Experimental Study On Mechanical Properties Of Polyacrylonitrile-Polypropylene Thick Fiber (PAN-PPTF) Concrete With Different Thickness

Cao Liang, Zhang Yun-fei and Li Zhen-shu*

1School of Engineering, Yan Bian University, Yanji, Jilin ,133002, China
2School of Engineering, Yan Bian University, Yanji, Jilin ,133002, China
*Corresponding author’s e-mail: lizs@ybu.edu.cn

Abstract: In order to improve mechanical properties of concrete and reduce the use of steel, in this experiment, polyacrylonitrile fiber (PAN) and polypropylene thick fiber (PPTF) were mixed to replace the use of steel fiber, and the thickness of the PAN-PPTF concrete was changed. The results showed that the compressive strength of concrete test blocks decreased with the increase of the thickness of PAN-PPTF concrete, but the split-tensile strength and bending strength of test blocks both increased. When PAN-PPTF concrete was 1/3 of the test block, the compressive strength decreased by 5.62%, but the split-tensile strength increased by 36.08%, and the bending strength increased by 38.48%.

1. Introduction
In recent years, with the development of material science, a variety of new concrete materials came into being. Since the application of fiber-reinforced concrete, many scholars have concluded through studies that fiber does not significantly improve the compressive strength and tensile strength of concrete, transforming the brittle failure of ordinary concrete into ductile failure of plastic deformation. [1-2]

Generally speaking, high-elastic modulus fiber (mainly steel fiber) has good strengthening and toughening effect, but its price is higher. [3] The fiber with low elastic modulus has a good toughening effect, and its crack and permeability resistance are good, which improves the durability greatly, but the enhancement effect is poor. [4] Compared with steel fiber, polypropylene thick fiber (PPTF), a new type of concrete material, has the characteristics of corrosion resistance, easy dispersion and no damage to mixing equipment. It can also improve the concrete's low tensile strength, brittleness and low ultimate elongation. But because its diameter is thick anf not easy to stir, most of the concrete is mixed with composite fiber. Polyacrylonitrile fiber (PAN) has high strength, acid, alkali, salt and other chemical corrosion characteristics, and low price, simple construction process. It can effectively inhibit the cracking of concrete and improve the durability of concrete. Therefore, in this experiment, two kinds of fibers were mixed to improve the brittleness of concrete. In order to effectively improve the tensile zone of concrete performance and reduce the dosage of steel fiber. This paper analyzed the mechanical properties of the concrete block by changing the thickness of the PAN-PPTF concrete from the bottom of concrete block. So as to obtain a reasonable thickness of the PAN-PPTF concrete and provide reference for the research and application of PAN-PPTF.
2. Test program

2.1. Test programme design

150×150mm×150mm standard specimens were used to make compression and split-tensile strength test blocks, and 150mm×150mm×600mm specimens were used to make bending test blocks, with 3 specimens in each group, a total of 21 groups of specimens. According to the proportion (adding height) of PAN-PPTF concrete mixed into the specimen as a whole, it could be divided into the following seven groups: F0 (without adding), F1 (1/6), F2 (2/6), F3(3/6), F4 (4/6), F5 (5/6) and F6 (6/6).

In the process of concrete preparation, the cementitious materials were mixed with coarse and fine aggregates and hybrid fibers for 60s dry stirring, and then the mixture solution of water reducing admixture and water was poured into the mixer for 180s wet stirring, and the stirring time met the requirements of the specification. In the casting process, the PAN-PPTF concrete was poured on the lower part of the specimen. After 2 hours of casting, the plain concrete was filled with test mold. Specific experimental steps for reference CECS13: 89 Experimental Methods For Steel Fiber Concrete.

2.2. Raw material and mix proportion design

The designed strength of concrete in this experiment was C30, and slump values were between 150 and 180mm. Coarse aggregate sized of 5~25mm continuous grading of gravel. Fine aggregate was natural medium sand. Cement adopted PO42.5 ordinary Portland cement of miaoling brand, yanbian Korean autonomous prefecture, jilin province, with water-binder ratio of 0.35. The density of fly ash was 2200kg/m³, and it is from tienan heating supply company in Yanji city, Jilin province. The content of fly ash was 20% of the total weight of cementitious materials. The specific mix proportion design was shown in table 1. The content of the two fibers was 0.15% of the total volume of the aggregate. The admixture was liquid polycarboxylic acid superplasticizer with a solid content of 40% and a content of 1.33% of the total weight of the gel.

Table 1 Concrete mix proportion design.

| Group name | Water dosage/kg | Cement /kg | Fly ash/kg | Sand /kg | Stone /kg | Polypropylene thick fiber /kg | Polyacrylonitrile fiber /kg | Water reducing admixture/kg |
|------------|-----------------|------------|------------|----------|-----------|-------------------------------|----------------------------|-----------------------------|
| JZ         | 171.0           | 390.9      | 97.7       | 838.9    | 908.8     | -                            | -                          | 6.5                         |
| HZ         | 171.0           | 390.9      | 97.7       | 838.9    | 900.6     | 1.4                          | 1.8                        | 6.5                         |

Fiber: polyacrylonitrile fiber (PAN), length19mm; poloypropylene thick fiber (PPTF), length 25 mm, cross section rectangular, killed surface. Its physical properties are shown in table2, table3.

