

Structure And Material Research For SFRC Pavement

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Abstract: The thesis, on the basis of summarizing the present study and appliance at abroad and home, integrates the present test standard with the special environment of pavement, to discuss systemically the design theory of pavement for supplying the reliable theory for the design. Then, ANSYS is used to make the stimulation calculation of SFRC, and to analyze the result, then as well as to put forward the slab length about 16m; Finally, to test the major property of SFRC verifies the favorable property of Steel fiber reinforced concrete, and connecting the practical conditions of pavement, by the structure design, verifies the feasibility of applied to supply a better way for designing the pavement.

Key words: Steel Fiber Reinforced Concrete, Numerical simulation, performance.

1. Introduction

Steel fiber reinforced concrete (SFRC) is a new kind of multiply-composite material using concrete as the matrix, where the steel fiber is dispersed. The dispersed steel fiber could reduce the stress concentration of the matrix caused by dynamic loads, so as to control the emergence and development of the interstice of the concrete, and improve the cracking resistance of it[1]. Meanwhile, owing to there is prodigious binding power on the interface between the concrete and steel fiber, the external force could be passed to the steel fiber which has a very high tensile strength and high elongation rate, so steel fiber reinforced concrete counteracts external force as a uniform whole[2]. SFRC improve the bending strength, impact toughness, crack resistance, anti-fatigue performance and durability of the matrix concrete dramatically, it is modified into composite materials with good toughness originally belonged to brittle material. So the appliance of Steel fiber reinforced concrete could reduce the road deck crack, pavement off board and so on significantly, improves the service life of the road, and improves the comfortableness and safety of driving and highway capacity much better than ordinary roads.

SFRC has excellent physical property and mechanical performance, its main manifestation as follows: (1) has remarkable shock resistance; (2) has higher modulus of elasticity and higher bending strength, shear strength; (3) has excellent crack resistance and anti-fatigue performance; (4) has good toughness; (5) modifies deformation behavior obviously; (6) its abrasion resistance is modified; (7) its strength and weight ratio increases, its construction is simple, high ratio of material, so it has advantageous application prospect and it is economical[3].

At present, domestic and foreign research institutions have done some related research to Steel fiber reinforced concrete pavement, but there is no a mature and comprehensive design method as is known to all.

2. Calculation Modeling

In order to provide scientific proof for the structure design and calculation of SFRC, according to the definition of SFRC actual use features and considering the environment of the pavement and the simplicity of the design and construction, we look the pavement structure as three-Decker, which is comprised of Steel fiber reinforced concrete layer, basement layer and soil-matrix, then this new structure can be calculated and analyzed with simulating the complex problem of interlayer binding

by ANSYS's contact element, which is based on three-dimensional finite element (3-D FEM) and multi-layer elastic system theory.

2.1 The effective calculation scope of foundation

In the SFRC structure, the foundation is elastic half-space body and is infinite in horizontal and vertical direction, but it can't be divided into unit in infinite domain in the process of solving the finite element equations, so we should be confirmed three-dimensional sizes of foundation reasonably.

This article chooses the initial sizes by 7.5m×16m (two pieces of boards which is 8 meters long) and then expands the plane sizes and foundation depth gradually, not until the stress converges do we stop observing the influence of bottom under external loads, finally, we could determine the effective sizes of the foundation. The paper determines the effective calculated depth and surface sizes on the base of calculation and analysis.

2.2 Effective calculation depth of foundation

The basic parameters of the model choose as follows: the slab dimensions of SFRC pavement is 7.5m×16m, the parameters of it shows in Table 1, the slab dimensions of the foundation is also 7.5m×16m, the modulus of resilience of the top surface of basement layer $E_t = 186$ MPa, Poisson ratio is 0.30. The external loads are standard axial load BZZ-100 in the newest pavement design standard.

Table 1. the material parameters of each layer in the finite element method

N	Structural layer	Materials	The modulus of resilience E/MPa	Poisson ratio
1	Asphalt layer	Asphalt concrete	1200	0.25
2	Steel fiber concrete layer	Steel fiber concrete	31000	0.20
3	Basement layer	C10 concrete	16000	0.25
4		Steel fiber	200000	0.30
5	Wall rock	Rock	5000	0.25

On the basic of the model and the change of the depth of foundation, the results of calculation are shown in Table 2.

