Finite element analysis of flexural performance of different fiber reinforced recycled concrete beams

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Abstract. In this paper, the influence of different kinds of fiber on the mid-span bending moment and deflection of the regenerated concrete beam under the initial cracking and yielding state is studied by ANSYS finite element simulation analysis. The results show that different kinds of fibers have little influence on the mid-span bending moment of the regenerated aggregate concrete beam at the initial cracking, and have a great influence on the deflection value at the initial cracking, among which the reinforced effect is obtained in the group mixed with steel fiber. The mid-span bending moment and deflection of the trabeculae at the yield of the trabeculae are reduced by the addition of different kinds of fibers.

1. Introduction
With the rapid economic development in recent years, a large number of old buildings have been demolished and reconstructed, resulting in a large amount of construction waste, resulting in waste of resources and environmental pollution. In order to recycle resources, people use waste concrete from construction waste to process them into recycled aggregates to prepare recycled concrete. However, due to defects such as cracks in the recycled aggregate and cement blocks on the surface of the aggregate, the formulated recycled concrete has low strength and is prone to cracks, so its application is limited. In order to improve the performance of recycled concrete, people add fibers to concrete to improve the tensile strength and crack resistance of concrete. The actual test data shows that the fiber can make up for the shortcomings of concrete in terms of tensile strength and crack resistance due to its own performance advantages. However, due to the differences in the properties of different types of fibers, they have varying degrees of impact on the mechanical properties of concrete [1]. In order to study the influence of different performance fibers on the mechanical properties of concrete members, this paper changes the types of fibers such as basalt fiber, carbon fiber, steel fiber, polypropylene fiber, and basalt-polypropylene hybrid fiber. ANSYS finite element simulation analyzes the initial cracking and yield state of recycled concrete beams. The lower mid-span bending moment and mid-span deflection provide a theoretical reference for the flexural theory research of fiber recycled concrete beams.
2. Design

The experiment designed and produced 5 groups of beams with a length of 1500mm, a clear span of 1200mm, and a cross-sectional dimension of 120mm×180mm (see Figure 1 for details). The longitudinal tensile steel bar in the beam is 2 C18, the steel grade is HRB400, and the reinforcement ratio is 4.7%; the erecting reinforcement is 2 C12, and the stirrup is B8@120 HRB335 steel, and the elastic modulus of the steel is 200GPa. In this paper, recycled concrete beams without fiber are used as the reference group. For the reference group, 5 levels of fiber types are changed as shown in Table 1. A total of 5 groups of recycled concrete beams are designed, and the initial cracking and yield state of the beams are simulated by ANSYS finite element. The load and mid-span deflection of different types of fibers are compared and analyzed on the initial cracking and bending moment and deflection of recycled aggregate concrete beams.

![Fig.1 The structure diagram of the specimen(Unit: mm)](image)

### Table.1 Details of Specimens

| Specimen number | Fiber variable          | Fiber volume content (%) | Tension bar | Erection bar | Stirrup | Cube compressive strength (MPa) | Uniaxial tensile strength (MPa) | Elastic Modulus (GPa) |
|-----------------|-------------------------|--------------------------|-------------|--------------|---------|---------------------------------|-------------------------------|-----------------------|
| RC1             | Basalt fiber            | 0.1                      | 2C18        | 2C12         | B8      | 40.1                            | 3.50                          | 29.01                 |
| RC2             | carbon fiber            |                          | 2C18        | 2C12         | B8      | 39.7                            | 3.76                          | 29.59                 |
| RC3             | Steel fiber             |                          | 2C18        | 2C12         | B8      | 41.6                            | 3.60                          | 31.91                 |
| RC4             | Polypropylene fibers    |                          | 2C18        | 2C12         | B8      | 43.0                            | 3.80                          | 31.69                 |
| RC5             | Basalt-polypropylene    |                          | 2C18        | 2C12         | B8      | 41.8                            | 3.31                          | 29.02                 |

3. Finite element simulation

3.1 Selection of unit type

Reinforced concrete beams are more complicated in the arrangement of steel bars, so a separate model is used to treat concrete and steel bars as different units. Since the compressive capacity of recycled high-strength concrete is much greater than the tensile capacity, SOLID65 element is used, and this element can comprehensively consider the material nonlinearity caused by plasticity and creep, several nonlinearities caused by large displacements, and concrete cracking (three positive Cross direction) and nonlinearity caused by crushing. The longitudinal bars and stirrups are all LINK8 bar units. In order to reduce the stress concentration phenomenon, this paper uses surface constraints (150mm×100mm) to simulate the rigid backing plate at the beam support part, and uses uniform load (150mm×100mm) at the three-point loading position. The finite element meshing of the test piece is shown in Figure 2, and the steel bar element is shown in Figure 3.
3.2. Material constitutive model

