# Experimental study on the crack resistance of steel-nanometre hybrid fibre concrete

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**Abstract.** To investigate the effects of steel fibre and nanometre fibre on the cracking of reinforced concrete, the cracking resistance of steel fibre reinforced concrete, nanometre fibre reinforced concrete, and hybrid fibre reinforced concrete with different doping levels were studied in comparison with the baseline concrete specimens by steel-Nano hybrid fibre reinforced concrete axial tensile tests. The results show that when the steel fibre admixture is 1.5% and the nanometre fibre admixture is 0.05%, the initial cracking load of reinforced steel-Nano hybrid fibre axial tensile specimens is enhanced the most, at this time, compared with the initial cracking load of plain concrete specimens by 58.9%, at the same steel stress level, when the steel fibre admixture is 1.5% and the nanometre fibre admixture is 0.10%, it is most effective for crack control.
**Keywords:** Reinforced concrete; Nanometre fibre; Steel fibre; Axial tensile test.

## 1 Introduction

As we all know, the problem of concrete cracks is inevitable. Nowadays, even many components work with cracks, such as the current widely used steel-lined reinforced concrete pipes in hydropower station projects, to give full play to their mechanical properties, the pipes are generally working with joints in the state, but the existence and development of cracks will cause a very serious problem, namely, the internal reinforcement corrosion occurs. The corrosion of the reinforcement will inevitably affect the load-bearing capacity and durability of the concrete material, and even endanger the overall safety of the building structure, so it is urgent to solve the cracking problem of concrete.

Blending fibres in concrete can well compensate for the low tensile strength, brittleness, and poor toughness of concrete. It is proved [9-12] that there are certain limitations to improving the performance of concrete by incorporating only one type of fibre, and incorporating two or more fibres into concrete can produce synergistic effects to give full play to their advantages and improve the mechanical properties of concrete, so hybrid fibre

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concrete should be born. In this paper, from the perspective of crack control, steel-Nano hybrid fibre reinforced concrete specimens are designed and tested in axial tension to study the effects of steel fibre admixture and Nano fibre admixture on the initial crack load, crack morphology, crack spacing and crack width of the specimens.

# 2 Test methodologies

## 2.1 Test materials

The strength of the reinforced concrete pressure pipeline is generally C20-C30, and the strength of the concrete matrix used in this test is C25, the coarse aggregate is crushed stone with a grain size of 5 mm-20 mm, the fine aggregate is high-quality river sand, the water reducing agent is polycarboxylic acid master batch with a solid content of 40±1%, the water used is tap water. The water used is tap water. The specific parameters of the selected steel fibre and nanometre fibre are listed below.

**Table 1.** Physical properties of steel fibre.

| Fibre Name | Aspect ratio L/D | Types | Density ($g/m^3$) | Tensile strength (MPa) | Elongation (%) |
|---|---|---|---|---|---|
| Steel fibre | 80 | Shear corrugated type | 7.8 | ≥600 | - |

**Table 2.** Physical properties of nanometre fibre.

| Fibre Name | Length (μm) | Widths (nm) | Morphological ratio | Exterior appearance | Concentration (%) | Tensile strength (MPa) |
|---|---|---|---|---|---|---|
| Nanometre fibre | >1 | 20-50 | >30 | Transparent gel | 4.85 | 222-233 |

## 2.2 Experimental program

The cross-sectional dimensions of the steel-Nano hybrid fibre axial tensile specimen are 100 mm × 100 mm and the length is 700 mm, and the force transmission of the specimen is using direct pulling of the main reinforcement.

The volume rates of steel fibre determined for this test were 0.5%, 1.0%, and 1.5%, the nanometre fibre was dosed at 0.05%, 0.10%, 0.15%, and 0.20% of the cement mass, in addition to control groups designed with steel fibre alone, nanometre fibre alone and no fibres. Twenty specimens were designed and fabricated and the basic parameters of the specimens are shown in Table 3 below. Note on specimen numbering: S and N represent the volume rate of steel fibre and nanometre fibre doping, respectively.

## 2.3 Effect of mixed fibres on the initial cracking load

In this test group, the test machine load corresponding to the sudden stress change in the steel reinforcement was used as the initial cracking load of the specimen by real-time monitoring, and then the results of the initial cracking load of the specimen were divided into three groups of single-doped steel fibre and single-doped nanometre fibre and steel-Nano hybrid fibre after data processing, and the graphs were plotted for each of them.