Table 2. The calculation depth of foundation

Depth(m)	2	3	4	5	6
Main stress (MPa)	0.261	0.255	0.251	0.249	0.247

As the Table 2, we could observed that when the depth of foundation is increase gradually, the convergence speed of main stress is very slow, and it is linear decreased basically, but after the depth of foundation is more than 4m, the main stress has converged. So we choose the efficient depth of the foundation as 4 m.

2.3 Effective plane sizes of foundation

Choosing the same parameters listed above, the depth of foundation is 4m, plane sizes is $a \times b$, then the results show in Table 3:

Table 3. The plane sizes of foundation

N	1	2	3	4	5
Plane sizes (m×m)	4.5×16	5.5×16	6.5×16	7.5×16	8.5×16
Main stress (MPa)	0.264	0.257	0.253	0.251	0.250

From the table above, when the plane sizes of foundation are increase, the convergence tendency of main stress is obvious; when the plane sizes is more than $7.5 \times 16\text{m}$, the main stress is barely decreasing, it means that the main stress is almost converged, so we choose the plane sizes of foundation as $7.5 \times 16\text{m}$ [4].

The results indicated that choosing the effective calculation scope of foundation as $B = 7.5\text{ m}$, $L = 16\text{ m}$, $Z = 4\text{ m}$, could satisfy the requirement of accuracy, in the process of analyzing the composite asphalt pavement structure by three-dimensional finite element (3-D FEM).

2.4 Calculating results and analysis

Based on “Specifications of Design of Cement Concrete Pavement for Highway” (JTJ D40-2002), the location of critical loads is in the middle of longitudinal edge. By the finite element model, this paper has calculated the results of the variation of stress on different boards, which is in the bottom of steel fiber concrete and the joint of the concrete pavement, without regard to the effect of the temperature stress, and the length of the boards are 8m,10m,12m,14m,16m,18m,and 20m.The results indicate that with the increase of the length of the boards the maximum tension stress of the bottom is located in the joint of adjacent boards[5], same as the maximum vertical shear strength. The results are shown in Table 4.

Table 4. The results of the stress of different boards in the bottom or the joint

	6	8	10	12
Max-tension stress of the bottom (MPa)	-0.041	-0.036	0.034	0.035
Max-vertical shear strength (MPa)	-0.312	-0.292	-0.266	-0.226
L (m)	14	16	18	20
Max-tension stress of the bottom (MPa)	0.033	0.031	0.035	-0.062
Max-vertical shear strength (MPa)	-0.237	-0.224	-0.225	-0.392

As can be seen from the results and table above, with the increase of the length of the boards, the tensile stress of the bottom is decreasing, and the vertical shear strength of the joint is decreased firstly and then increased when the length of the board is 16m, and reaches its maximum when the length of the board is 20m. According to the specifications and practical projects, this paper suggests that the length of the boards of SFRC should choose between 6m, 18m and 16m is the best.

3. The Design of SFRC and Indicators of Assessment

3.1 The design of SFRC

This paper verifies the excellent performance of SFRC by comparing the mix proportion of SFRC with ordinary concrete when the proportion of steel fiber is different[6].

In the experiment the design strength of SFRC is C40, when volume rate of the steel fiber is 1%,the mix proportion of SFRC (cement: sand: gravel: steel fiber: cement admixture: water) is

445:804:988:78:3.56:178, and the mix proportion of ordinary concrete (cement: sand: gravel: steel fiber: cement admixture: water) is 440:749:0:3.52:175.

3.2 The indicators of assessment

The design of SFRC for highway is assessed by bending strength and compressive strength. This paper takes bending strength as the major indicators of assessment to design and takes compressive strength as the referenced criteria of strength classes of SFRC. The experiment basically assesses compressive strength, cleavage strength and bending strength while the proportion of the steel fiber is changed, water cement ratio and sand ratio remain unchanged. After determining a logical mix proportion, we make an X-radiography test to the specimen to observe the distribution of the steel fiber in SFRC.

3.3 Preparations to the specimens

The following process of the preparations to the specimens:

Step 1: we determine the dosage of gravel in each groups by designated water cement ratio, the dosage of the steel fiber, sand ratio and the dosage of cement, and the dosage of cement admixture is 3.56kg/m³.

Step 2: We prepare 45 steel moulds in different sizes for the experiment, including 9 steel moulds for ordinary concrete), then 9 specimens are divided into a group, and 3 specimens are divided into a smaller group, and their average is took as test result.