3.2.1. The constitutive relationship of recycled concrete

As there are few domestic experimental studies on the constitutive relationship of high-strength recycled concrete, this paper selects the stress-strain curve equation proposed by Professor Guo Zhenhai.

\[
y = \begin{cases} 
  ax + (3 - 2a)x^2 + (a - 2)x^3 & 0 \leq x \leq 1 \\
  \frac{x}{b(x-1)^2 + x} & x \geq 1
\end{cases}
\]

Where, \( x = \varepsilon / \varepsilon_0, y = \sigma / f_c \). Professor Xiao Jianzhuang fits according to equation (1) to get:

\[a = 2.2 \times (0.748r^2 - 1.231r + 0.975)\]
\[b = 0.8 \times (7.6483r + 1.142)\]

The Poisson's ratio of concrete is 0.21, and the Poisson's ratio of recycled concrete is calculated according to formula (2).

\[v = 0.21 - 0.0003\delta \ (\delta \geq 30\%)\]

Where, \( \delta \) is the replacement rate of recycled aggregate.

3.2.2. Constitutive relationship of steel bars

The reinforcement in the beam in the finite element simulation analysis adopts the bilinear BKin follow-up strengthening model, and the corresponding parameters are determined in accordance with GB 50010-2010 "Specification for Design of Concrete Structures", and the constitutive relationship (3)

\[
\sigma_s = \begin{cases} 
  E_s \varepsilon_s & \varepsilon_s \leq \varepsilon_y \\
  f_y & \varepsilon_s \geq \varepsilon_y
\end{cases}
\]

where, \( E_s \) is the elastic modulus of the steel bar, \( \varepsilon_y \) is the yield strain of the steel bar, and \( f_y \) is the yield stress of the steel bar.

The Poisson's ratio of the steel bars in the beam is 0.3.

3.3. Material constitutive model

3.3.1. Concrete crush setting

Because the engineering structure does not allow large plastic deformation, and the yield point of concrete and other materials is not clear enough, but the failure point is very clear, so the concrete has a linear stress and strain relationship before cracking and crushing, and William is used after cracking and crushing - Warnke breaks the guidelines. In the parameter design, the shear transfer coefficient of open cracks is 0.5, the shear transfer coefficient of closed cracks is 0.95, and the uniaxial tensile strength is the corresponding tensile strength \( f_t \) of each strength design value and the uniaxial compressive strength is shown in Table 1. The intensity value within, and the other parameters all take default values.
3.3.2. Non-linear option settings
Complete Newton-Raphson equilibrium iteration \(^{[2][3][4]}\) is used for nonlinear solution, automatic time step control and linear search are turned on, and all calculations are performed until the loading process is completed or the calculation fails to converge. Turn on the large deformation switch, the number of loading substeps is 60, and the result output frequency is Write every substep. Set the maximum number of cycles to 20 in the Nolinear option. The displacement convergence criterion is adopted to reduce the calculation time to accelerate the convergence, and the convergence accuracy is relaxed to 1.5%.

4. Finite element simulation results and analysis

4.1. Analysis of mid-span bending moment and deflection during initial cracking of component

4.1.1. Analysis of mid-span bending moment during initial cracking

Figure 4 and Figure 5 are the stress cloud diagrams and the mid-span bending moment diagrams of different types of fiber reinforced concrete beams during initial cracking. It can be seen from the figure that, compared with the RC1 group, with the change of the type of the added fiber, the mid-span bending moment of the initial cracking of the component changes to different degrees. Among them, the initial cracking moment of the RC4 group blended with polypropylene fiber was 1.204kN·m, and the maximum value was obtained, followed by the order of RC3, RC2, RC5, and RC1 group. This is because polypropylene fibers are more uniformly dispersed in the concrete, and the fiber bridges in the concrete to improve the tensile strength of the concrete, and then effectively improve the crack resistance of the concrete.

