Feasibility Analysis of Replacing Partial Longitudinal Steel Bars with Layered Steel Fibers

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Abstract. In order to study the feasibility of replacing part of longitudinal reinforcement with layered steel fibers, four-point bending tests were carried out on a group of ordinary recycled concrete beam and three groups of layered steel fibers recycled concrete beams. The cracking moment and ultimate moment, ductility and energy dissipation, deformation and deflection of the experimental groups with lower contents of steel fibers and higher reinforcement ratio and the experimental groups with lower reinforcement ratio and higher contents of steel fibers were compared and analyzed. The results show that it is feasible to replace some longitudinal bars with layered steel fibers when considering cracking moment, ultimate moment, elastic stage and working stage with cracks of load-deflection curve, while it is not feasible when considering ductility, energy dissipation and post-yield stage of load-deflection curve.

1. Introduction
Layered steel fiber reinforced concrete structure is a new type of concrete structure, which can save the amount of steel fiber(SF) and reduce the project cost [1-2], because of the special structure form of SF distribution, the mixing of SF can be avoided, and the construction difficulty can be reduced [3-4]. Zhu Mengliang et al.[5] studied the influence of SF distribution position and dosage on the compressive strength, flexural strength and flexural toughness of concrete, and the results showed that the effect of upper SF on the strength of concrete was not obvious, and the lower SF could significantly improve the flexural strength of concrete; the flexural strength and flexural toughness gradually increased with the increase of SF content; the spreading SF significantly improved the failure mode of concrete, the concrete block is cracked but not broken in the compression test, and in the bending test, the concrete block is cracked but not apart. Jiang Pin[6] analyzed the feasibility of the spread type SF concrete from the economic aspect, and the results showed that the SF dosage was reduced by 43% and the cement consumption was reduced by 7% compared with the integral SF concrete.Recycled concrete is a kind of environment-friendly green concrete material. It breaks, sieves and cleans the waste concrete into recycled aggregate, which is used to replace part of natural aggregate, so that construction waste can be reused and solid waste can be recycled. Therefore, it has significant social and economic benefits and environmental protection benefits. In July 2019, the Ministry of science and technology of the people's Republic of China issued the notice of the Ministry of science and technology on Issuing the guidelines for the application of key special projects such as "solid waste recycling" in the national key R & D plan[7] on the website of the Ministry of Science
and technology, aiming to strengthen the disposal of solid waste and garbage, and promote the comprehensive conservation and recycling of resources.

In this study, the layered steel fiber reinforced concrete is combined with recycled concrete, that is, layered steel fiber recycled aggregate concrete (LSFRAC). From the aspects of cracking moment and ultimate moment, ductility and energy dissipation, deformation and deflection, the feasibility of replacing part of longitudinal reinforcement with SF in LSFRAC beam is analyzed, which provides a reference for the research of layered structural members.

2. Test overview

2.1. Experimental scheme design

Table 1 is the scheme design of this study. It can be seen from the table that the longitudinal reinforcement diameter of S0-R16 group and S2.0-R16 group are the same, and the steel fiber distribution is different, while the S1.5-R14 group and S1.5-R18 group are just the opposite. By comparing the test group with low steel fiber distribution and high reinforcement ratio and the test group with higher steel fiber distribution and lower reinforcement ratio, that is, comparing S0-R16 group with S1.5-R14 group, S1.5-R18 group and S2.0-R16 group, the feasibility of replacing part of longitudinal reinforcement with distributed SF is analyzed.

| Specimen number | SF spreading rate (kg/m²) | Diameter of longitudinal reinforcement (mm) | Reinforcement ratio(%) |
|-----------------|---------------------------|---------------------------------------------|------------------------|
| S0-R16          | 0                         | 16                                          | 2.31                   |
| S2.0-R16        | 2.0                       | 16                                          | 2.31                   |
| S1.5-R14        | 1.5                       | 14                                          | 1.77                   |
| S1.5-R18        | 1.5                       | 18                                          | 2.93                   |

Note: S2.0-R16 represents the simply supported beam specimen with SF spreading amount of 2.0 kg/m², longitudinal reinforcement diameter of 16 mm and reinforcement ratio of 2.31%, and the number of other specimens is similar.

