ISSN: 2414-1895 DOI: 10.6919/ICJE.202401_10(1).0049

Research on Uniaxial Compression Test of Fiber Reinforced Concrete based on Computer Numerical Simulation

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Abstract

Based on the software PFC2D, this paper explores the physical and mechanical properties of the fiber reinforced concrete and plain concrete under uniaxial compression test, and further analyze the influence of the fiber length and fiber mortar properties and friction coefficient and deformation modulus of mesoscopic parameters on the mechanical behavior of fiber reinforced concrete. The main conclusions are as follows: the addition of fiber can effectively improve the development of cracks in concrete, enhance the bonding strength between particles in concrete, and further improve the strength and ductility of concrete. With the increase of fiber length, the compressive strength of fiber reinforced concrete increases first and then decreases. There is a certain limit of fiber length in fiber reinforced concrete, over which the physical and mechanical properties of fiber reinforced concrete may be reduced. With the increase of fiber content, the compressive strength and ductility of fiber reinforced concrete increase as a whole. Among the microscopic parameters, the friction coefficient and deformation modulus of fiber have little influence on the compressive strength of fiber reinforced concrete, while the deformation modulus of fiber has a certain influence on the deformation modulus of fiber reinforced concrete.

Keywords

Computer Numerical Simulation; Discrete Element Method; Fiber Concrete; Uniaxial Compression Test.

1. Introduction

With the acceleration of urban modernization in the world, the demand of concrete, especially high strength concrete, is becoming increasingly scarce. The high strength concrete can appear brittle difference normally, the problem of easy fracture, restricting the development of concrete. As early as 1964, Romualdi et al. [1] proposed the fiber spacing theory based on the theory of linear elastic fracture mechanics, which solved the problem of concrete failure caused by excessive concentration of stress at the crack tip inside concrete. Naaman et al. [2] proposed the theory of conforming material mechanics in 1975 and found that there was a strong bond between fiber and matrix. At the same time, Walton et al. [3] conducted relevant experiments on hybrid fiber cement-based composites. KKobayashi et al. [4] conducted the bending toughness test of steel-polyethylene hybrid fiber concrete in 1982, and found that the toughness of concrete was improved after mixed fibers were added. Muchala and Zhou [5-6] conducted an experimental study on lightweight fiber-reinforced concrete and its dynamic performance, which showed that lightweight fiber-reinforced concrete has a good damping effect on crack development. Luo Honglin et al. [7-8] studied the application of polypropylene fiber in concrete and analyzed the influence of aspect ratio on the mechanical properties of polypropylene concrete. The physical experiments of fiber reinforced concrete focus

 Volume 10 Issue 1, 2024
DOI: 10.6919/ICJE.202401_10(1).0049

more on the discussion of its macroscopic physical and mechanical properties, and less on the microscopic fracture damage [9-10].

With the rise of numerical tests, more and more researches have studied fiber reinforced concrete by numerical simulation test. Tian Xiao [11] used ABAQUS finite element software to simulate the P-CMOD relationship of the three-point curved notch beam, and analyzed and determined the material parameters of the bilinear softening relationship of steel-basalt hybrid fiber concrete. Ren et al. [12] established a multi-scale damage model to simulate the uniaxial tensile failure process of STEEL fiber concrete. Chu Xihua et al. [13] established a near-field dynamic model of fiber-reinforced concrete, simulated multiple concrete tests and analyzed the failure process of fiber-reinforced concrete. At present, the numerical simulation of fiber concrete mainly focuses on the finite element method and the extended finite element method [14-17]. The finite element method to deal with material damage needs to repartition the grid, and the spatial discontinuity cannot meet the continuity requirements of the balance equation.

However, the discrete element method can better simulate the discontinuous phenomenon of fiber concrete fracture without dividing grids, which can solve the problems of the finite element method. Based on previous studies on concrete using discrete element [18-20], this paper conducted numerical simulation of fiber concrete uniaxial compression test using discrete element. Through comparative analysis of mechanical properties and fracture morphology of fiber reinforced concrete and plain concrete, the influence of fiber length and fiber addition amount on the mechanical properties of concrete is further explored, which finally provides reference for engineering practice.

