Analysis of Tensile Fatigue Crack Propagation Path of Polypropylene Fiber Reinforced Concrete

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Abstract: Since 1830, concrete has become one of the most important materials in modern construction engineering after nearly 200 years of development and application. With the continuous improvement of the quality requirements of contemporary construction projects, ordinary concrete has been unable to achieve its reasonable application in construction and parts construction because of its drawbacks, such as far less tensile strength than compressive strength, poor toughness and brittle failure under special load conditions. One of the effective ways to improve the mechanical properties of concrete is to incorporate polypropylene fibers into its matrix. At present, the research on polypropylene fiber reinforced concrete mostly focuses on the compressive and frost resistance, while the research on the propagation path of tensile fatigue crack is less. Based on this, through the in-depth study on the calculation, simulation experiment and data analysis of the crack propagation path parameters, further realizes the analysis of the tensile fatigue crack propagation path of polypropylene fiber reinforced concrete, in order to provide some theoretical support for improving the tensile strength of polypropylene fiber reinforced concrete and achieving more scientific and rational application.

1. Introduction

Polypropylene fibers have the advantages of good chemical resistance, excellent mechanical properties and low melting point. By adding polypropylene fibers into concrete matrix, the mechanical properties of concrete can be improved, the settlement and bleeding of concrete can be reduced, the impermeability of concrete can be improved, and the polypropylene fiber concrete with better performance can be obtained. In the construction of concrete structure, polypropylene fibers play a supporting role. But at the same time, the tensile, bending, compression and failure of concrete are more caused by the ultimate tensile strain or shear stress strain of polypropylene fiber reinforced concrete. Therefore, the tensile fatigue performance of polypropylene fiber reinforced concrete has a very important impact on the safety of Engineering structures. Based on this, through in-depth study on the calculation of propagation path parameters, simulation experiments and experimental data analysis, the analysis of the propagation path of tensile fatigue crack of polypropylene fiber reinforced concrete is realized, in order to provide some theoretical support for improving the tensile strength of polypropylene fiber reinforced concrete and achieving more scientific and rational application.

2. Tensile Fatigue Crack Simulation of Polypropylene Fiber Reinforced Concrete

With cement as cementitious material, sand and stone as aggregate, adding a certain amount of water and additives, concrete can be formed by slowly setting and hardening after mixing, vibration and maintenance. When polypropylene fibers are added in the process of making polypropylene fibers, polypropylene fibers concrete with relatively better properties can be obtained. Under the action of external loads, the original micro-cracks in polypropylene fiber reinforced concrete materials will form macro-cracks with the increase of loading force, which will lead to the tensile fatigue of polypropylene fiber reinforced concrete and cracks, resulting in the damage of polypropylene fiber reinforced concrete materials [1]. The crack propagation of polypropylene fiber reinforced concrete under tension fatigue has a certain regularity. Next, we further analyze it through simulation experiments.

2.1 Setting of Experimental Parameters

The simulation experiment of tensile fatigue of polypropylene fiber reinforced concrete is carried out. The parameters design includes the setting of tensile test die parameters and concrete mix ratio parameters. The specific parameters setting information is shown in Table 1.

Table 1 Experimental parameter setting information

Name of parameter	Parameter Settings
Concrete mix ratio	Water: 170kg/m³, Cement: 360kg/m³, Sand: 647kg/m³, Limestone macadam: 1100kg/m³
Polypropylene fiber length	19mm
Diameter of polypropylene fibers	48μm
Dosage of polypropylene fiber	1.3kg/m³
Tension fatigue experimental mould	100mm×100mm×400mm
Load action level	I/II/III
Number of experiments	10

2.2 Experimental data

The tensile fatigue of polypropylene fiber reinforced concrete is simulated by the experiment based on the experimental external environment parameters. The experimental data of tensile fatigue crack growth of polypropylene fiber reinforced concrete are given in Table 2. Under the action of load level III (105), the propagation of polypropylene fiber reinforced concrete is shown in Fig. 1.