2.2. Specimen design and test method

Figure 1 shows the section size and reinforcement structure of each test group. It can be seen that the size of the beam is 120 mm × 180 mm × 1500 mm, the clear span is 1200 mm, the shear span is 400 mm, and the pure bending section in the middle of the span is 400 mm. HRB400 reinforcement, HRB335 reinforcement (diameter of 10 mm) and hpb300 reinforcement (diameter of 8 mm, spacing of 100 mm) are used for longitudinal reinforcement, erection reinforcement and stirrup. According to the results of the previous mechanical property test, when the number of SF spreading layers is 4 or 7, the elastic strength ratio is small, and the concrete crack resistance is good[8]. Considering that the construction is difficult to spread 7 layers of SF, the number of SF spreading layers is determined to be 4, and the SF spreading position is shown in Figure 2. According to the standard for test methods of concrete structures (GB/T 50152-2012)[9], after 28 days of curing under standard conditions, the four point bending loading test was carried out by using YAS-5000 microcomputer controlled electro-hydraulic servo pressure testing machine.

Figure 1. The structural diagram of LSFRAC beams

Figure 2. SF position
3. Feasibility analysis

In order to quantitatively study the feasibility of replacing part of longitudinal reinforcement with spreading SF, referring to reference [10], the amount of longitudinal reinforcement is converted into equivalent spreading amount (4 layers) according to mass, and the conversion formula is as follows:

\[
S_R = \frac{m_R}{nbl}
\]

Where: \(S_R\) — Equivalent spreading amount of longitudinal reinforcement; \(m_R\) — Total mass of longitudinal reinforcement; \(n\) — Number of layers; \(b\) — Width of beam; \(l\) — Span of beam.

After conversion by formula (1), the equivalent spreading amount of longitudinal reinforcement with reinforcement ratio of 1.77%, 2.31% and 2.93% is 4.9 kg/m², 6.4 kg/m² and 8.1 kg/m² respectively.

3.1. Cracking moment and ultimate bending moment

Figure 3 and 4 show the cracking moment and ultimate bending moment of each test group. The reinforcement ratio of S0-R16 group is 0.54% higher than that of S1.5-R14 group (equivalent spreading amount is increased by 1.5 kg/m²), SF spreading amount is reduced by 1.5 kg/m², and the cracking moment of the latter is 33.3% higher than that of the former, and the ultimate bending moment of both groups is equal. It can be seen that 1.5 kg/m² SF can replace the longitudinal reinforcement with 1.5 kg/m². By comparing and analyzing S2.0-R16 group and S1.5-R18 group, it can be seen that the SF spreading amount of the former group is increased by 0.5 kg/m², and the reinforcement ratio is reduced by 0.62% (equivalent spreading amount is reduced by 1.7 kg/m²), but the cracking moment of the latter is the same, but the ultimate bending moment of the latter is increased by 11.5%, and the SF with 0.5 kg/m² is not enough to replace the longitudinal reinforcement of 1.7 kg/m². It can be seen that from the perspective of cracking moment and ultimate bending moment, when the SF spreading amount is the same as the longitudinal reinforcement equivalent spreading amount, it is feasible to replace part of the longitudinal reinforcement with the SF spreading amount; however, when the SF spreading amount is less than the longitudinal reinforcement equivalent spreading amount, the replacement is not feasible.

3.2. Ductility and energy consumption

Figure 5 and 6 show the displacement ductility coefficient and energy dissipation of each experimental group of beams. It can be seen that the ductility and energy dissipation capacity of S0-R16 group are higher than those of S1.5-R14 group, in which the displacement ductility coefficient increases by 22.5% and the energy consumption increases by 27.2%; the ductility and energy dissipation capacity of S1.5-R18 group with the same higher reinforcement ratio and lower steel fiber distribution are higher than those of S2.0-R16 group with low reinforcement ratio and high steel fiber distribution, and the
displacement ductility coefficient increases by 41.4% and energy consumption increases by 46.6%. Therefore, in terms of ductility and energy consumption, 0.5 kg/m² spread SF is not enough to replace 1.7 kg/m² longitudinal reinforcement, and 1.5 kg/m² distributed SF is not enough to replace 1.5 kg/m² longitudinal reinforcement.

