Study on Mechanical Properties of Hybrid Fiber Reinforced Concrete

Dongqing He1,2, Min Wu1,3 and Pengyu Jie1,4

1School of Civil Engineering and Architecture, Henan University, Kaifeng 475004, China
2he_dongqing@163.com
31728773646@qq.com
4546915580@qq.com

Abstract. Several common high elastic modulus fibers (steel fibers, basalt fibers, polyvinyl alcohol fibers) and low elastic modulus fibers (polypropylene fiber) are incorporated into the concrete, and its cube compressive strength, splitting tensile strength and flexural strength are studied. The test result and analysis demonstrate that single fiber and hybrid fiber will improve the integrity of the concrete at failure. The mechanical properties of hybrid steel fiber-polypropylene fiber reinforced concrete are excellent, and the cube compressive strength, splitting tensile strength and flexural strength respectively increase than plain concrete by 6.4%, 3.7%, 11.4%. Doped single basalt fiber or polypropylene fiber and basalt fibers hybrid has little effect on the mechanical properties of concrete. Polyvinyl alcohol fiber and polypropylene fiber hybrid exhibit ‘negative confounding effect’ on concrete, its splitting tensile and flexural strength respectively are reduced by 17.8% and 12.9% than the single-doped polyvinyl alcohol fiber concrete.

1. Introduction

According to the needs of the construction and development of our country, it is the future development trend to apply the excellent performance and low price of fiber concrete in all engineering fields. The fibers used for construction can be divided into: metal fiber, inorganic fiber, organic fiber, plant fiber and so on. In recent years, through the research and engineering application, a lot of achievements have been obtained and accumulated rich experience. The improvement of fiber on concrete is reflected in the following aspects: first the low strength of organic synthetic fiber can effectively reduce the initial cracks during the curing period of concrete[1]. Then the high strength fibers can effectively transmit and disperse loads to increase the strength of concrete. After cracking, it can also depend on the bond between the fiber and concrete in the cracking surface to improve the strength and integrity of the concrete [2]. Simultaneously, with the incorporated of fiber, the development of cracks become much and tiny after the concrete crack because of loads, also impair the erosion of the environment to concrete, which is beneficial to enhance the durability of concrete[3].

Hybrid Fiber Reinforced Concrete (HFRC) is a multiphase composite material, which consists of two or more than two fibers incorporated into concrete at the same time. It utilizes the different characteristics of the fibers to improve the performance of concrete. Compared with the doped single fiber reinforced concrete, the hybrid fibers use the properties of different fibers to improve the...
performance of concrete in various loading stages, play complementary roles of different fibers in concrete, and achieve the "positive confounding effect" of the fiber. But it sometimes reduces some of the mechanical strength of concrete, namely "negative confounding effect". In this paper, the author study the impact of the high elastic modulus steel fibers, basalt fibers, polyvinyl alcohol fibers and the low elastic modulus polypropylene fiber a mixed into the concrete on the cube compressive strength, flexural strength and splitting tensile strength are studied.

2. Experiment Materials
The materials used for this investigation are obtained with:
- Portland cement 42.5.
- Coarse aggregate, crushed stones (grain diameter 5~30mm).
- Fine aggregates, river sand (fineness modulus 2.6).
- Water reducer: poly carboxylic acid water reducing agent (MY-IX) from Henan MEIYA, water reducing rate is 20%~25%.
- The specific properties are shown in Table 1.

| Fiber | Diameter (μm) | Length (mm) | Density (kg/m³) | Tensile strength (MPa) | Elastic modulus (GPa) | Elongation (%) |
|-------|---------------|-------------|-----------------|------------------------|-----------------------|---------------|
| PPF   | 18-48         | 19          | 910             | >358                   | >3.5                  | >15           |
| SF    | 300-1200      | 30          | 7850            | >600                   | 200                   |               |
| BF    | 18            | 25          | 2650            | 3800-840               | 93.1-110              | 3.1           |
| PAF   | 12            | 6           | 1300            | 1428                   | 37.9                  | 6.0-8.0       |

3. Test methods and Contents
The mix proportion design of plain concrete (PC) is according to "Specification for mix proportion design of ordinary concrete" (JGJ 55-2011), such as table 2. According to the relevant literature [5][6][7], and the dispersion of the field fiber in the concrete mixture, the volume of steel fiber was 1%(78kg/m³), 0.1%(0.91kg/m³) of polypropylene fiber, 0.2% (5.3kg/m³) of basalt fiber, 0.1%(1.3kg/m³) of alcohol fiber, the specific fiber content of each test group is shown in Table 3.

| Water | Cement | Sand | Stone | Water reducer |
|-------|--------|------|-------|---------------|
| 161.3 | 460.8  | 620  | 1203.5| 5.5           |

Table 3. Fiber content.

