Study on the flexure performance of fine concrete sheets reinforced with textile and short fiber composites

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Abstract. In order to study the influences of the contents of short fiber on the mechanical properties of concrete matrix, the properties of compressive, flexure and splitting of concrete matrix reinforced by alkali resistant glass fiber and calcium carbonate whisker were tested. To study the reinforced effect of different scale fibers on the flexure behavior of fine concrete sheets, the flexural tests of concrete sheet of fine concrete reinforced with basalt fiber mesh and short fiber composites were carried out. The results show that the properties of the compressive, flexure and splitting of fine concrete reinforced with appropriate amount of alkali resistant glass fiber and carbonate whisker are improved compared with that of concrete reinforced by one type of fiber. The flexure properties of the concrete sheets are improved obviously when continuous fiber textile and short fiber composite are adopted to reinforce.

0 Introduction

Concrete is widely used in construction because of its good performance. However, concrete has poor crack resistance and toughness, which will affect the mechanical properties and the durability of the concrete structures. In order to improve the toughness of concrete and inhibit cracking, suitable fibers can be added to concrete to form fiber reinforced concrete composites with better mechanical properties. At present, many scholars have carried out researches on the mechanical properties of reinforced concrete materials with single type of fiber (such as steel fiber, carbon fiber and alkali resistant glass fiber) [1-3]. The results show that the single type of fiber can improve the mechanical properties of concrete, but it cannot enhance the comprehensive mechanical properties of concrete at different levels. The mechanical properties of concrete can be enhanced from different structural levels by using a variety of scale fibers. For example, the mechanical properties of concrete materials can be improved by using short and fine fibers. The continuous long fibers contributes to improve the directional mechanical properties of concrete materials, and the multiple fibers composite reinforcement can complement each other, so the comprehensive mechanical properties of concrete materials can be improved efficiently [4].

As for the mechanical properties of reinforced concrete materials mixed with different fibers, scholars all over the world have carried out relevant studies from different perspectives, such as Walton and Majumdar [5] used two fibers to enhance cement-based materials. Kobayashi et al. [6], Blbal et al. [7] and Sukontaukku [8] studied the properties of steel-polypropylene hybrid fibers reinforced cement based materials. Gupta [9] and Dong et al. [10] studied the mechanical properties of cement based materials reinforced by steel hybrid fibers with different shapes. These studies show that the effects of mixing different fibers to enhance mechanical properties of concrete is better than that of using single type of fiber for reinforcing. Although the above studies all indicated that the enhancement effects of composite fibers on mechanical properties of concrete are obvious, most of the studies only considered the intermixture of different types of short fibers but not different scales of fibers (e.g. continuous long fibers and short fibers). In recent studies, Qian et al. [11] and Wu et al. [12] have studied the enhancement effects of fibers for different scales on the mechanical properties of fine concrete at different structural levels and the results show that the effects of multifibers on concrete are obvious. In order to further study the mechanical properties of concrete materials reinforced by multifibers, the effects of sizes and amounts of calcium carbonate whiskers and alkali resistant glass fibers on reinforced fine aggregate concrete are studied in this research. Also, the flexure behavior of the basalt fiber textile reinforced fibers concrete sheets was studied. In this study, the reinforcement effects of multiscale fiber composites on the flexure capacity and deformation of concrete sheets are detailed investigated.

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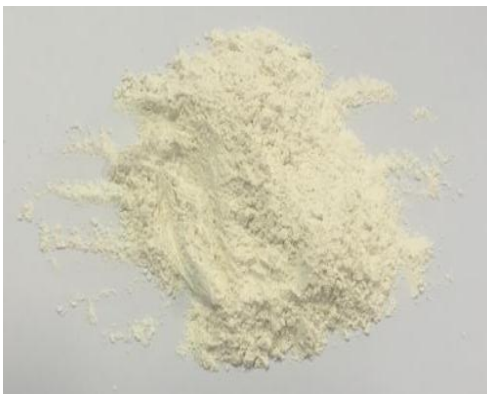
1 Mechanical properties of fine concrete matrix reinforced by multifiber composites

1.1 Mechanical properties tests of concrete matrix

P.O 42.5 grade ordinary Portland cement, sand, tap water and JM - PCA (Ⅰ) water reducing agent are adopted as the test materials. The mixture ratio of concrete (measured by mass ratio) is cement: sand: water: water reducing agent = 1:1.36:0.34:0.016. The microscopic fibers are made of NP-CW2 calcium carbonate whisker with a white powder appearance, as shown in Fig. 1(a). The contents of calcium carbonate whisker were 5% and 10% in the tests. The chopped fibers are made of the alkali resistant glass fibers, whose length is 6mm and 12mm respectively. The appearance of the alkali resistant glass fibers is white bundle, as shown in Fig. 1(b). The admixture amounts of alkali resistant glass fiber in fine concrete are taken 5% according the previous research results [12].