Table 2 Tension fatigue crack information of polypropylene fiber concrete

Load level (kN)	Crack width of face A(mm)	Crack width of face B (mm)	Average crack width (mm)
I(1-37)	0	0	0
II(40)	0.1	0.04	0.07
II (45)	0.25	0.11	0.12
II(50)	0.27	0.12	0.135
II(60)	0.18	0.2	0.19
II(70)	0.22	0.22	0.22
III(80)	0.26	0.24	0.25
III(90)	0.28	0.28	028
III(100)	0.31	0.3	0.305
III(105)	0.36	036	0.36

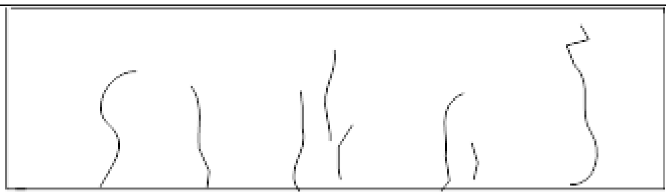

Fig. 1 Tensile fatigue crack growth of polypropylene fiber reinforced concrete

2.3 Computation of experimental data

The application of polypropylene fiber reinforced concrete in modern society is often affected by the complex stress of building structure. The important physical parameter of crack propagation path is stress intensity factor [2]. Based on the above experimental data, the stress intensity factor is calculated and analyzed. Stress intensity factor is a physical parameter to measure the tensile fatigue crack of polypropylene fiber reinforced concrete. For a point (r,θ) in the vicinity of the tensile fatigue crack tip of polypropylene fiber reinforced concrete, the stress is determined by the stress intensity factor. Regardless of the single mode load or the composite mode load, the full solution expression of the stress component of the tensile fatigue crack of polypropylene fiber reinforced concrete is as follows:

$$\sigma_{ij} = \frac{K_m}{\sqrt{2\pi}}\left(r^{-\frac{1}{2}}\right) f_{ij}(\theta) + o\left(r^0\right) + ... \tag{1}$$

In the formula: σ_{ij}——Stress

K_m——Stress intensity factor

θ——Polar angle

$f_{ij}(\theta)$——Angular distribution function

Considering the fact that r is very small in the crack tip region of polypropylene fiber reinforced concrete under tension fatigue, several items behind the first item can be omitted, and the stress in the crack tip region can be expressed as follows:

$$\sigma_{ij} = \frac{K_m}{\sqrt{2\pi}}\left(r^{-\frac{1}{2}}\right) f_{ij}(\theta) \tag{2}$$

Formula (2) shows that the magnitude of stress intensity factor is a parameter related to the load properties of polypropylene fiber reinforced concrete and the geometric shape of tensile fatigue cracks [3]. The method of calculating stress intensity factor is usually based on stress extrapolation. Extrapolation method is the best curve fitting method by using least square method to calculate the stress intensity factor at the tip of tensile fatigue crack of polypropylene fiber reinforced concrete, which provides data reference for analyzing the propagation path of tensile fatigue crack of polypropylene fiber reinforced concrete. The specific calculation method is shown in formula (3).

$$K_{Ii} = \sigma_{yi}\sqrt{2\pi r_i} \tag{3}$$

By substituting the experimental data obtained in the experiment into the above formula (3), the parameters of stress intensity factors for 10 times under different load levels are 18.26 MPa, 17.86 MPa, 18.10 MPa, 15.35 MPa, 15.71 MPa, 15.74 MPa, 17.81 MPa, 15.55 MPa, 17.79 MPa and 17.86 MPa, respectively.

3. Analysis of Tensile Fatigue Crack Propagation Path of Polypropylene Fiber Reinforced Concrete by Experiments

In the above experimental part, through the tensile fatigue simulation experiment of polypropylene fiber reinforced concrete, the parameters of experimental stress intensity factor and the analysis of specific tensile fatigue crack propagation are obtained, and the following conclusions about the tensile fatigue crack propagation path of polypropylene fiber reinforced concrete are summarized.

3.1 Longitudinal Tensile Fatigue Crack Propagation Path under Single Mode Load

As a kind of artificial stone material, the quantity of components, the nature of components, the proportion of components and the influence of external conditions in the process of making polypropylene fiber concrete will have different effects on the mechanical properties of polypropylene fiber concrete. In addition, under the influence of external load, the propagation of tensile fatigue cracks of polypropylene fiber reinforced concrete shows certain regularity. Under the condition that the load action is relatively low and the action force is approximately equal to the ultimate strength of polypropylene fiber reinforced concrete, only the fiber cracks appear. With the increase of loading force, the strain of concrete material is offset by more and more fiber cracks in the interior. At this time, the occurrence of matrix cracks and interface cracks of polypropylene fiber reinforced concrete is less, and the initial interface cracks have little effect on the overall microcracks. This is also due to the shear force between the matrix and the interface of polypropylene fiber reinforced concrete to transfer the tensile force of the fibers, resulting in a large number of fiber cracks in the material. In addition, the location of fiber cracks is also directly related to the surrounding fiber cracks and fiber spacing. The bridging effect of polypropylene fibers increases with the thickness of concrete matrix. Under a certain load, the number of fiber cracks will not increase, but the opening displacement of fiber cracks will increase obviously. Moreover, the tensile fatigue cracks of polypropylene fiber reinforced concrete transfer to the interface or matrix. In this case, if the polypropylene fibers are evenly distributed in the matrix, the propagation path of fiber cracks depends on the relative relationship between the mechanical properties of the material and the interfacial properties, that is, the better the interfacial toughness, the easier the fiber cracks will propagate into the matrix [4]. If the polypropylene fibers are not uniformly distributed in the matrix, the cracks tend to propagate to the matrix when the matrix is thicker, and to the interface when the matrix is thinner. At this time, the cracks in the thinner position of the matrix layer are easy to connect. On the contrary, thicker matrix layer will hinder the crack penetration. There are three ways of penetration. Firstly, the cracks of adjacent polypropylene fibers extend to the matrix layer and connect in the form of matrix cracks. Secondly, the cracks of adjacent polypropylene fibers first extend to the interface, and then form the penetration of matrix cracks in the form of interface cracks. Finally, the intersection between cracks in polypropylene fibers and interfacial cracks.