2. Model Establishment

This paper mainly uses the discrete element software PFC2D to simulate the uniaxial compression test of fiber reinforced concrete. The simulation process mainly includes three steps: the generation of fiber reinforced concrete numerical samples, the consolidation of fiber reinforced concrete numerical samples, and the loading of fiber reinforced concrete numerical samples. Among them, the generation of fiber reinforced concrete sample is the difficulty of simulation, because in the real test, the fiber in concrete is bent and can be deformed, so clump cannot be used to simulate the fiber. In order to achieve this effect, clump body with a certain content proportion is formed, and the position of each pebble is recorded to generate balls to replace pebble and form fibers. The original clump body can be deleted, and the generated numerical fibers are shown in Figure 1 (a). After the fibers are generated, the coarse and fine aggregate are generated in concrete. In the process of numerical sample balancing, the fiber body will also be squeezed and become curved, as shown in Figure 1 (b). The Figure 1 (c) shows the test sample of fiber concrete, and fibers can be seen from the sample. In the test, the fiber is polypropylene fiber, whose properties are shown in Table 1. The contact model adopted in this paper is the parallel bonding model, which is mainly used for the mechanical behavior of bonding materials, similar to the bonding of cement aggregate. After the generation of simulated concrete samples, different contact parameters were set for the particles inside the samples, as shown in Table 2, to form consolidated samples. Finally, a loading program was written, and the rigid wall was used to load. The loading speed is controlled as 0.5 MPa/s (consistent with the loading speed of the servo mechanism in the experimental process).

Table 1. Basic performance parameters of fiber

Length /mm	Diameter /mm	Tensile strength /MPa	Modulus of elasticity /MPa	proportion	Melting point /°C	Flash point /°C
20	0.2	>400	>350	0.91	170	590

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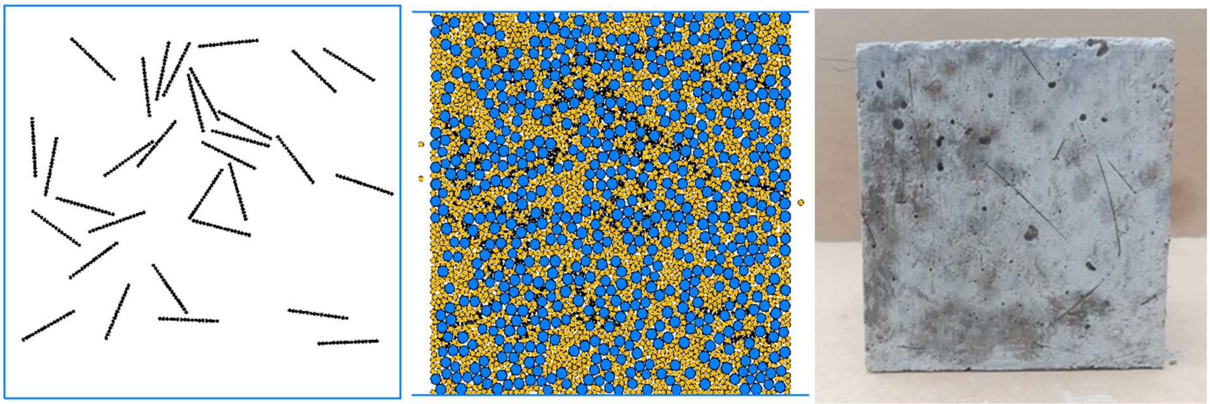


