different fiber contents.

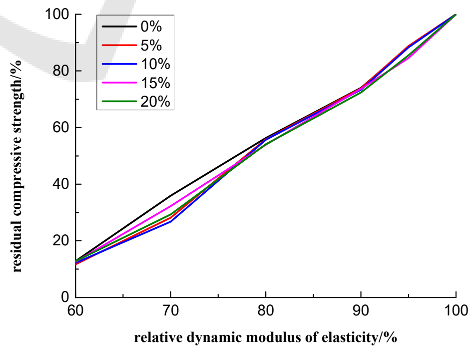

Figure 2：Line diagram of relative dynamic elastic modulus and residual compressive strength of concrete with different fiber contents.

Table 2：Relative dynamic elastic modulus, mass loss rate and compressive strength of different concretes after freezing and thawing.

	Freeze-thaw count	Relative dynamic elastic modulus/(%)	Compressive strength before freeze thaw/MPa	Compressive strength after freeze thaw/MPa	Relative compressive strength/(%)	Mass loss rate/（%）
Ordinary concrete	0	100.000%	40.000	40.000	/	/
	40	93.372%	40.000	34.863	87.158%	0.924%
	80	85.463%	40.000	25.622	64.055%	0.389%
	120	73.037%	40.000	17.478	43.695%	2.753%
	160	/	40.000	10.390	25.975%	/
	200	/	40.000	4.651	11.628%	/
5% fiber concrete	0	100.000%	46.000	46.000	/	/
	40	94.647%	46.000	40.619	88.302%	0.285%
	80	84.332%	46.000	33.031	71.807%	1.282%
	120	75.421%	46.000	20.316	44.165%	3.115%
	160	64.061%	46.000	12.034	26.161%	4.184%
	200	/	46.000	5.175	11.250%	/
10% fiber concrete	0	100.000%	49.000	49.000	/	/
	40	95.113%	49.000	43.021	87.798%	0.427%
	80	86.597%	49.000	35.878	73.220%	0.863%
	120	74.619%	49.000	21.707	44.300%	2.857%
	160	65.443%	49.000	13.063	26.659%	3.964%
	200	/	49.000	5.728	11.689%	4.886%
15% fiber concrete	0	100.000%	50.000	50.000	/	/
	40	95.863%	50.000	43.695	87.390%	0.337%
	80	88.616%	50.000	33.881	67.762%	0.986%
	120	77.918%	50.000	23.034	46.068%	1.779%
	160	69.843%	50.000	13.176	26.352%	3.864%
	200	61.194%	50.000	7.742	15.484%	4.482%
20% fiber concrete	0	100.000%	51.000	51.000	/	/
	40	96.034%	51.000	44.462	87.180%	0.119%
	80	88.976%	51.000	36.064	70.714%	0.652%
	120	78.329%	51.000	23.418	45.918%	1.597%
	160	72.448%	51.000	14.093	27.633%	3.696%
	200	64.268%	51.000	7.392	14.494%	4.558%

The overall trend of Figure 2 can basically ben considered as a positive correlation. It can be roughly divided into four stages: in the first stage, the percentage of residual compressive strength of concrete (especially the concrete with high fiber content) directly dropss by 25% immediately within a very low relative dynamic elastic modulus range (10%), for which the reason may be the internal aggregate of the concrete is not tight enough, resulting in a rapid lost of concrete strength. In the second stage, relative dynamic elastic modulus of concrete changes slowly when the residual compressive strength is 60%-75%, the strength of concrete is fully utilized. In the third stage, the residual strength is 25%-60%, as freeze-thaw count increases, the concrete strength is almost completely destroyed, and the relative dynamic elastic modulus of concrete drops more rapidly comparing with the first and second stages. In the fourth stage, the residual strength is 10%-25%, the elastic modulus of concrete is already less than 60%, and concrete has been completely destroyed.

4 MASS LOSS RATE OF CONCRETE

Figure 3 is a scatter plot showing the relation between freeze-thaw and mass Loss of concrete with different fiber contents, in which the curve data fitted software ANSYS is used as a reference. Conclusions can be drawn from Table 2 and Figure 3 as follows:

From the fitted curve and mass loss ratio line, it can be seen that the change mass loss rate of ordinary test block has no obvious rule, and the mass loss rate even decreases when freeze-thaw cycles reach near 80. The reason may be that the surface of test blocks surface sheds and cracks after frozen resulting in the water content in model aggregate rises, and thereby the mass of concrete increases after frozen.

The mass loss rate of 5% fiber concrete exceeds 5% after the freeze-thaw cycles exceed 160, however, both cost and concrete agitation have a certain influence when the fiber content is too high. Therefore, it is considered that 10% fiber concrete is most cost-effective and engineering practical.

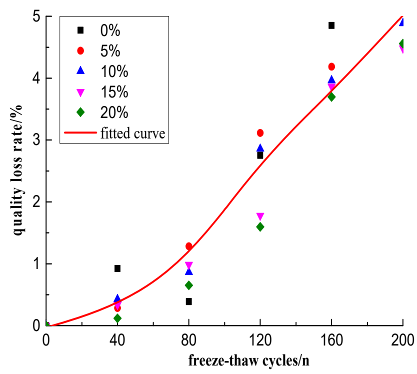

Figure 3：relation between freeze-thaw cycle count and mass loss rate of concrete with different fiber contents.

5 CONCLUSIONS

Water has a great influence on the frost resistance of concrete under freezing conditions. Thus, reducing the water-cement ratio as much as possible without increasing the strength and other properties of the concrete in general is an effective measure to enhance its frost resistance.

Under the freeze-thaw environment, the residual compressive strength percentage of concrete and the relative dynamic elastic modulus are basically positively correlated, so it is appropriate to use the relative dynamic elastic modulus as an indicator for the durability performance of concrete in low temperature freeze-thaw environment;

Proper amount of fiber content can enhance the durability of concrete. Combining with the economical and practical nature of concrete, it is concluded that concrete with approximately 10% fiber content is the most suitable.

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