Study on Basic Mechanical Properties of Plastic-Steel Fiber Concrete

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Abstract

With the addition of 6kg / m³ plastic-steel fiber, the experiments of basic mechanical properties such as the cubic compressive strength, axial compressive strength, splitting tensile strength, and flexural strength were performed respectively on plain concrete and plastic-steel fiber concrete. The experimental results show that compared with plain concrete, the cubic compressive strength and the axial compressive strength of the concrete mixed with 6kg / m³ plastic-steel fiber are reduced, while the splitting tensile strength and flexural strength are improved.

Keywords

Plastic-steel fiber; Basic mechanical properties; Control variable method.

1. Introduction

With the rapid development of the economy, science and technology, the requirements for building structures are increasing sharply. Building technology has also made enormous progress, and plenty of extensive projects have been constructed.

Among them, plain concrete, which is one of the raw materials, gradually fades out of people's vision due to its weak tensile strength. Gradually, lightweight aggregate concrete has become a very popular building material due to its advantages of good shock resistance and durability, simple manufacturing process, light weight and high compressive strength. With its more and more applications, light aggregate concrete has also exposed some problems, such as low tensile strength, small elastic modulus, and sudden brittle failure often occurs during failure. In addition, because concrete is a man-made multi-phase composite material, some tiny voids and cracks will inevitably be generated during pouring. When concrete is subjected to various loads during normal work, these micro-cracks will gradually develop over time, and eventually macro-cracks will appear. With the development of technology, it has been found that adding some composite fibers to light aggregate concrete can effectively improve its toughness, and the strength is also improved to a certain extent compared to plain concrete. Under such circumstances, modified concrete formed by doping different types of fibers or particles is gradually being used.[1]

Plastic-steel fiber is a high-strength fiber widely used in construction engineering to control the toughness and impact resistance of concrete.[2] At the same time, it can replace traditional steel mesh and steel fiber. The construction cost is more economical and convenient. Plastic-steel fiber is a new type of synthetic fiber which is widely used as a new concrete reinforcement material. It mainly uses polypropylene and polyethylene as raw materials and is synthesized through a special process. It combines the advantages of both steel fiber and plastic synthetic fiber, and is mainly used to replace the welded metal grid and steel fiber in the concrete panel structure.

Because the composite fiber concrete structure has many advantages, it is widely used in various projects. However, the basic mechanical properties of concrete with plastic-steel fiber as the main admixture need to be studied. Foreign studies on fiber-reinforced concrete began in the early 20th century. In 1910, Porter published a research report on short fiber reinforced concrete, which is the first research record on fiber concrete.[3-4] The research on fiber-reinforced concrete began in China in the 1970s. In recent years, scholars have continued to enrich the research content.[5-6]

This paper mainly tests the basic mechanical properties of modified concrete obtained by mixing plastic-steel fibers, such as cubic compressive strength, axial compressive strength, split tensile strength, and flexural strength, and explores the influence of plastic-steel fibers on mechanical properties.

2. Methods

2.1 Experimental Materials

(1) Cement: Jilin Yatai Dinglu Cement Co., Ltd. Dinglu Brand P·O 42.5 Ordinary Portland Cement. The specific technical indicators are shown in Table 1. SCWQ is short for standard consistency water quantity.

(2) Medium sand: Fineness Modulus 2.82, Apparent Density 2700kg / m³.

(3) Crushed stones: Graded Grid, Apparent Density of 2700kg / m³.

(4) Plastic-steel fiber: Density 0.91kg / m³, Equivalent Diameter 0.8~1.8mm, Length 40mm, Elongation at Break 12~40%, Melting Point 170 ℃, Tensile Strength 380~550MPa, Elastic Modulus ≥5000MPa, No water absorption, Good Resistance to acid and alkali.

(5) Water: Ordinary tap water.