| Test group | Fiber content (kg/m³) |
|------------|-----------------------|
|            | Steel fiber | Basalt fiber | Alcohol fiber | Polypropylene fiber |
| PC         | 0          | 0            | 0             | 0                 |
| SFRC       | 78         | 0            | 0             | 0                 |
| S-PPC      | 78         | 0            | 0             | 0.91              |
| BFRC       | 0          | 5.3          | 0             | 0                 |
| B-PPC      | 0          | 0            | 1.3           | 0.91              |
| PVAFRC     | 0          | 0            | 1.3           | 0                 |
| PVA-PPC    | 0          | 0            | 1.3           | 0.91              |

According to "The standard of test method for mechanical properties of ordinary concrete" (GB/T 50081-2002). The cube compressive strength, flexural strength and splitting tensile strength of Steel fiber reinforced concrete(SFRC), hybrid steel fiber and polypropylene fiber concrete(S-PPC), basalt fiber reinforced concrete (BFRC), hybrid basalt fiber and polypropylene fiber concrete(B-PPC), polyvinyl alcohol fiber reinforced concrete(PVAFRC), hybrid polyvinyl alcohol fiber and polypropylene fiber concrete(PVA-PPC) are tested and calculated. The specimen size of the cube
compressive strength and splitting tensile strength is $150mm \times 150mm \times 150mm$, and the size of the flexural tensile strength specimen is $150mm \times 150mm \times 550mm$ [8].

4. Test Results and Analysis

4.1. The test of cube compressive strength. The compressive failure pattern of cube specimens in each group is shown in Figure 1.

![Figure 1. Failure pattern of cube specimens](image)

(a) PC (b) SFRC (S-PPC) (c) PVAFRC (PVA-PPC)

We can see in Figure 1 that when the specimens of the PC are damaged, the concrete is broken into a heap, and no numbers could be seen (Figure 1(a)), and the rest of the groups are clearly visible. Obviously, the incorporation of fibers (single fiber or mixed fiber) improve the failure pattern of concrete, in which there are a distinct area of damage after the two specimens of PVAFRC, PVA-PPC are destroyed (Figure 1(c)). Compared with others, their integrity is slightly worse. The integrity of the specimen with steel fiber is the best and the crack is thin and uniform (Figure 1(b)).

The cube compressive strength is the basic index of concrete strength. The results of each group are shown in Table 4, and the comparison of different concretes is shown in Figure 2.

| Test group | PC  | SFRC | S-PPC | BFRC | B-PPC | PVAFRC | PVA-PPC |
|------------|-----|------|-------|------|-------|--------|---------|
| $f_{cc}$ (MPa) | 56.36 | 57.61 | 59.97 | 54.83 | 57.42 | 53.24 | 55.73 |

![Figure 2. Comparison of cube compressive strength of different concretes](image)

It can be seen from Figure 2, the cube compressive strength of SFRC and S-PPC than the PC increase by 2.2% and 6.4%. Obviously, the S-PPC shows a good advantage about fiber mixing, and increase by 4.1% than the SFRC. Compared with PC, the BFRC decreases slightly by 2.7%, and B-PPC shows a certain "positive confounding effect", which is 1.9% and 4.7% higher than PC and BFRC, respectively. PVAFRC and PVA-PPC are reduced by 5.5% and 1.1%, respectively, compared with PC, and PVAFRC has a significant decrease, however, when the polyvinyl alcohol fiber is mixed with polypropylene fiber, the cube compressive strength is increased, and PVA-PPC is 4.7% higher than PVAFRC.
4.2. The test of splitting tensile strength. The splitting failure pattern of specimens in each group is shown in Figure 3.

![Figure 3. Splitting failure pattern of Specimen](image)

(a) PC, BFRC (b) SFRC, S-PPC (c) B-PPC, PVA, PV A-PPC

From Figure 3, after the splitting of the specimen with steel fiber, the specimen is connected together by the steel fibers at the fracture surface (Figure 3(b)), unlike the other specimens directly split into two halves (Figure 3(a), (c)). At the same time, the fracture of PC and BFRC is accompanied by a brittle sound.

The splitting tensile strength reflects the tensile properties of concrete. The results of each group are shown in Table 5, and the comparison of different concretes is shown in Figure 4.

### Table 5. The splitting tensile strength.

| Test group | PC   | SFRC | S-PPC | BFRC | B-PPC | PVAFRC | PVA-PPC |
|------------|------|------|-------|------|-------|--------|---------|
| $f_{td}$ (MPa) | 4.01 | 4.01 | 4.16  | 4.01 | 4.02  | 4.11   | 3.38    |

![Figure 4. Comparison of splitting tensile strength of different concretes](image)

As shown in Figure 4, the splitting tensile strength of S-PPC increases by 3.7% compared with PC and SFRC, which reflects the "positive confounding effect". Compared with PC, there is no obvious change in BFRC and B-PPC, the PVAFRC increases by 2.5%, and the PVA-PPC decreases by 15.7%, which shows a "negative confounding effect".