Step 3: The concrete is mixed by forced concrete mixer, and then it is vibrated mechanically by vibration standard exciter. At first, we choose the dry-batch method. Then, we add water into the dry mixture. The SFRC is ready until the mixture is well-proportioned. The process of it is shown in Figure 1:

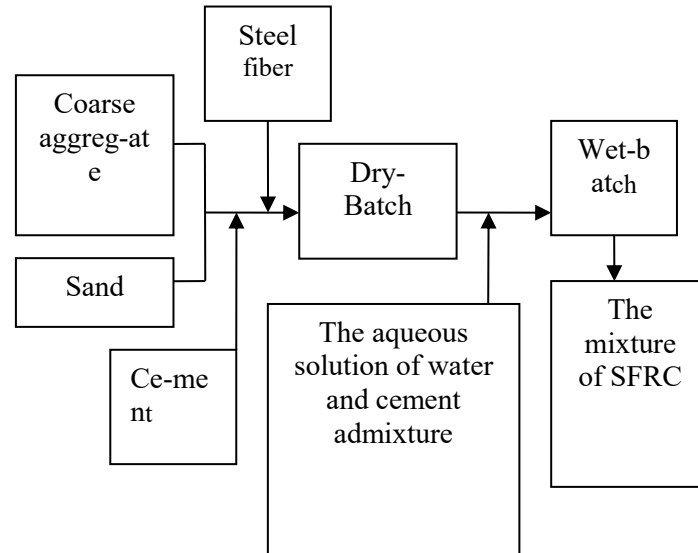


Fig. 1 The process of preparations to SFRC

Step 4: after making a slump test to the concrete, we should fill the prepared steel moulds with the workable concrete as soon as possible.

Step 5: we remove the specimens from the steel moulds after 24 hours, and put the specimens in the standard curing room where's temperature is 20 ± 2 °C and humidity is not less than 90%, until the curing time requires the specifications, then we could make the next test.

3.4 The requirements of the specimens

We remove the specimens from the curing room after the standard curing time, and then measure the dimensions of the clean specimens, accurate to 1mm. Compressive specimens should check the roughness of its pressure-bearing surface, whose standards is not more than 0.05mm per 100mm. It

is not permissible that a superficial hole with its sizes is more than 7mm and its depth is more than 2mm appears in the center of specimens for bending test. While this preparation is ready, we could perform the next experiment by “Test methods used for steel fiber reinforced concrete” .

3.5 Test of compressive strength

SFRC is a kind of composite materials consisted of continuous phase and disperse phase, so its compressive strength is influenced by continuous phase and disperse phase and the joint-face of the two constituents, but because water is bleeding from the concrete in the casting and the aggregate prevents the shrinkage of the cement slurry, the joint-face may gradually develop into micro-fracture. These micro-fractures will gain further development to microscopic fracture after external loads is added on the concrete structure, the process of the failure process of the concrete is the process of the production, broadening and instability[7].

Because the dimension of the cubic test specimen is 100mm, the measurement of compressive strength should be multiplied by size conversion coefficient 0.9.

The compressive strength test results are shown in Table 5 below.

Table 5.The test result of compressive strength

Testing plan				Test result	
N	Dosage of steel fiber (%)	Water cement ratio	Sand ratio (%)	Slumps (mm)	28-d compressive strength (MPa)
1	0	0.4	41.0	50.4	49.2
2	0.8	0.4	44.9	42.2	51.1
3	1.0	0.4	44.9	36.8	52.3
4	1.2	0.4	44.9	28.5	53.1
5	1.4	0.4	44.9	24.5	53.7

Analysis the test results using linear regression, it is obvious that with the increase of the proportion of steel fiber the pressure strength is increase, so there is a good linear relationship about their variations, the following figure 2 displays it:

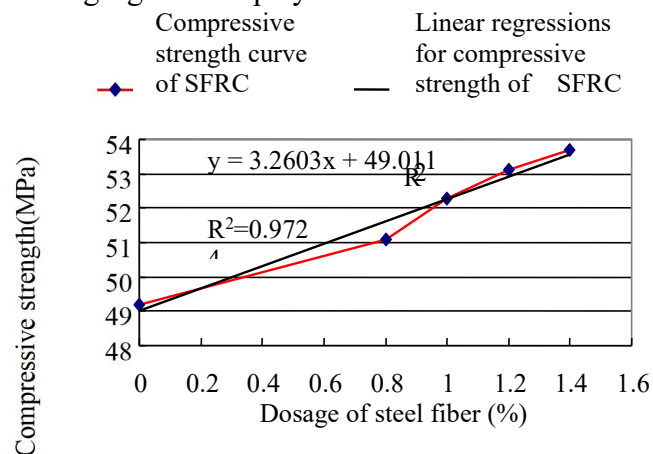


Fig. 2 linear regressions for compressive strength of SFRC

As the test results showed, with the increase of fiber volume fraction, the compressive strength of each specimen is increased slightly, and the slow rate of increase is 3.9% ~ 9.2%. The compressive strength curve is smooth and flat. Therefore, the main factor of the influence to the SFRC' s compressive strength is the same as ordinary concrete' s, whose main factor are water cement ratio, coarse aggregate and fine aggregate and so on, rather than the proportion of steel fiber, which does not improve the compressive strength of concrete significantly[8].

3.6 Cleavage strength test

Bending strength of concrete is one of the fundamental mechanical performances, and is an important index for measuring crack resistance of concrete, and is an index for indirectly measuring the other mechanical performance of concrete, such as shearing strength, punching strength and cohesive strength.

Because the sizes of cube specimens we chose is 100mm, the test result of cleavage strength should be multiplied by size conversion coefficient 0.8.

The result of cleavage strength test for SFRC is shown in Table 6:

Table 6. The result of cleavage strength test for SFRC

Testing program				Results	
N	Steel Fiber (%)	C/W	Sand (%)	Slump (mm)	Cleavage strength (MPa)
1	0	0.4	41.0	50.4	5.17
2	0.8	0.4	44.9	42.2	6.63
3	1.0	0.4	44.9	36.8	6.76
4	1.2	0.4	44.9	28.5	6.99
5	1.4	0.4	44.9	24.5	7.58

Analysis the test results by linear regression, and then it is concluded that the improvement of cleavage strength has a good linear relationship with different proportion of steel fiber; the relation is shown in following Figure 3:

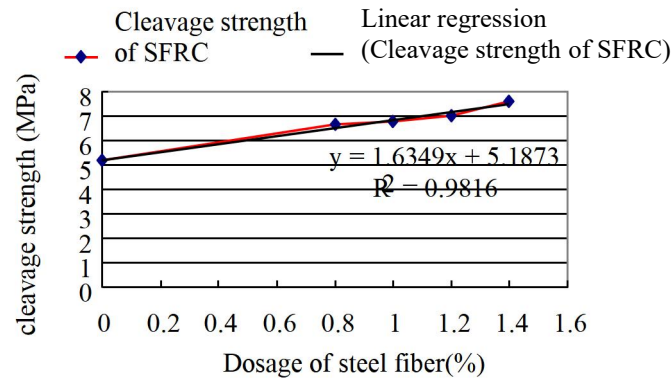


Fig. 3 Linear regression curves for cleavage strength of SFRC

In Figure 3, with the fiber volume ratio increasing, the cleavage strength of each specimen has increased obviously, increased by 28.2% ~ 46.6%. The cleavage strength curve is smooth and flat. While the proportion of the steel fiber increases steadily, the cleavage strength increases in linear growth. Therefore, the cleavage strength of SFRC is greatly raised by adding some steel fiber[9].

3.7 Bending strength test

The bending strength is a main guidepost of the design of SFRC, and is also a major advantage of SFRC compared to ordinary concrete. Its load-bending curves are quite different with common concrete' s.

Because the sizes of cube specimens we chose is 100 mm x 100 mm x 400 mm, the test result of cleavage strength should be multiplied by size conversion coefficient 0.82.