Table 1 Cement Physical Properties

Technical index	Density kg/m³	SCWQ /%	Setting Time /min		Compressive Strength /MPa		Flexural Strength /MPa	
			Initial	Final	3Days	28Days	3Days	28Days
Value	3100	26.7	97	152	19.7	45.8	4.2	8.3
Requirements	——	——	≥45	≤390	≥17	≥42.5	≥3.5	≥6.5

2.2 Mixing Ratio Design

The design of concrete mix ratio should meet the design requirements of concrete configuration strength, mix performance, mechanical properties and durability performance. The test methods for the performance, mechanical properties and durability of concrete mixtures should be in accordance with the current National Standards "Standard Test Methods for Performance of Common Concrete Mixtures" (GB/T 50080-2016) and "Standards for Test Methods of Mechanical Properties of General Concrete" (GB/T 50081-2002) and "Standard Test Method for Long-term Performance and Durability of General Concrete" (GB/T 50082-2009).[7-9]

The design of the concrete is based on the industry standard "Specification for Mix Proportion Design of Ordinary Concrete" (JGJ 55-2011)[10] issued by the People's Republic of China Ministry of Housing and Urban-Rural Development.

The designed concrete strength index is C30, the configuration strength $f_{cu,0}$ is 38.225MPa, the sand rate is 0.38, and the water-cement ratio is 0.43.

In the experiments of plastic-steel fiber modified concrete, the method of controlling variables was used to analyze and check the effect of plastic-steel fiber doping on the performance of concrete. Plain concrete without plastic-steel fiber (Group A) was used as a control group, and concrete of 6 kg / m³ plastic-steel fiber (Group B) was used as a test group. The specific control variable design method is shown in Table 2.

Table 2 Proportioning Design of Concrete Based on Control Variable Method

Groups	Water-Cement Ratio	Water kg/m³	Cement kg/m³	Sand kg/m³	Crushed Stones kg/m³	Plastic-Steel (PS) Fiber kg/m³
A(Plain)	0.43	195	453.49	591.74	1200.29	0
B(PS Fiber)	0.43	195	453.49	591.74	1200.29	6

2.3 Test Equipment

During the test of the mechanical properties of the plastic-steel fiber concrete and plain concrete, the mixing equipment is HJW-60 60L single-horizontal shaft concrete mixer (Fig.1). The compression test instrument is a pressure tester. The split tensile test is performed by a pressure tester, and the flexural test is performed by a universal tester. Fig.2 are some facilities which are used in these experiments.

Fig.1 HJW-60 Single-Shaft Shaft Concrete Mixer

Fig.2 Some Test Equipment

2.4 Experimental Principles and Formulas

The experimental methods and formulas are in accordance with the National Standard of the People's Republic of China "Standard for Test Method of Mechanical Properties on Ordinary Concrete" (GB/T 50081-2002).

2.4.1 Cubic Compressive Strength Test of Concrete

In order to study the influence of plastic-steel fiber incorporation on the compressive strength of concrete cubes, a cubic compressive strength test of concrete was carried out. The test uses 100mm × 100mm × 100mm cube test pieces with a conversion factor of 0.95. After removing the test piece, place the test piece on the lower plate or pad of the testing machine, and wipe the surface of the test piece and the upper and lower pressure plates. The speed of loading is 0.5 MPa / s constantly.

The formula for calculating the compressive strength of concrete cubes is as follows:

$$f_{cc} = \frac{F}{A} \tag{1}$$

Where: f_{cc}——Cubic compressive strength of concrete (MPa) ;

F ——Specimen failure load (N) ;

A——Pressure area of the test piece (mm^2) .

2.4.2 Axial Compressive Strength Test of Concrete

In order to study the influence of plastic-steel fiber incorporation on the axial compressive strength of concrete, the axial compressive strength test of concrete was carried out. The test uses 150mm ×

150mm × 300mm test pieces. After removing the test piece, place the test pieces on the lower plate or pad of the testing machine, and wipe the surface of the test piece and the upper and lower pressure plates. The speed of loading is 0.5 MPa / s constantly.

The formula for calculating the axial compressive strength of concrete specimens is as follows:

$$f_{cp} = \frac{F}{A} \tag{2}$$

Where: f_{cp}——Axial compressive strength of concrete (MPa) ;

F——Specimen failure load (N) ;

A——Pressure area of the test piece (mm^2) .