The tests involves three types of fine aggregate concrete matrix with different fiber contents, which are control groups (PC), single fibers group (GF) and composite fibers group (CW+GF) respectively. The design parameters of each group are shown in Tab. 1. In the table, the symbol "PC" represents the reference group without fibers. "GF6" represents that 5% alkali resistant glass fibers are added to the concrete. "CW5GF6" indicates that 5% calcium carbonate whiskers and 5% alkali resistant glass fibers are added into the concrete, and so on. The specimens in each group are tested for strengths of compression, flexure and splitting tensile respectively. The dimensions of specimens used in the compression and splitting strength tests are 0.7mm × 70.7mm × 70.7mm, and the dimensions of specimens used in the flexure strength tests are 40mm×40mm× 160mm. Three specimens were cast in each group, and the mean value of strength result was presented in this study.



(a) Calcium carbonate whisker

(b) Alkali-resistant glass fibre

Fig.1 Appearances of calcium carbonate whisker and alkali resistant glass fiber

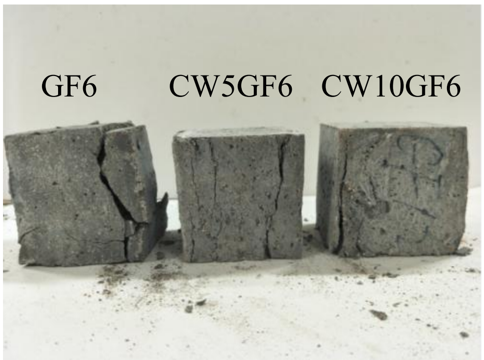
Table.1 Design parameters of fiber reinforced concrete specimens.

Specimen gorups	Calcium carbonate whisker contents （wt%）	6mmGF contents （wt%)	12mmGF contents （wt%)
PC	0	0	0
GF6	0	5	0
GF12	0	0	5
CW5GF6	5	5	0
CW10GF6	10	5	0
CW5GF12	5	0	5
CW10GF12	10	0	5

1.2 Fine concrete matrix test results

1.2.1 Failure modes of fine concrete specimens

The concrete matrix has obvious brittleness, and the matrix is destroyed without any warning signs when the load reaches its limit. The fragility and mechanical properties of concrete matrix are improved after being reinforced with alkali resistant glass fibers. Fig.2 shows the comparisons of the failure modes of compressive and splitting tensile tests of the concrete matrix reinforced with and without the fibers respectively. The concrete specimens without fibers fracture in a state of fragmentation and the specimens can hardly remain integrity, but the concrete specimen reinforced with fibers has good integrity when fractures. It is note that the failure modes of the concrete specimens reinforced with only calcium carbonate whiskers is almost as same as that of the control group specimens without fibers. These can be explained that micron-scale whiskers have minor effects on macro-crack of concrete. The failure morphology of concrete matrix reinforced with alkali resistant glass fibers and calcium carbonate whiskers are basically the same as that of concrete mixed only with glass fibers .



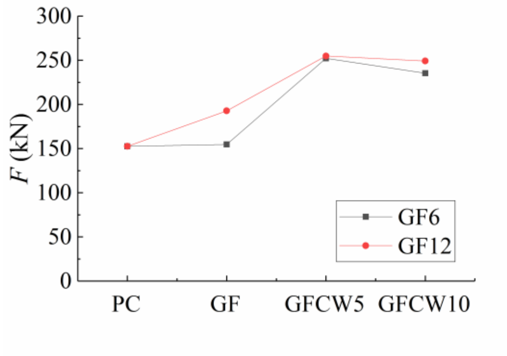
(a) Compressive failure

(b) Splitting failure

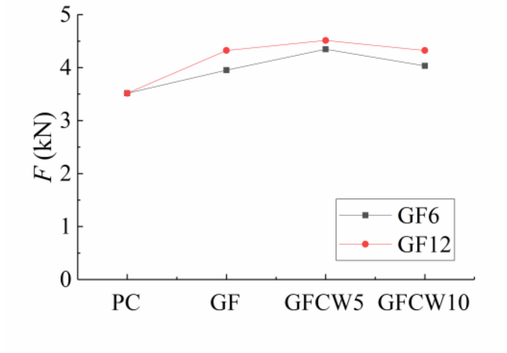
Fig.2 Comparisons of failure modes of fine concrete matrix