(a)Numerical fiber (b) numerical sample (c) test sample

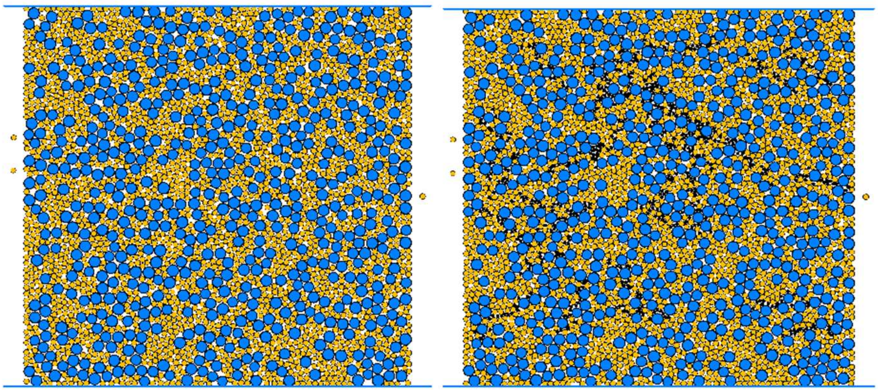
Figure 1. Fiber reinforced concrete sample

Table 2. Simulation parameters

Particle type	Density(kg/m^3)	Porosity	Fric	Pb_ten(Pa)	Pb_coh(Pa)	Stiffness ratio	Deform emod	Damp
Aggregate	1950	0.25	0.50	3.5e7	1.2e6	1.0	6.5e7	0.7
Fiber	900	0.1	0.5	5.5e9	4.2e8	1.0	5.5e9	0.7

3. Results and Analysis

Through comparison of concrete performance before and after adding fibers, we can understand the influence of fiber on concrete performance more deeply. Figure 2 shows the concrete sample before and after adding fibers.



(a) No fiber (b) Adding fibers

Figure 2. Concrete sample before and after adding fibers

3.1 Comparison of Force Chain Distribution

The development of force chain distribution of concrete specimens before and after adding the fibers is shown in Figure 3. The initial state of the force chain distribution of fiber concrete chain is more dense than that of plain concrete, and the force chain of fiber reinforced concrete is more complete than that of the plain concrete after damaging. As shown in Figure 3(a), it can be seen that the plain concrete damages relatively seriously, but only two penetrating cracks appear after the fiber reinforced concrete is damaged and the other parts are relatively intact in Figure 3(b). It can be seen that the addition of fiber can effectively improve the crack development of concrete and also improve the bond strength between particles in concrete.

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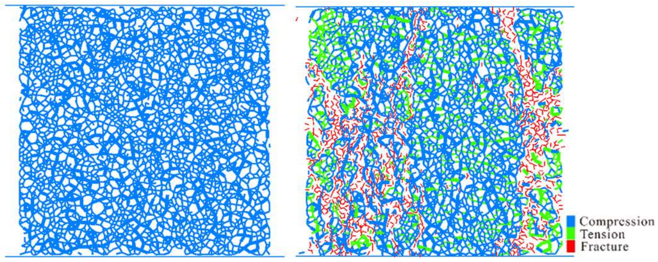
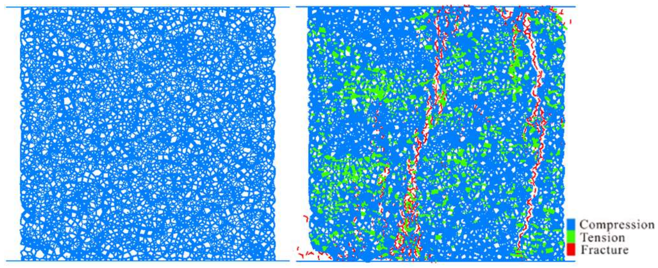