![Stress nephogram of concrete at initial cracking](image1.png)

Fig.4 Stress nephogram of concrete at initial cracking

![Mid-span bending moment at initial cracking of beam](image2.png)

Fig5 Mid-span bending moment at initial cracking of beam

4.1.2 Analysis of the deflection of the mid-span during initial cracking

Figure 6 and Figure 7 are the deflection cloud diagrams and mid-span deflection diagrams of different types of fiber recycled concrete beams at the initial cracking. It can be seen from the figure that, compared with the RC1 group, with the change of the type of added fiber, the mid-span deflection of the component during initial cracking increases or decreases to different degrees. Compared with natural aggregates, general recycled aggregates have their own micro-crack defects, water absorption, and
Porosity larger than natural aggregates, resulting in reduced beam resistance to deformation and increased deflection. After the recycled aggregate concrete is mixed with fibers, the fibers are more evenly dispersed in the concrete, which can prevent the generation and development of a part of the micro-cracks in the concrete, and can make the internal structure of the concrete more compact, so that the ability of concrete beams to resist deformation is improved. It can be seen from Figure 7 that the initial cracking deflection value of the RC5 group mixed with basalt-polypropylene fiber is 0.101 mm, followed by RC1, RC2, RC4, and RC3. This shows that when steel fiber and polypropylene fiber are mixed, the easy dispersion of the fiber can effectively improve the cohesive force between concrete, thereby reducing the deflection of concrete. However, when the other three types of fiber are mixed into recycled concrete, the concrete mixing process, the fibers tend to form agglomerates, which reduces the bonding force and strength of the concrete, thus increasing the deflection of the beam.

4.2 Analysis of bending moment and deflection of mid-span when the member yields

4.2.1 Analysis of mid-span bending moment at yield

Figure 8 and Figure 9 are the stress cloud diagrams and mid-span bending moment diagrams of different types of fiber recycled concrete beams in the yield state. Compared with the RC1 group, the mid-span bending moment decreases with the change of the fiber type. Among them, the mid-span bending moment at yield of the RC4 group mixed with polypropylene fiber is 15.965 kN·m, followed by RC4, RC1, RC2, and RC3. This is because the surface roughness of the recycled aggregate is relatively large. The adhesion between fresh mortar and natural aggregate is strengthened, thereby increasing the strength of RC. With the change of fiber type, the air content of concrete is increased, thereby reducing the strength of concrete. This shows that the incorporation of fibers has a greater impact on the strength of concrete, and the degree of weakening is more serious, resulting in a greater reduction in the mid-span bending moment of the beam when it yields.
4.2.2 Analysis of mid-span deflection at yield

Figure 10 and Figure 11 are the deflection cloud diagrams and mid-span deflection diagrams of different types of fiber recycled concrete beams in the yield state. Among them, the mid-span deflection of the RC1 group mixed with basalt fiber is 3.029mm at yield, followed by the order of RC5, RC4, RC2, and RC3, which indicates that the mixed fiber can enhance the concrete resistance to deformation and slow down the regeneration. Due to the influence of more cracks and voids in the aggregate, the deflection value in the middle of the span when the beam yields is obviously reduced. Among them, the most obvious reinforcement effect is the RAC-4 beams mixed with steel fibers. Because of the properties of steel fibers themselves, they can not only resist the development of cracks, but also bear part of the stress, so they are better than other low-strength fibers.
5. Conclusion and Outlook
In this paper, through ANSYS finite element simulation analysis, the influence of the same volume mixing rate of different types of fibers on the mid-span bending moment and deflection of the recycled aggregate concrete beam during the initial cracking and the mid-span bending moment and deflection at the yield state are studied. Research indicates:

(1) Different types of fibers have different degrees of small changes in the mid-span bending moment of recycled aggregate concrete beams when they are initially cracked, but the change is not large; they have different degrees of influence on the deflection value of recycled aggregate concrete beams when they are initially cracked. The steel fiber reinforced group has the largest deflection reduction rate, which is 3.09%.

(2) The incorporation of different types of fibers reduces the mid-span bending moment of the recycled aggregate concrete beam in the yield state; both reduce the deflection value of the recycled aggregate concrete beam in the yield state, and the steel fiber group performs better in terms of enhancement effect.

In short, adding a certain amount of polypropylene fiber to the recycled aggregate concrete has the least effect on the initial cracking and mid-span bending moment of the beam at the yield state, while adding a certain amount of steel fiber can reduce the initial cracking and yielding of the beam. The mid-span deflection in the state is most favorable.

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