It can also be seen from figures 5-6 that when the SF spreading amount increases from 0 to 2.0 kg/m², the displacement ductility coefficient decreases by 21.5%, and the energy dissipation capacity decreases by 0.7%; when the reinforcement ratio increases from 1.77% to 2.93%, that is, the equivalent longitudinal reinforcement spreading amount increases from 4.9 kg/m² to 8.1 kg/m², the displacement ductility coefficient increases by 36.0% and the energy dissipation capacity increases by 85.1%. It can be seen that the reinforcement ratio has a more significant effect on ductility and energy dissipation than SF, so it is not feasible to replace part of longitudinal reinforcement with distributed SF when considering ductility and energy consumption.

### 3.3. Deformation and deflection

Figure 7 compares the load deflection curves of S0-R16 group (lower steel fiber distribution & higher reinforcement ratio) and S1.5-R14 group (higher steel fiber distribution and lower reinforcement ratio). It can be seen that the deflection of S1.5-R14 group beam is smaller than that of S0-R16 group under the same load level in the elastic stage and the working stage with cracks, which means that the stiffness of S1.5-R14 group beam is larger at this stage. According to the code for design of concrete structures (GB 50010-2010)[11], the deflection limit of flexural members with higher requirements on deflection is \( \frac{l_0}{250} \) (when \( l_0 < 7 \text{ m} \), \( l_0 \) is the calculation span). In this study, the deflection limit is 4.8 mm. When the deflection of S1.5-R14 beam is 4.8 mm, the corresponding load value is 2.6 kN higher than that of S0-R16 group, increasing by 3.6%. The reinforcement ratio of S0-R16 group is 0.54% higher than that of S1.5-R14 group, but the yield load of both groups is the same, 80 kN. Therefore, it can be considered that the 1.5 kg/m² spread SF can replace the longitudinal reinforcement with 1.5 kg/m² before yielding. After the specimens yield, the corresponding deflection of S0-R16 group is smaller than that of S1.5-R14 group under the same load. The deflection of S0-R16 group is larger than that of S1.5-R14 group, and the bearing capacity and deformation capacity are better. This is because after the reinforcement yield, the tensile force is mainly borne by the distributed SF. At this time, the crack width is wide, and some SF is pulled out and quit the work[12].

Figure 8 shows the comparison of load deflection curves between S2.0-R16 group and S1.5-R18 group. It can be seen from the figure that when the load is less than 110 kN (before yielding), the load deflection curves of the two groups of beams are approximately coincident, and the yield load is also the same. It can be considered that the 0.5 kg/m² distributed SF can replace the longitudinal reinforcement with the equivalent spreading amount of 1.7 kg/m². After the specimens yield, the deflection value of S1.5-R18 group beam under the same load level is smaller than that of S2.0-R16 group, and the deflection is larger when the beam is damaged, and the stress characteristics of the
beam are better. It can be seen that the distributed SF has a great influence on the early crack resistance and stiffness of the beam, while the longitudinal reinforcement has a greater impact on the bearing capacity and deformation capacity of the beam at the later stage.

![Figure 7. Load deflection curves for S0-R16 and S1.5-R14 groups](image1)

![Figure 8. Load deflection curves for S2.0-R16 and S1.5-R18 groups](image2)

4. Conclusions

1. Considering the cracking load and ultimate load of the beam, when the steel fiber spreading amount is equal to the equivalent spreading amount of longitudinal reinforcement, it is feasible to replace part of the longitudinal reinforcement with the steel fiber spreading amount, while it is not feasible when the steel fiber spreading amount is less than the equivalent longitudinal reinforcement spreading amount.

2. Considering the ductility and energy consumption of beams, it is not feasible to replace part of longitudinal reinforcement with distributed steel fiber because the reinforcement ratio has a significant effect on the displacement ductility coefficient and energy dissipation capacity.

3. Considering the deformation and deflection of the beam, it is feasible to replace part of the longitudinal reinforcement with distributed steel fiber in the elastic stage and the working stage with cracks, but it is not feasible at the stage after the steel yield.

4. The distribution of steel fiber has a great influence on the crack resistance and stiffness of the beam at the early stage of loading, while the longitudinal reinforcement has a great influence on the bearing capacity and deformation capacity of the beam at the later stage of loading.

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