**Table 3.** Basic parameters of the specimen, cross section (100 ×100 mm), diameter of reinforcing steel (14 mm), and reinforcement rate (1.58 %).

| Number | Steel fibre Volume rate (%) | Nanometre fibre Dosage (%) |
|---|---|---|
| S0N0 | 0 | 0 |
| S05N0 | 0.5 | 0 |
| S10N0 | 1 | 0 |
| S15N0 | 1.5 | 0 |
| S0N05 | 0 | 0.05 |
| S0N10 | 0 | 0.1 |
| S0N15 | 0 | 0.15 |
| S0N20 | 0 | 0.2 |
| S05N05 | 0.5 | 0.05 |
| S05N10 | 0.5 | 0.1 |
| S05N15 | 0.5 | 0.15 |
| S05N20 | 0.5 | 0.2 |
| S10N05 | 1 | 0.05 |
| S10N10 | 1 | 0.1 |
| S10N15 | 1 | 0.15 |
| S10N20 | 1 | 0.2 |
| S15N05 | 1.5 | 0.05 |
| S15N10 | 1.5 | 0.1 |
| S15N15 | 1.5 | 0.15 |
| S15N20 | 1.5 | 0.2 |

## 3 Analysis of experimental results

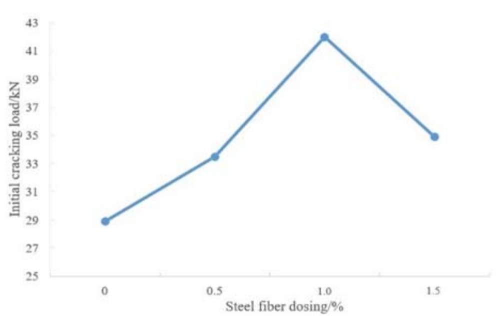



**Fig. 1.** Initial cracking load of single-doped steel fibre specimens

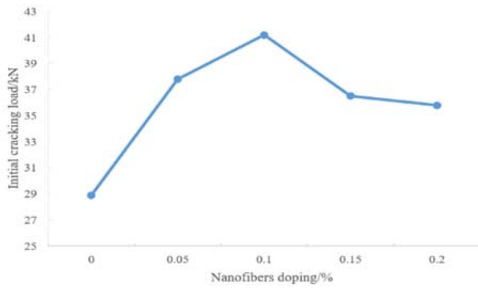



**Fig. 2.** Initial cracking load of single-doped nanometre fibre specimens

From the above two figures, it can be seen that when steel fibre or nanometre fibre are doped alone, the initial cracking load on the specimens is elevated to some extent.

The initial cracking load increased with the increase of steel fibre dosing for single-doped steel fibre axial tensile specimens at 0%-1%, the initial cracking load showed a decreasing trend when the dosing was increased from 1% to 1.5%. In this test, the initial cracking load reached the maximum at 1% of steel fibre doping, at which time the initial cracking load was increased by 45.3% compared to the plain concrete specimens. The initial cracking load increased with the increase of nanometre fibre admixture at 0%-0.10% for the single-doped nanometre fibre axial tensile specimens, the initial cracking load showed a decreasing trend when the admixture increased from 0.10% to 0.20%. In this test, the maximum initial cracking load was reached at 0.10% nanometre fibre dosing, and at this time, the initial cracking load was increased by 42.6% compared to the plain concrete specimens.

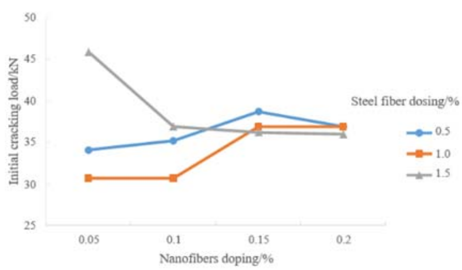



**Fig. 3.** Relationship between mixed fibre dosing and the initial cracking load of specimens.

As can be seen from the analysis in Figure 3 above, the initial cracking loads of the specimens and the blended fibre admixture do not show a significant regularity. Compared to the case of steel and nano-fibers alone in Figure 1 and Figure 2, the initial cracking load of the steel-Nano hybrid fibre specimens increased but not significantly with the increase of the blended doping of both fibres. The peak was reached at 1.5% of steel fibre and 0.05% of nanometre fibre, at which point the initial cracking load elevation reached 58.9% compared to the plain concrete specimens.