2.4.3 Splitting Tensile Strength Test of Concrete

In order to study the influence of plastic-steel fiber incorporation on the splitting tensile strength of concrete, a splitting tensile compressive strength test of concrete was performed. The test uses 100mm × 100mm × 100mm test pieces. After removing the test piece, place the test piece on the lower plate or pad of the testing machine, and wipe the surface of the test piece and the upper and lower pressure plates. The speed of loading is 0.5 MPa / s constantly.

The formula for calculating the split tensile strength of concrete specimens is as follows:

$$f_{ts} = \frac{2F}{\pi A} = 0.637\frac{F}{A} \tag{3}$$

Where: f_{ts}——Splitting tensile strength of concrete (MPa) ;

F——Specimen failure load (N) ;

A——Split surface area of the test piece (mm^2) .

2.4.4 Flexural Strength Test of Concrete

In order to study the influence of plastic-steel fiber on the flexural strength of concrete, the flexural strength test of concrete was carried out. The test used 100mm × 100mm × 400mm test pieces, and the size conversion factor was 0.85. After taking out the test piece, place the test piece in the center of the equipment support of the testing machine, wipe the surface of the test piece and the surface of the loading plate, and use the side as the pressure bearing surface. After the data is cleared, continuous loading is started, and the loading speed is 0.05 MPa / s.

The formula for calculating the axial compressive strength of concrete specimens is as follows:

$$f_{f} = \frac{Fl}{bh^2} \tag{4}$$

Where: f_f——Flexural strength of concrete (MPa) ;

F——Specimen failure load (N) ;

l——Span between supports (mm) ;

b & h——Width and height of the concrete specimen (mm) .

3. Examples

3.1 Cubic Compressive Strength Test of Concrete

The compressive strength of concrete cubes is closely related to the experiment method. Under the normal circumstances, friction between the upper and lower surfaces of the test piece and the pressure plate of the experimental machine will prevent the test piece from deforming outward and block the cracks. Development, thereby improving the compressive strength of the test block. At the time of failure, the concrete in the middle of the test piece far from the bearing plate was subject to the least restraint, and the concrete also spalled the most, forming two pairs of truncated square vertebrae stacked on top of each other.

During the experimental, we used the test method without lubricant. Due to the limitation of the experimental conditions, we used a cube non-standard test piece with a side length of 100 mm for testing. Therefore, it needs to be multiplied by a conversion factor of 0.95 to convert to the compressive strength of the concrete cube of 150mm. Substituting the conversion factor into Formula (1), the formula is as follows:

$$f_{cc} = \frac{0.95F}{A} \tag{5}$$

Where: f_{cc}——Cubic compressive strength of concrete (MPa) ;

F ——Specimen failure load (N) ;

A——Pressure area of the test piece (mm^2) .

We did three sets of parallel experiments. Fig.3 and Fig.4 are the process of the experiment. The test data and results are shown in Table 3 below:

Table 3 Cubic Compression Strength

Groups	Plain Concrete				Plastic-Steel Fiber Concrete			
	7Days		28Days		7Days		28Days	
	F/kN	f_{cc}/MPaa	F/kN	f_{cc}/MPa	F/kN	f_{cc}/MPa	F/kN	f_{cc}/MPa
1	734.21	31.0	1117.89	47.2	670.26	28.3	1065.79	45.0
2	686.84	29.0	1101.32	46.5	686.84	29.0	1080.00	45.6
3	698.68	29.5	1125.00	47.5	651.32	27.5	1049.21	44.3
Average	706.58	29.8	1114.74	47.1	669.47	28.3	1065.00	45.0

From the test results, we can see that the compressive strength of plastic-steel fiber concrete cubes was reduced by 5.0% compared to plain concrete at 7d, and the compressive strength of plastic-steel fiber concrete cubes was reduced by 4.5% compared to plain concrete at 28d. Therefore, we can get that when adding 6kg / m^3 plastic-steel fiber to the medium-strength concrete, the cubic compressive strength of the concrete will be slightly reduced. Adding fibers to the concrete can reduce the micro-cracks caused by the load on the substrate and the stress concentration caused by the tip of the defect. Therefore, it can effectively prevent the development of cracks and improve the concrete's bending toughness and impact resistance. However, if the rate of the fiber is too high, the compressive strength of fiber concrete will decrease to some extent.