1.2.2 Analysis of mechanical properties of concrete matrix

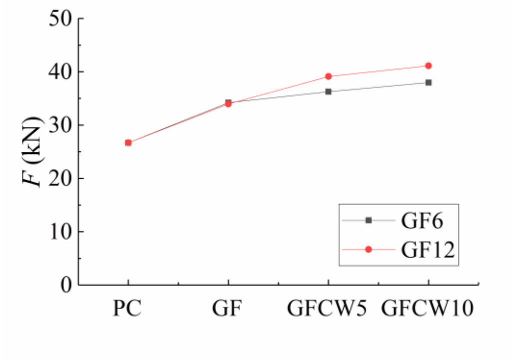
Fig. 3 shows the variation trend of compressive strength, flexure strength and splitting strength of fine concrete matrix with different fiber contents. From the figure, the strength indexes of the concrete matrix increase with the contents of alkali resistant glass fibers. The enhancement effects increase with the increases of dimension length, and the reinforcing effect of using 12mm alkali resistant glass fibers is more obvious than that of using 6mm fibers. The mechanical property of concrete matrix is further improved when alkali resistant glass fibers and calcium carbonate whiskers are combined for reinforcing. The compressive strength, flexure strength and splitting tensile strength of concrete matrix respectively increase by 67%, 28% and 36% when the concrete reinforced with 6mm alkali resistant glass fibers and calcium carbonate whiskers, while the compressive, flexure and splitting tensile strength respectively increase by 65%, 23% and 46% when the concrete reinforced with 12mm alkali resistant glass fibers and calcium carbonate whiskers.



(a) Compressive strength



(b) Flexure strength



(c) Splitting tensile strength

Fig.3 Compressive strength, flexure strength and splitting tensile strength of reinforced concrete with different amounts of fiber

2 Mechanical properties of fine concrete sheet enhanced by multiple fibers

2.1. Flexural properties tests of fine concrete sheets

In order to find out the flexure properties of fine concrete sheets enhanced by multiple fibers, two layers of basalt fiber textile were laid in the matrix of short fibers reinforced fine concrete with different amounts shown in Tab.1. The sheet specimens with dimensions of 400mm

×100mm×20mm were prepared and four-point flexural tests were carried out. The mesh size of textile is 10mm ×10mm, as shown in fig 4. The mechanical properties of textile are shown in Tab. 2. The flexuretest device of sheet specimens is shown in Fig. 5. The load P is measured by load sensor and the deflection is measured by LVDT during testing.

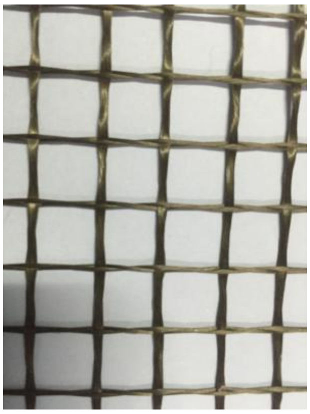


Fig. 4 10mm×10mm basalt fabric mesh

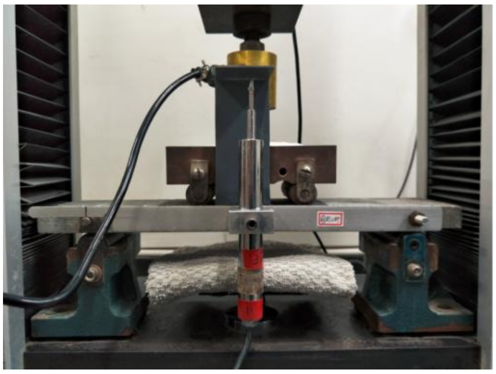


Fig. 5 Four-point flexural test device

Table. 2 Mechanical properties of basalt fiber fabric mesh

Specification	10mm×10mm fiber mesh
Tex（g/km）	132
Density（g/cm^3）	2.65
Numbers of fiber monofilament in single fiber bundle	400

2.2 Analysis of test results of texitile reinforced concrete sheets

2.2.1 Flexure failure modes of sheets

The comparison of flexure failure modes between the specimens of fine concrete reinforced with and without multi-fibers is shown in Fig.6.