The uneven distribution of hybrid fibers in the concrete matrix leads to defects in the specimen, so the initial crack load may decrease with the increase of the content.Thus, the initial cracking load of the specimens did not show any obvious regularity between the specimens and the number of mixed fibres.

### 3.1 Effect of steel-Nano hybrid fibre on crack morphology

(a) Crack discontinuity. (b) Crack bifurcation. (c) Crack misdirection.

**Fig. 4.** Local crack pattern diagram

The above figure shows the local crack morphology of the axial tensile specimen, and after observation, it can be found that the crack morphology of the concrete has been significantly changed after the admixture of mixed fibres. The crack development in the specimens is chaotic due to the three-dimensional chaotic distribution of fibres in the concrete, which is blocked by the fibres during cracking. After further observation, it was found that the crack discontinuity, bifurcation, and chaotic direction were more evident in the specimens mixed with hybrid fibre compared to the specimens mixed with steel fibre alone.

To analyze the reason, the incorporated nanometre fibre generates many pin-rod crystal structures between the concrete hydride C-S-H gels, which realize the filling and bridging function of rigid particles. Thus, it can resist deformation and prevent the development of micro fine cracks, making the crack discontinuity, bifurcation, and disorderly direction of the specimen more obvious.

### 3.2 Effect of steel-Nano hybrid fibre on the average crack spacing

Figure 5 shows the average crack spacing of the axial tensile Specimens corresponding to the nanometre fibre dosing of 0%, 0.05%, 0.1%, 0.15%, and 0.2% of cement mass for several different dosing levels of steel fibre at 0%, 0.5%, 1%, and 1.5%, respectively.

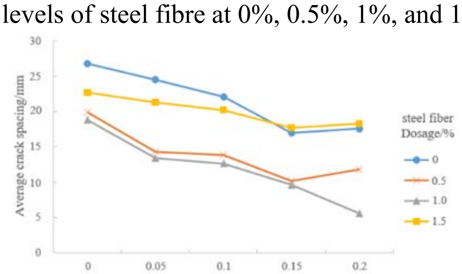



**Fig. 5.** Average crack spacing of axial tension specimens.

Observing Figure 5, it can be seen that the average crack spacing of the specimens got significantly reduced compared to plain concrete after mixing with mixed fibres. The average crack spacing decreases with the increase of admixture when the steel fibre admixture is 0%-0.15% at a certain amount of steel fibre, however, the average crack spacing appears to increase when the admixture is increased from 0.15% to 0.20%. The average crack spacing decreases with the increase of the dose when the nanometre fibre dose is 0%-1%, however, the average crack spacing increases when the dose increases from 1.0% to 1.5%.

According to the research results [15], the main factor affecting the average crack spacing of reinforced concrete is the ratio of the difference between the tensile strength of concrete and the residual tensile stress on the crack section to the average bond stress between the reinforcement and concrete. Therefore, the reasons for this are mainly the following two aspects: (i) the admixture of mixed fibres certainly improves the tensile strength of concrete, but the steel fibre can assume the role of tensile stress at the crack section, thus increasing the residual tensile stress on the crack section, so that the difference between the tensile strength of fibre concrete and the residual tensile stress on the crack fracture surface does not change significantly compared with plain concrete, (ii) the nanometre fibre incorporated in this test have a diameter of 20 nm- 50nm, which can play a good role in structurally filling the 20nm-150nm micro-pores in the cement paste, reducing the porosity of the material, making the cementations material more and more dense, which in turn improves the average bond between the reinforcement and the concrete, thus reducing the average crack spacing of the specimen. When the fibre dosing is too high, the agglomeration phenomenon is easy to occur, which makes the internal defects of the specimen make the average crack spacing of the specimen increase instead, that is, the negative mixing effect occurs, but the average crack spacing is still smaller than the average crack spacing of the plain concrete specimen without fibre dosing.

### 3.3 Effect of reinforcement stress on the average crack width

The load loading step was taken as 0.1 times of the load corresponding to the yield stress of the reinforcement, and the crack widths of the specimens under all levels of loading from the beginning to the end of loading were measured, and the average crack widths measured for all specimens were processed by the data and divided into three groups: single-doped steel fibre, single-doped nanometre fibre, and mixed steel-nanometre hybrid fibre, and plotted as the following graphs.