4.3. The test of flexural strength. The failure pattern of specimens in each group is shown in Figure 6.

![Figure 5. Failure modes of flexural specimens](image)

(a)PC, BFRC (b)SFRC, B-PPC (c)B-PPC, PVAFRC, PVA-PPC.
When the specimen of PC, BFRC is destroyed, the bearing capacity decreases rapidly instantly, the specimen form a through folded section (Figure 5(a), BFRC) and with specimen muffled. At the moment the specimen of B-PPC with Polypropylene Fiber is damaged, it is not completely cracked (Figure 5(c)), which indicates that polypropylene fibers are also effective in reducing the development of cracks after concrete failure. The failure of SFR, S-PPC shows good integrity (Figure 5(b)).

Flexural strength is the main strength index of concrete for road surface or airport pavement, and three point loading method is used in flexural test. The results of each group are shown in Table 6 and the comparison of different concretes is shown in Figure 6.

| Test group  | PC   | SFRC | S-PPC | BFRC | B-PPC | PVAFRC | PVA-PPC |
|------------|------|------|-------|------|-------|--------|---------|
| f\(_t\) (MPa) | 5.60 | 6.19 | 6.24  | 5.57 | 5.61  | 5.75   | 5.01    |

**Figure 6.** Comparison of flexural strength of different concretes

It can be seen from Figure 6, SFRC and S-PPC are increased by 5.5% and 1.1%, respectively, compared with PC. Obviously, the fiber mixing of S-PPC is not obvious, and its flexural strength is almost unchanged compared with that of PC. The incorporation of basalt fiber has little effect on the flexural strength of concrete, and it has little effect after mixing with polypropylene fiber. Compared with PC, the flexural strength of BFRC is decreased by 0.5%, and the B-PPC is only increased by 0.2%, the PVAFRC is increased by 2.7%, and the PVA-PPC is decreased by 10.5%. PVA-PPC shows the "negative confounding effect", which is not only a significantly reduced compared with the PC, but also decreased by 12.9% compared with PVAFRC.

5. Conclusions

1. Single fiber and hybrid fiber will improve the integrity of the concrete at failure, when the specimen is destroyed, steel fiber and mesh polypropylene fiber are often pulled out, and polypropylene fibers are across the failure surface of concrete. And basalt fiber and polyvinyl alcohol fiber are mostly fractured.

2. The mechanical properties of hybrid steel fiber-mesh polypropylene fiber reinforced concrete are excellent, and the cube compressive strength, splitting tensile strength and flexural strength respectively increase more than plain concrete by 6.4%, 3.7%, 11.4%. The strength values of concrete have also increased compared with steel fiber.

3. Doped single basalt fiber or polypropylene fiber and basalt fibers hybrid has little effect on the mechanical properties of concrete.

4. Polyvinyl alcohol fiber and polypropylene fiber hybrid exhibit negative confounding effect on concrete, its splitting tensile and flexural strength respectively are reduced by 17.8%, 12.9%, than the single-doped polyvinyl alcohol fiber concrete.

References

[1] Xiao Rong S and Bai Sheng W. Experiment on the Flexural Properties of Simply Supported Polypropylene Fibers Reinforced Concrete Beams: *Journal of Henan University*, Vol. 23(2008) No.1, P328-334
[2] Yi Ning D, Xiang Jun D and Yue Hua W. Strength and Flexural Toughness of Hybrid Fiber Reinforced Self-compacted Concrete: *Journal of Building materials*, **Vol. 35**(2005) No.3, p294-298

[3] Li X and Fei Y. Application of Fiber in Concrete: Coal Ash (2013) No.6, p42

[4] Xue Zhi W, Jing Jing H and Hao F: Experimental Study on Basalt-polypropylene Hybrid Fiber Reinforced Concrete Flexural Toughness Characteristic. *Concrete*, (2014) No.4, p 82-86

[5] An Qi L, Ye Ran Z and Ke L. Experimental Study of Polypropylene Fiber Reinforced Concrete: *Journal of Hydraulic Engineering*, (2002) No. 12, p14-19

[6] Dong Tao X and Li Hua X. Experiment on Hybrid Fiber Reinforced High Strength Concrete: *Journal of Shenyang Construction University*, (2007)No.7, P 77-81

[7] Yong Y and Qing Wen R. Study on mechanical properties of steel fiber reinforced concrete: *Journal of Hehai University*, (2006) No.1, p92-94

[8] GB/T 50081-2002: Standard for Rest Method of Mechanical Properties on Ordinary Concrete *(China Architecture & Building Press, China 2002)*