It can be seen from the figure that concrete sheets without textile and short fiber immediately fractures when the load reaches the limit. The fracture surface appears in the mid-span position of the sheet, and the damage shows obvious brittleness, as shown in Fig. 6 (a). When two layers of fiber textile are laid in the sheets, the load-carrying capacity and ductility of the reinforced concrete sheets are improved because of the effects of directional carrying reinforcement and toughening of the textile. In the ultimate load, although the damage cracks appear in the span of sheets, the sheet specimens don’t fracture, and the width of cracks is minor than that of concrete sheets reinforced without textile, as shown in Fig. 6 (b). When the fine concrete sheets are reinforced with the combination of textile and short fibers, the load-carrying capacity and ductility of the concrete sheet are improved due to the effects of the directional carrying and toughening of the textile. The reinforced sheets present the state of multiple cracks under flexure failure mode, as shown in Fig.6 (c). It indicates that the use of multi-fiber composites of different scales can play a key role in enhancing the performance of fine concrete materials.

(a) PC-0 (b) PC-2 (c) CW10GF12-2

Fig. 6 Flexure failure modes of concrete sheets

2.2.2 Ultimate load and deformation capacity

2.2.2.1 Ultimate load

Tab. 3 shows the ultimate load (i.e. cracking load) and deformation test results of the concrete sheets reinforced with textile and different amounts of fibers. From the table, the ultimate loads of the concrete sheets increased with different fiber reinforcement. The peak loads and crack displacements of the concrete sheets have been increased slightly when only the fiber textile was laid, and only 15% higher than that of concrete sheets without reinforcing by fibers. This can be explained that the limited effects of the fiber mesh on the crack resistance of fine concrete matrix. The ultimate loads and cracking displacements of the sheets were significantly increased after composite reinforcing by the textile and the short fibers, and the increase trend was related to the length of the short fibers and the contents of calcium carbonate whiskers. The enhancement effects increase with the increase of the fiber length. The optimal enhancement effect for the contents of calcium carbonate whiskers is the range of 5% to 10%. When 12mm alkali resistant glass fibers with 5% mass content and calcium carbonate whiskers with 10% mass content were added into the concrete matrix, the peak load and cracking displacement of the concrete sheet were increased by 58% and 75% respectively.

2.2.2.2 Displacement ductility

Since there is no obvious yield point in the high-performance fiber textile, the nominal yield point of the textile reinforced concrete sheets can be defined by the cracking point of the sheets [12].The displacement ductility coefficient of the corresponding textile reinforced concrete sheets can be calculated by the following formula:

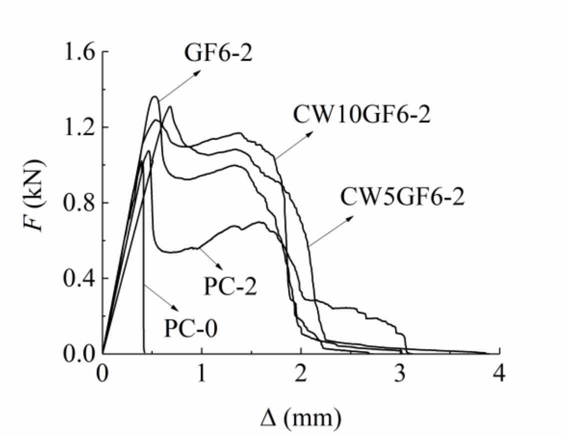
$$\mu_{\Delta} = \frac{\Delta_u}{\Delta_{cr}} \tag{1}$$

where, Δ_{cr} is the corresponding displacement when the sheet cracks. Δ_u is the ultimate displacement of the sheet, corresponding to the displacement when peak load is reduced to 80%.