(a) No fiber

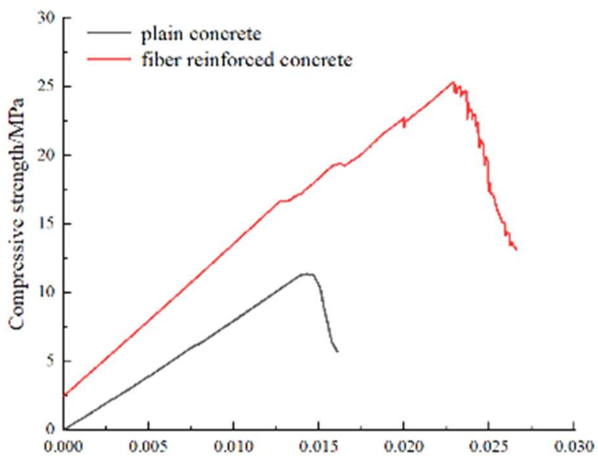


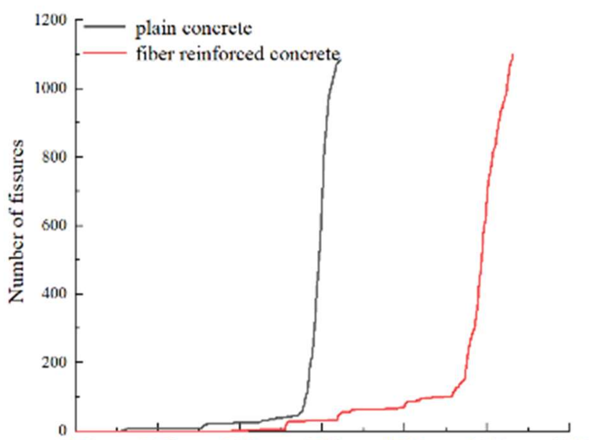
(b) Adding fibers

Figure 3. Force chain distribution of concrete samples in fracture state

3.2 Comparison of Physical and Mechanical Properties

Mechanical properties are an important indicator for comparing concrete before and after fiber addition. Figure 4(a) shows the comparison curve of compressive strength and strain of concrete before and after fiber addition. It can be seen that the compressive strength of concrete increases greatly after fiber addition, and the maximum compressive strength of fiber concrete is about 26.4 MPa. The highest compressive strength of plain concrete is only 12.2MPa. In addition, compared with plain concrete, the ductility of fiber reinforced concrete is also effectively increased. The plain concrete begins to fracture when the strain is less than 0.015, while fiber concrete begins to fracture when the strain reaches 0.023. It can be seen that the addition of fiber can effectively improve the compressive strength and ductility of concrete. Figure 4(b) shows the concrete cracks development quantity contrast curve before and after adding the fiber. Finally, the number of cracks in plain concrete and fiber concrete is basically the same. Therefore, it can be seen that the fiber can significantly inhibit the development of cracks in concrete, delay the time of occurrence of cracks, and effectively improve the physical and mechanical properties of concrete.





(a) Stress-strain curves (b) Number of cracks

Figure 4. physical and mechanical properties of concrete

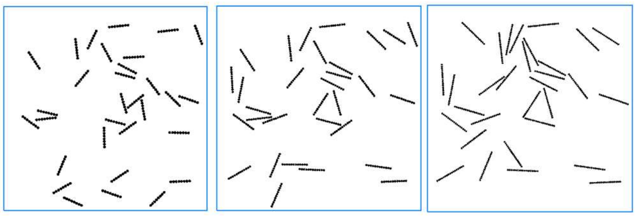
ISSN: 2414-1895 DOI: 10.6919/ICJE.202401_10(1).0049

4. Influence of Fiber Properties on Concrete Numerical Samples

It has been known in the previous part that the addition of fiber greatly improves the physical and mechanical properties of concrete. Next, it is necessary to specifically explore the influence of fiber properties on the physical and mechanical properties of concrete. The influence of fiber length and fiber addition amount on the physical and mechanical properties of concrete will be analyzed.