![Polyacrylonitrile fiber (PAN)](image1)

![Polypropylene thick fiber (PPTF)](image2)

Table 2 Physical and mechanical properties of polyacrylonitrile fiber (PAN).

| Diameter /μm | Density/(kg/m³) | Initial modulus/GPa | Tensile strength/MPa | Denier/dtex | Fracture elongation/% |
|--------------|-----------------|---------------------|----------------------|-------------|-----------------------|
| 12~21        | 1.18            | >7                  | >600                 | 1.3~2.5     | ≥10                   |
Table 3 Physical and mechanical properties of Polypropylene thick fiber (PPTF).

| Diameter /um | Density / (kg/m3) | Elasticity modulus/GPa | Tensile strength /MPa | Alkali resistance | Fracture elongation /% |
|--------------|-------------------|------------------------|-----------------------|-------------------|-----------------------|
| >100         | 0.9               | 5~7.6                  | 400~550               | ≥98               | ≥15                   |

3. Test results and analysis of compressive properties

3.1. Results and analysis of compressive strength

The test results of 28d cubic compressive strength of each group are shown in table 4.

Table 4 Cubic compressive strength test results.

| Group name | F0     | F1     | F2     | F3     | F4     | F5     | F6     |
|------------|--------|--------|--------|--------|--------|--------|--------|
| Compressive strength/Mpa | 65.60  | 53.97  | 61.91  | 55.82  | 57.26  | 50.40  | 48.27  |

The table 4 shows that with the increase of thickness of PAN-PPTF concrete block of compressive strength as a whole is declining. This is because the addition of fiber changed the internal structure of concrete, so that the density of concrete decreased, the internal defects increased, easy to appear micro-cracks and pores [5]. And elastic modulus of fiber is lower than the elastic modulus of concrete, so the mixing polypropylene fiber concrete cubic compressive strength is the benchmark of PAN-PPTX concrete will fall in [6], and. However, when the thickness of concrete is 1/3 of the whole, the strength loss rate is 5.62%, which was the smallest compared with other groups.

3.2. Analysis of compression failure mode

From the analysis of the destruction form figure 3, the F0 group shows the typical brittle fracture and burst phenomenon during the destruction. For the group with PAN-PPTF fiber concrete, when the specimens were damaged, the part without fiber showed obvious brittle failure (upper part of the test block), while the part with fiber only showed peeling and micro-cracks, which showed plastic failure (lower part of the test block). This indicated that although the compressive strength of the test piece was reduced after adding fiber, the failure form of the test specimen was changed and the integrity of the test specimen was retained.

Figure 3 Failure pattern diagram of compressive specimen (F2 and F3 group)

4. Split-tensile test results and analysis

4.1. Test results and analysis of split-tensile properties

The results of 28d split tensile test and the tensile pressure ratio of each group are shown in table 5.
Table 5 Split-tensile test results and tensile compression ratio.

| Group name | Split-tensile strength /MPa | Improvement rate relative to group F0 group/% | Tensile compression ratio |
|------------|-----------------------------|-----------------------------------------------|--------------------------|
| F0         | 3.88                        | ———                                          | 1/16.75                  |
| F1         | 4.87                        | 25.52%                                       | 1/11.08                  |
| F2         | 5.28                        | 36.08%                                       | 1/11.72                  |
| F3         | 5.41                        | 39.43%                                       | 1/10.32                  |
| F4         | 5.07                        | 30.07%                                       | 1/11.29                  |
| F5         | 5.17                        | 33.25%                                       | 1/9.75                   |
| F6         | 3.90                        | 0.50%                                        | 1/12.38                  |

Table 5 shows that the split-tensile strength of the test block increases first and then decreases with the increase of the thickness of fiber concrete. When the thickness of PAN-PPTX concrete reached 1/2 of the test block, the splitting tensile strength of the test block reached the maximum value of 5.41MPa, 39.43% higher than that of the benchmark group. However, for groups F4, F5 and F6, when the thickness of PAN-PPTX concrete exceeded 1/2 of the test block, the percentage of the increase in the split-tensile strength was lower than that at 1/2. It showed that the split-tensile strength of test blocks was broken when PAN-PPTX concrete was distributed in compression zone. The tensile compression ratio of test blocks with different thickness of PAN-PPTF was between 1/13 and 1/9, indicating that the combination of PAN-PPTX concrete and plain concrete could significantly improve the tensile compression ratio of concrete, and the splitting tensile strength of concrete was significantly improved.