The result of bending strength test for SFRC is showed in table 7:

Table 7. The result of bending strength test

Testing program				Results	
N	Steel fiber (%)	C/W	Sand (%)	Slump (mm)	Bending strength (MPa)
1	0	0.4	41.0	50.4	5.09
2	0.8	0.4	44.9	42.2	6.52
3	1.0	0.4	44.9	36.8	7.57
4	1.2	0.4	44.9	28.5	7.99
5	1.4	0.4	44.9	24.5	9.15

Analysis the test results by linear regression, and then it is concluded that the improvement of bending strength has a good linear relationship with different proportion of steel fiber; the relation is showed in following Figure 4:

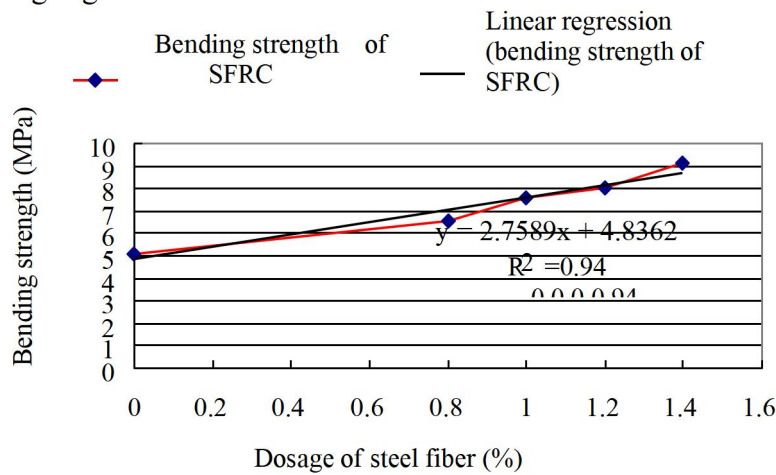


Fig. 4 Linear regression curves for bending strength of SFRC

In Figure 4, with the fiber volume ratio increasing, the bending strength of each specimen has increased obviously, increased by 28.1% ~ 78.8%. The cleavage strength curve is smooth and flat. While the proportion of the steel fiber is 1.4%, the increase of bending strength is faster. Therefore, the bending strength of SFRC is greatly raised by adding some steel fiber.

3.8 X-ray flaw detection

X-ray flaw detector is an X-ray generator used for nondestructive testing of industrial products. It generates X-rays by high-speed electronic bombard anode target, and the X-ray transilluminate test sample, then we could judge whether if it is defective by internal structure picture on photographic film or other imaging device[10]. This test acquire the distribution situation of steel fiber in the SFRC by this detector. The photographic picture is showed in the following picture 5:

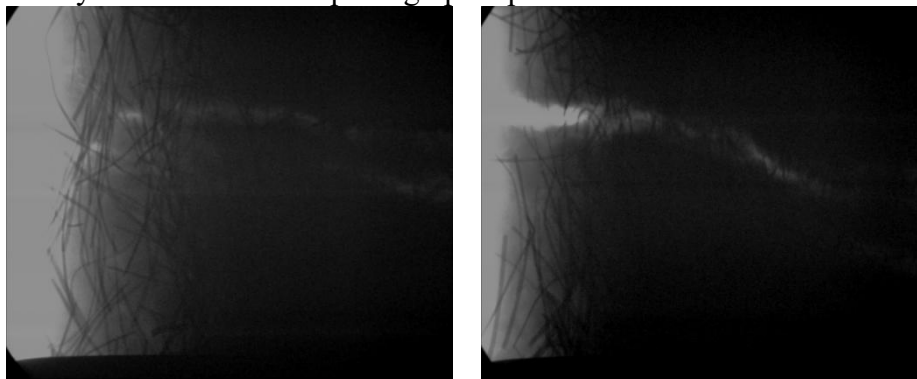


Fig. 5 the internal distribution situation of steel fiber

In the picture, the internal distribution of steel fiber is widely distributed, so it is illustrated that the blending of concrete and length diameter ratio of steel fiber don't make the steel fiber conglomerated. It has also been proven that these factors do not hinder the influence of steel fibers on SFRC[11].

4. Conclusions

(1)The dosage of steel fiber and water cement ratio is a major factor of influence to the strength of concrete and the slump of concrete, so it is very important for the strength and durability and working performance of concrete that choose reasonable proportion and water cement ratio.

(2)The addition of steel fiber is insignificant to the compressive strength of SFRC, so the major factors to the compressive strength are cement strength and water cement ratio and the performance of fine aggregate, rather than the proportion of steel fiber.

(3)The major influence of steel fiber to SFRC is the improvement of cleavage strength and bending strength, especially the later. So we choose the bending strength as the major guideposts for the design of SFRC.

(4)A major factor of the enhancement and anti-cracking performance of the uniform distribution of steel fiber in SFRC, before preparing SFRC we should pay attention to reasonable choose of constructional materials, length-d

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