4.1 Influence of Fiber Length

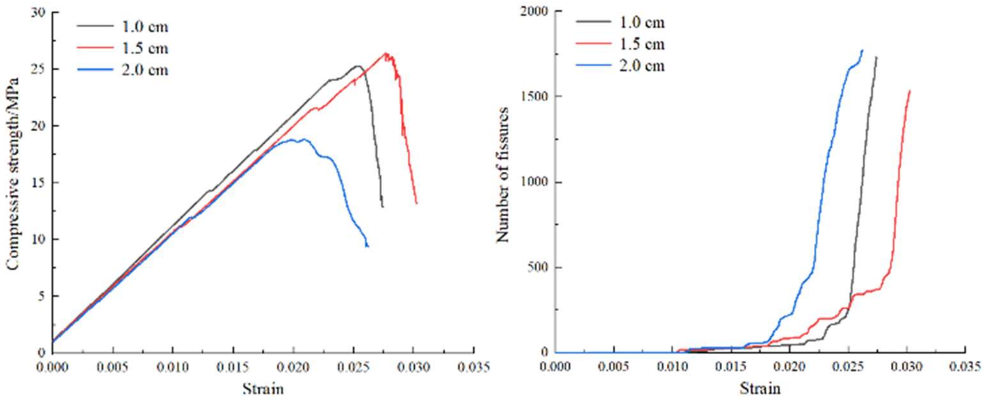
The schematic diagrams of fibers of different lengths is shown in Figure 5. It can be seen from the figure that the length of fibers increases with the increase of the number of balls constituting fibers. Three working conditions are arranged for the analysis of fiber length, 1cm, 1.5cm and 2cm respectively. The influence of fiber length on physical and mechanical properties of fiber concrete is analyzed by using three kinds of different lengths of fiber to generate three kinds of different numerical samples.



(a)1 cm (b)1.5 cm (c)2 cm

Figure 5. Schematic diagram of fibers of different lengths

The final simulation results are shown in Figure 6. Figure 6(a) shows the comparison of the curve of compressive strength and strain under different fiber lengths. It can be seen that with the increase of fiber length, the compressive strength of fiber concrete first increases and then decreases, and the uniaxial compressive strength of 2cm fiber length is smaller than that of 1cm fiber length, while the uniaxial compressive strength of 1.5cm fiber length is the largest, which is 27.5MPa. In addition, the numerical sample with fiber length of 2cm also has the worst ductility and begins to fracture when the strain is 0.2, while the numerical sample with fiber length of 1.5cm has the best ductility and begins to fracture when the strain is 0.27. Figure 6(b) shows the development curve of the number of cracks in concrete under different fiber lengths. It can be seen that there is little difference in the number of cracks in concrete diagram with different fiber lengths, but there is a certain difference in the initiation time. Therefore, it can be known that there is a certain limit of fiber length in fiber concrete, over which the physical and mechanical properties of fiber concrete may be reduced.



(a)Stress-strain curves (b) Number of cracks

Figure 6. Physical and mechanical properties of concrete with different lengths

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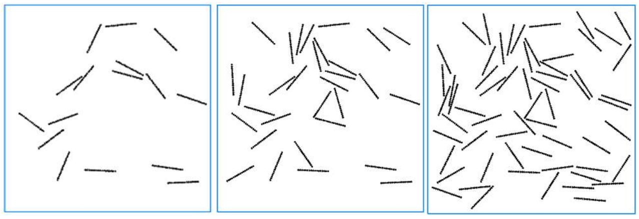
4.2 Influence of Fiber Incorporation Amount