Fig.3 Trial in Progress

Fig.4 Partially Damaged Test Pieces

3.2 Axial Compressive Strength Test of Concrete

Generally, the length of a concrete member is much larger than the length of its section side. Therefore, the stress state of the prism test piece (the test piece whose height is greater than the section side length) is closer to the concrete in the actual member. In this experiment, three sets of parallel tests were performed. The test data was substituted into Formula (2). The test data and results are shown in Table 4 below:

Table 4 Axial Compressive Strength

Groups	Plain Concrete				Plastic-Steel Fiber Concrete			
	7Days		28Days		7Days		28Days	
	F/kN	f_{cp}/MPa	F/kN	f_{cp}/MPa	F/kN	f_{cp}/MPa	F/kN	f_{cp}/MPa
1	460.4	20.5	702.9	31.2	417.6	18.6	668.9	29.7
2	450.2	20.0	731.3	32.5	441.9	19.6	680.4	30.2
3	444.7	19.8	685.4	30.5	422.6	18.8	695.0	30.9
Average	451.8	20.1	706.5	31.4	427.4	19.0	681.5	30.3

From the test results, we can get that the axial compressive strength of plastic-steel fiber concrete decreased by 5.5% compared to plain concrete at 7d, and the axial compressive strength of plastic-steel fiber concrete decreased by 3.5% compared to plain concrete at 28d.

At 28d, the f_{cp}/f_{cc} of plain concrete is 0.667, and the f_{cp}/f_{cc} of plastic-steel fiber concrete is 0.673, the results meet the relationship of theoretically 0.67 times. The tests show that the axial compressive strength is lower than that of the cube test block. The larger the ratio of the height h of the prism specimen to the side length b, the lower the strength. When it increasing from 1 to 2, the strength of the concrete decreases rapidly, but when it increasing from 2 to 4, its compressive strength does not change much, because within this range, the friction between the pad and the contact surface of the specimen can be eliminated and the compressive strength can also avoid the influence of the additional eccentricity caused by the longitudinal initial bending of the test piece against the compressive strength, so the measured axial compressive strength is relatively stable.

3.3 Splitting Tensile Strength Test of Concrete

Splitting tensile strength is also an important test index to characterize the mechanical properties of concrete. It is of great significance to examine the influence of plastic-steel fiber on the flexural strength of concrete. Substituting the data obtained from the test into Formula (3), the split tensile strength can be obtained, as shown in Table 5. It can be seen that the split tensile strength of 6kg / m^3 plastic-steel fiber concrete is 17% higher than that of ordinary concrete, indicating that the addition of plastic-steel fiber can improve the brittleness of concrete.

Table 5 Split Tensile Strength

Groups	Plain Concrete		Plastic-Steel Fiber Concrete	
	28Days		28Days	
	F/kN	f_{ts}/MPa	F/kN	f_{ts}/MPa
1	98.90	2.80	120.09	3.40
2	102.43	2.90	120.09	3.40
3	104.20	2.95	116.56	3.30
Average	101.84	2.88	118.92	3.37

3.4 Flexural Strength Test of Concrete

Flexural strength is one of the most important parameters to characterize the mechanical properties of concrete. It is of great significance to investigate the influence of plastic-steel fiber on the flexural strength of concrete. The experiment used 100mm × 100mm × 400mm cube test pieces with a conversion factor of 0.85. This test was conducted in three sets of parallel tests. Substituting the conversion factor into Formula (4), the formula is as follows:

$$f_{\mathrm{f}} = \frac{0.85Fl}{bh^2} \tag{6}$$

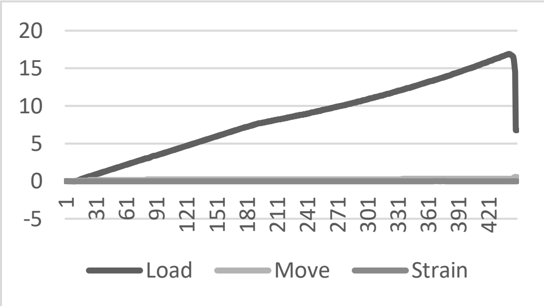
Where: f_{f} ——Flexural strength of concrete (MPa) ;

F ——Specimen failure load (N) ;

l——Span between supports (mm) ;

b & h——Width and height of the concrete specimen (mm) .