3.2 Transverse Tensile Fatigue Crack Propagation Path under Single Mode Load

The stress intensity factor parameters calculated from the above experimental data prove that the results of 10 sets of parameters are relatively stable. The size of stress intensity factor is related to the geometric shape of tensile fatigue crack of polypropylene fiber reinforced concrete. It can be concluded that the propagation path of transverse tension fatigue crack of polypropylene fibers under single mode loading is the matrix-interface-matrix-interface path, and the wavy microcracks will be formed. But this wavy fluctuation is relatively small [5]. The wavy cracks with small fluctuation indicate that polypropylene fiber reinforced concrete has better interfacial strength and toughness. In addition, under the condition of single-mode loading, if the cracks produced by tensile fatigue of polypropylene fiber reinforced concrete are very close, they will propagate along their interfaces in the longitudinal section until the cracks in all directions intersect in the fiber.

3.3 Tensile Fatigue Crack Propagation Path under Compound Load

The crack propagation path of polypropylene fiber reinforced concrete under composite loading is mainly affected by the angle of loading force. Under low loads, there are no cracks in the zero-degree direction of polypropylene fiber reinforced concrete, and the propagation path of microcracks is basically the same as that under single-mode loads [6]. However, when the main crack is formed, the interfacial crack propagation along the load direction is hindered by the force of different angles, which will inhibit the irregular propagation path of the crack, and eventually make the macro-fracture of the material present a basically smooth state.

4. Conclusion

The contemporary polypropylene concrete material will crack under the complex stress of building structure. The propagation path of tensile fatigue crack will reduce the mechanical properties of concrete. After calculating and simulating the tensile fatigue crack of polypropylene fiber reinforced concrete, the effect of loading on the crack propagation path can be obtained by analyzing the experimental data, showing different propagation laws. However, due to the influence of fiber distribution and thickness in polypropylene fiber reinforced concrete, the specific crack propagation path and damage evolution need to be further explored.

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References

[1] Chen Jing, Pan Qinglin, Yu Xuehong, et al. Effect of Heat Treatment on Microstructure and Fatigue Crack Growth Behavior of Al-Zn-Mg-Sc-Zr Alloy[J]. Journal of Central South University of Technology, 2018, 25(5):961-975.

[2] Guo Qingqing, Wang Jialiang, Wu Yonghong, et al. Influence of Microstructure on the Fatigue Crack Growth in Near-α Ti Alloy BT-20[J]. Journal of Northeastern University(Natural Science), 2017, 38(3):345-349.

[3] Wang Yue, Xiong Yuping, Zhao Xia, et al. Analysis of Fatigue Crack Propagation for Repaired Aluminum Alloy Plate Containing Crack with Single Patch[J]. Journal of Propulsion Technology, 2018, 39(4):9-12.

[4] Xu Tianhan, Wang Danghui. Tensile Property and Fatigue Crack Growth Property of Casing-Drilling Steels with Different Microstructures[J]. Materials for Mechanical Engineering, 2017, 41(9):19-24.

[5] LI Jian.Effects of Chopped Basalt Fiber on Mechanical Properties and Microstructure of Slag Fly Ash Concrete[J]. Bulletin of the Chinese Ceramic Society, 2017(2):727-732.

[6] LI Xin-yu, YANG Mao-sheng, ZHOU Xiao-long, et al. Torsion fatigue characteristics and crackpropagation behavior of 15Cr14Co12Mo5Ni2 gear steel[J].Iron & Steel, 2017, 52(9):84-91.