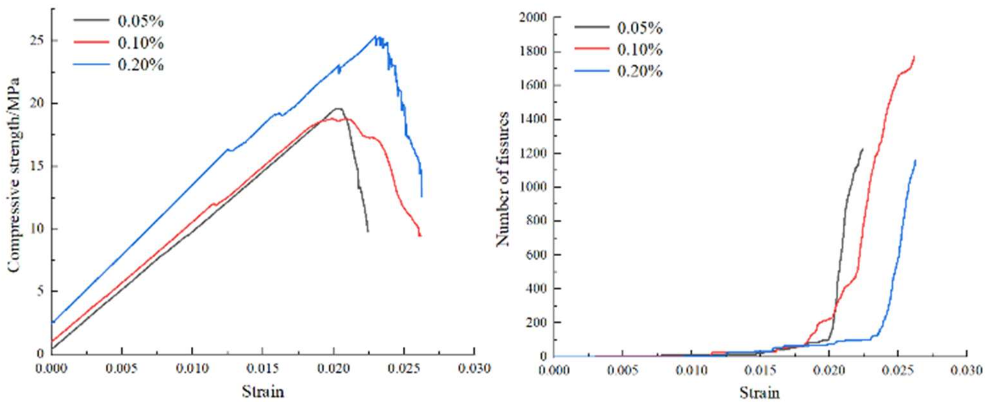
Figure 7 shows concrete numerical samples with different fiber incorporation amounts, which are 0.05%, 0.1% and 0.2% respectively. It can be seen that the fiber incorporation amount increases significantly. Then, three kinds of fiber concrete with different fiber incorporation amounts were used to conduct numerical tests, and the results are shown in Figure 8.



(a)0.05% (b)0.1% (c)0.2%

Figure 7. Numerical samples with different fiber incorporation

Figure 8(a) shows the comparison of mechanical properties of concrete with different fiber content. It can be seen from the figure that the compressive strength of concrete samples does not change much with the change of fiber content, and the numerical sample with fiber content of 0.2% has the largest compressive strength and relatively highest ductility. The compressive strength and ductility of the sample with 0.1% and 0.05% fiber content are similar. Figure 8(b) shows the variation curve of the number of cracks in concrete with different fiber contents. The number of cracks is the largest when the fiber content is 0.1%, but the crack initiation time is basically the same when the fiber content is 0.1% and 0.05%, while the crack initiation time of concrete with fiber content is 0.2% is relatively late. In general, the strength and ductility of concrete increase with the increase of fiber content.



(a) Stress-strain curves (b)Number of cracks

Figure 8. Physical and mechanical properties of concrete with different contents

5. Influence of Fiber Microscopic Parameters on Concrete Numerical Samples

5.1 Influence of Friction Coefficient

Friction coefficient is an important microscopic parameter in concrete materials. Figure 9(a) shows the relationship between compressive strength and strain of concrete under different friction coefficients of fibers. It can be seen from Figure 9(a) that compressive strength and deformation modulus of concrete are basically invariant with the change of friction coefficient, indicating that the friction coefficient of fiber in fiber concrete has little effect on the promotion of fiber concrete. Figure 9(b) shows the variation curve of concrete crack development under different friction coefficients, and it can be seen that as the change of the coefficient of friction, the number of the crack development

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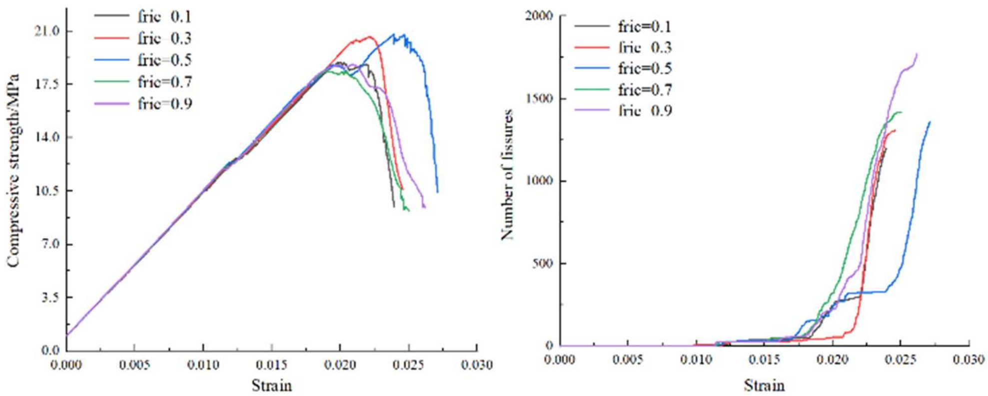
in the concrete has no difference, but when the friction coefficient is 0.9, the number of the fracture is the most. So friction coefficient has certain influence to the development of inside the concrete crack, but the effect is not obvious.