4.2. Split-tensile failure morphology and analysis

It can be seen from the failure pattern of the reference group that the specimens were fractured along the cleavage line. However, as can be seen from figure 5, when the test block with a certain thickness of PAN-PPTF concrete at the bottom of the specimen failed, it did not crack in half directly, but took place along the splitting line. From the crack surface of the test block, it could be seen that the width of the crack decreased gradually from top to bottom, which showed that the fiber concrete had good ductility and reduced the expansion of the crack.

![Figure 4 Group F0 damage mode](image1.png)  ![Figure 5 Group F3 damage mode](image2.png)

In the process of concrete specimen hardening, the elastic modulus of polyacrylonitrile fiber itself was much lower than that of concrete, so its main function was to reduce the tiny cracks caused by the scattered distribution of polypropylene steel fiber, so as to reduce the defects inside the test block and indirectly enhance the tensile strength of the test block. The elastic modulus of polypropylene thick fiber was much higher than that of concrete, and it had a good bonding effect with concrete. Therefore, when the test block began to split and produced cracks, the internal force of concrete could be transferred to polypropylene thick fiber, which improved the split-tensile strength of the test block and retained the integrity of the test block.
5. Results and analysis of bending strength

5.1. Failure strength results and analysis

The bending strength of concrete specimen refers to the ultimate bending stress under bending moment per unit area. The width and height of the specimen were measured in the middle and accurate to 1mm. The bending test device is shown in figure 6.

![Figure 6 The bending test device](image)

The results of 28d bending test in each group are shown in table 6.

| Group name | Bendingl strength/Mpa | Improvement rate relative to group F0 group % |
|------------|-----------------------|-----------------------------------------------|
| F0         | 8.16                  | 0.00%                                         |
| F1         | 9.62                  | 17.89%                                        |
| F2         | 11.31                 | 38.48%                                        |
| F3         | 10.47                 | 38.31%                                        |
| F4         | 10.87                 | 33.21%                                        |
| F5         | 11.21                 | 37.38%                                        |
| F6         | 9.62                  | 17.89%                                        |

It can be seen from table 6 that the bending strength of the test block increases first and then decreases with the increase of the thickness of PAN-PPTF concrete, and reaches the maximum strength of 11.31Mpa. When the thickness of the test block was 1/3 of that of the test block, which was 38.48% higher than that of the benchmark group, indicating that this arrangement was the most favorable for increasing the bending strength. The strength of all test blocks with fiber reinforced concrete increased by 17.57%, indicating that the strength of all test blocks with fiber reinforced concrete did not increase much only when they were distributed in the tensile zone of test blocks. The bending strength of F1 and F2 specimens increased the fastest, with an average growth rate of 18.50%, which indicated that the bending strength of PAN-PPTF concrete distributed in the tensile zone of the test block increased obviously.

5.2. Failure mode analysis of bending specimens

It can be seen from the failure pattern diagram of the three groups that the specimens of the reference group without PAN-PPTF concrete distribution had brittle fracture, which was directly broken in half at the midspan. However, the PAN-PPTF concrete with a certain thickness distributed at the bottom first had a tiny crack and then cracked along the crack. With the increase of the thickness of PAN-PPTF concrete, cracks appeared first and then fracture with the increase of load. This indicated that the incorporation of PAN-PPTF concrete made the test block had some ductile damage and retained the integrity of the test block to a certain extent.

When tiny cracks appeared in the upper part of the test block, as the lower crack expands, the bonding surface between the PPTF and the concrete matrix started to break, and the fibers were pulled or torn from the concrete, and the specimen broke. In the whole process, PPTF absorbed a lot of energy and improved the toughness and ductility of concrete [7].
6. Conclusion

i. The split-tensile strength and bending strength of the test block can be improved by distributing a certain thickness of PAN-PPTF concrete from the bottom of the test block, but the compressive strength reduced to some extent. Its mechanical properties tended to rise first and then fell with the increase of the thickness of PAN-PPTF concrete. When the thickness of PAN-PPTF concrete was 1/3 of the test block, it was the best distributed thickness. The compressive strength decreased by 5.62%, but the split-tensile strength increased by 36.08%, and the bending strength increased by 38.48%.

ii. The addition of PAN-PPTF concrete changed the failure mode of the test block and significantly reduced the brittleness of the test block and improved the toughness, thus greatly retained the integrity of the test block.

iii. The mechanical properties of the test blocks with PAN-PPTF concrete and plain concrete mixed in proportion to a certain volume were better than those of all distributed PAN-PPTF concrete test blocks. Therefore, mixing two kinds of concrete in proportion to a certain volume can reduce the use of fiber and improve the mechanical properties of concrete. Moreover, the construction difficulty was small, which can be widely applied to the tensile part of the building, saving the use of steel reinforcement. However, the optimal content of polyacrylonitrile fiber and polypropylene thick fiber needs to be further studied so as to achieve the best mechanical properties of the specimen.

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