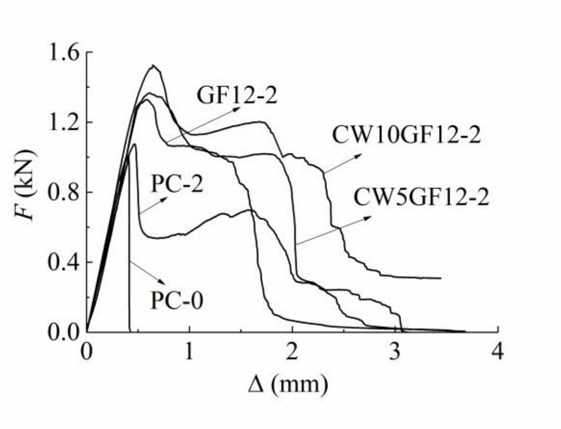
Tab.3 shows the calculation results of displacement ductility of the fine concrete reinforced by different amounts of fibers. It is shown in table that the displacement ductility coefficients of the sheets increase obviously with the increase of the contents of short fiber. This indicates that the mixing of short fibers can improve the ductility of the textile reinforced concrete. The effects of multiple fibers reinforcement are better than single fiber reinforcement. When 12mm alkali-resistant glass fiber with 5% mass content and calcium carbonate whisker with 5% mass content were mixed into the concrete matrix, the displacement ductility coefficient of the concrete sheet was 3.75 with the maximum improvement.

2.2.3 Load - displacement curves

Fig. 7 shows the load-deformation curves of the textile reinforced concrete sheets made of different concrete matrix. It can be seen from the figures that the concrete sheet without reinforcing by textile is damaged fragility subjected to the ultimate load, the corresponding curve drops straight after cracking and the brittleness is obvious. After reinforcing with short fibers, the mechanical properties of concrete sheet were improved, and the effects of mixing by multiple fibers were better than that of mixing by single type of fiber. For the fibers reinforced concrete sheet, the load-deformation curves can be divided into elastic section, strengthening section and descending section. The strengthening section of the sheets without reinforcing by the short fibers is not obvious. However, the peak loads of load-deformation curves of the sheets reinforced with alkali resistant glass fibers were increased, and the curves had obvious strengthening sections. Moreover, after the sheets reinforcing with the mixing of alkali resistant glass fibers and calcium carbonate whiskers, the ductility of the load-deformation curve of the sheets was increased, and the strengthening section was extended, and the load-carrying capacity was obviously improved. This suggests that the short and fine fibers play a bridging role in the concrete matrix, which is made the internal stress changes of the concrete matrix more continuous and even, and improve the flexure performance of the concrete sheets efficiency.



(a) Mixing with 6mm fibers



(b) Mixing with 12mm fibers

Fig. 7 Load-bending deformation curves of concrete sheets reinforced with different fibers and textile

Table.3 Peak load and deformation test results of sheet specimens

Specimens	**Peak loads (kN)**	**Cracking displacements (mm)**	**Displacement ductility** μ_{Δ}
PC-0	0.946	0.414	1.00
PC-2	1.074	0.471	1.05
GF6-2	1.332	0.564	1.37
GF12-2	1.473	0.667	2.23
CW5GF6-2	1.233	0.707	2.25
CW5GF12-2	1.402	0.531	3.75
CW10GF6-2	1.210	0.584	3.09
CW10GF12-2	1.493	0.724	2.72

3 Conclusions

The following conclusions can be obtained by analyzing the mechanical property test results of different fibers reinforced concrete matrix and flexure properties of multi-fibers reinforced concrete sheets:

(1) The compressive strength, flexure strength and splitting tensile strength of the fine concrete matrix reinforced with the multiscale fibers are improved. The micron calcium carbonate whiskers can improve the compressive performance of the concrete significantly, while the short alkali resistant glass fibers have obvious effects on the macro cracks control of the concrete.

(2) Fiber length has obvious influences on the mechanical properties of fine concrete matrix. The mechanical properties of concrete matrix are improved with the increase of fiber length. Compared with concrete without fibers, the compressive, flexure and splitting strengths of concrete matrix with 6mm alkali resistant glass fiber increased by 65%, 23% and 36% respectively, and the strengths of concrete matrix mixed with 12mm alkali resistant glass fiber increased by 67%, 28% and 46% respectively.

(3) The continuous fiber textile acts as a directional carrying reinforcement in the concrete sheets. The flexure capacity and deformability of the textile reinforced concrete sheets are improved obviously after adopting the fiber composite reinforced concrete matrix, and the enhancement efficiency of the sheets is also improved obviously.

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