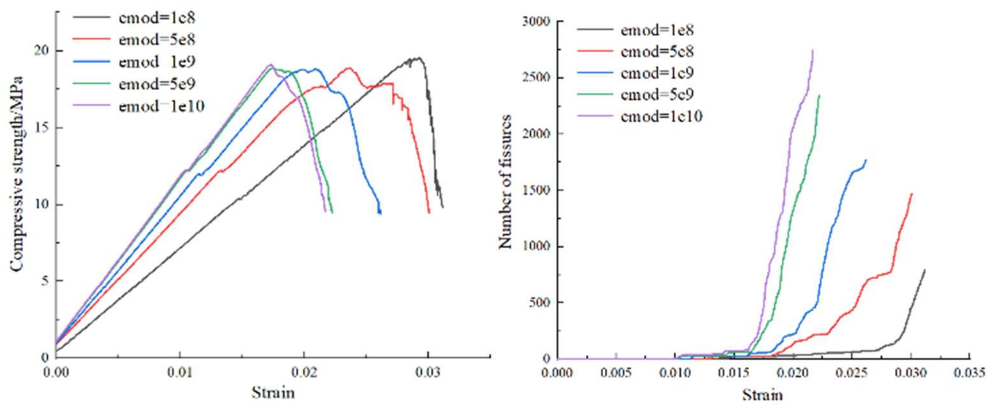
5.2 Influence of Deformation Modulus

The deformation modulus of fiber is simulated under five working conditions, which are 1e8, 5e8, 1e9, 5e9 and 1e10 respectively. Figure 10(a) shows the compressive strength and strain curves of concrete with different deformation modulus. It can be seen that the deformation modulus of fiber has little influence on the compressive strength of fiber concrete. However, it has a certain influence on the deformation modulus of fiber concrete. With the increase of the deformation modulus of fiber, the deformation modulus of concrete also increases. Figure 10(b) is the variation curve of the number of cracks in concrete under different deformation modulus. It can be seen that when the deformation modulus of fiber is relatively large, the crack initiation time of concrete is advanced and the number of cracks also increases significantly. It can be seen that the fiber deformation modulus has a certain influence on the crack development of concrete.



(a) Comparison of stress-strain curves (b)Number of cracks

Figure 9. Physical and mechanical properties of concrete under different friction coefficients



(a) Stress-strain curves (b) Number of cracks

Figure 10. Physical and mechanical properties of concrete under different deformation modulus

6. Conclusion

In this paper, using particle flow software PFC2D has carried on the numerical simulation of fiber reinforced concrete under uniaxial compression test, exploring the influence of fiber on physical and mechanical properties of concrete, further analyzing the influence of the fiber length and fiber properties and the coefficient of friction and deformation modulus of mesoscopic parameters on the physical and mechanical behavior of fiber reinforced concrete. The main conclusions are as follows:

(1) The addition of fiber can effectively improve the development of cracks in concrete, effectively improve the bonding strength between particles in concrete, and further improve the strength and ductility of concrete.

(2) With the increase of fiber length, the fiber concrete compressive strength increases first, then decreases. The fiber length of fiber concrete has the certain limit, and beyond a certain length of fiber, the physical and mechanical properties of fiber reinforced concrete may be reduced.

(3) With the increase of fiber content, fiber concrete compressive strength is increased on the whole, the ductility of fiber reinforced concrete at the same time also increased.

(4) Among the microscopic parameters, the friction coefficient and deformation modulus of fiber have little influence on the compressive strength of fiber concrete, while the deformation modulus of fiber concrete has a certain influence on the deformation modulus of fiber concrete.

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