At the meantime, we get the load-stress-strain curves of plain concrete and the plastic-steel fiber concrete (Fig.5 and Fig.6). The flexural strength test data are shown in Table 6. Fig.7 and Fig.8 are the process of the experiment.



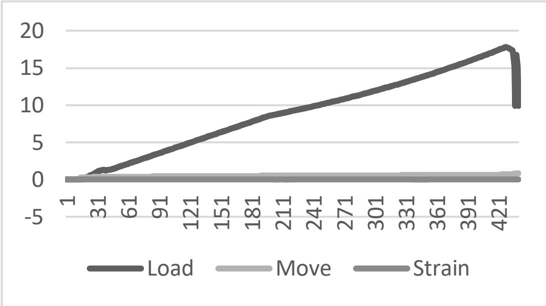


Fig.5 & 6 Load-Stress-Strain Curve of Plain Concrete & Plastic-Steel Fiber Concrete

Table 6 Flexural Strength

Groups	Plain Concrete 7Days		Plain Concrete 28Days		PSF Concrete 7Days		PSF Concrete 28Days	
	F/kN	F_f/MPa	F/kN	f_f/MPa	F/kN	f_f/MPa	F/kN	f_f/MPa
1	12.59	3.2	16.31	4.2	13.29	3.4	17.61	4.5
2	11.84	3.0	15.88	4.1	13.76	3.5	17.76	4.5
3	12.12	3.1	16.08	4.1	14.86	3.8	18.04	4.6
Average	12.18	3.1	16.09	4.1	13.97	3.6	17.80	4.5

It can be seen that the 7d flexural strength of 6kg / m^3 plastic-steel fiber concrete is 16.1% higher than the 7d flexural strength of ordinary concrete, and the 28d flexural strength of 6kg / m^3 plastic-steel fiber concrete is 9.7% higher than the 28d flexural strength of ordinary concrete. It shows that the plastic-steel fiber mixed with 6kg / m^3 can improve the flexural strength of concrete. The toughness of concrete is improved. The plastic-steel fiber can improve the flexural strength of the concrete. The main reason is that the randomly distributed fibers can inhibit the cracks in the concrete from extending, delay the damage, as fibers are broken or pulled out, the concrete test pieces will be eventually destroyed.

Fig.7 Concrete Flexural Strength Test Fig.8 Flexural Test Specimens

4. Conclusion

In this article, the basic mechanical properties such as cubic compressive strength, axial compressive strength, split tensile strength, and flexural strength of modified concrete obtained by incorporating plastic-steel fibers are tested to analyze the incorporation of plastic-steel fibers into plain concrete. The effects of various mechanical properties are as follows:

(1) The cubic compressive strength of 7d plastic-steel fiber concrete is reduced by 5.0% compared to plain concrete, and the cubic compressive strength of 28d plastic-steel fiber concrete is reduced by 4.5% compared to plain concrete. Therefore, when 6kg / m³ plastic-steel fiber is added to the medium-strength concrete (C30), the cubic compressive strength of the concrete will be slightly reduced;

(2) The axial compressive strength of 7d plastic-steel fiber concrete is reduced by 5.5% compared to plain concrete, and the axial compressive strength of 28d plastic-steel fiber concrete is reduced by 3.5% compared to plain concrete;

(3) The splitting tensile strength of plastic-steel fiber concrete is 17% higher than that of plain concrete, indicating that the incorporation of plastic-steel fiber has improved the brittleness of concrete;

(4) The flexural strength of 7d plastic-steel fiber concrete is 16.1% higher than that of plain concrete, and the flexural strength of 28d plastic-steel fiber concrete is 9.7% higher than that of plain concrete.

In summary, compared with ordinary concrete, the compressive strength of the cubic and the axial compressive strength of 6kg / m³ plastic-steel fiber concrete are reduced, while the splitting tensile strength and flexural strength are improved.

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