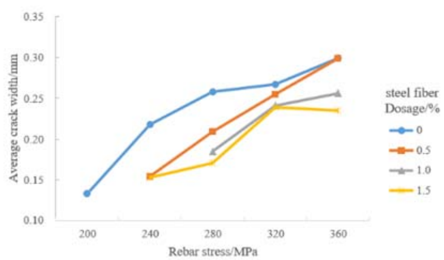



**Fig. 6.** Steel stresses and average crack width of single-doped steel fibre specimens.

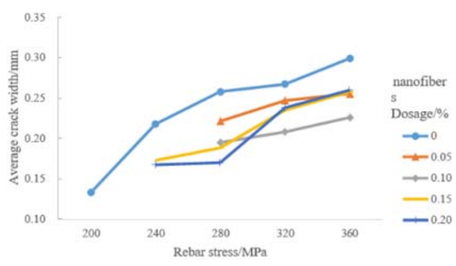



**Fig. 7.** Stress and average crack width of reinforcement in single-doped nanometre fibre specimens.

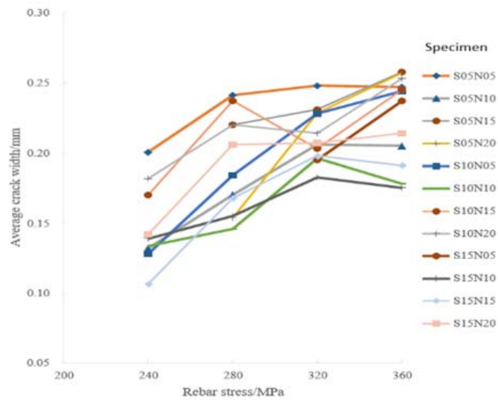
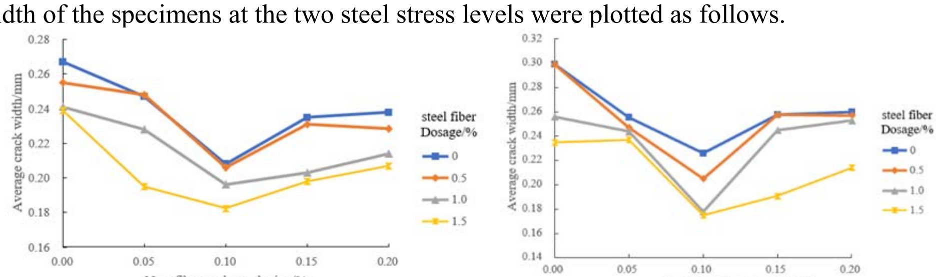



**Fig. 8.** Mixed fibre specimens reinforcement stress and average crack width,cross section (100 ×100 mm), diameter of reinforcing steel (14 mm), and reinforcement rate (1.58 %)

From the above graphs, it can be seen that the average crack width of the specimens in all three cases of single-doped steel fibre, single-doped nanometre fibre, and mixed steel-Nano hybrid fibre show a linear relationship with the steel stress. It is found in Figure 6 that the average crack width of the specimen is the smallest when the steel fibre admixture is 1.5% for the single-doped steel fibre specimen, i.e., the optimal crack limiting effect, so the optimal admixture of steel fibre is 1.5%, it is found in Figure 8 that the average crack width of the specimen is the smallest when the nanometre fibre admixture is 0.1% for the single-doped nanometre fibre specimen, i.e., the optimal crack limiting effect, so the optimal admixture of nanometre fibre is 0.1%.

To better explore the effect of different blended fibre doping on the crack limiting effect of the specimens, the average crack data at two steel stress levels of 320 MPa and 360 MPa were selected, and the relationship between the blended fibre doping and the average crack width of the specimens at the two steel stress levels were plotted as follows.




(a) Reinforcement stress of 320 MPa. (b) Reinforcement stress of 360 Mpa.

**Fig. 9.** Average crack width of specimens under the same reinforcement stress.

Analysis of the above graph shows that at the stress levels of 320 MPa and 360 MPa for reinforcement stress, the average crack width of the specimen decreases with the increase of nanometre fibre doping when the nanometre fibre doping is between 0% and 0.10%, when the nanometre fibre doping is greater than 0.10%, the average crack width of the specimen increases with the increase of nanometre fibre doping at this time. At fixed nanometre fibre dose, the average crack width of the specimen decreased when the steel fibre dose increased from 0% to 1.0% at the level of steel stress 320 MPa, and the average crack width of the specimen increased when the steel fibre dose increased to 1.5%, but it was still smaller than the average crack width of the specimen with single-doped steel fibre, at the level of steel stress 360 MPa, the average crack width of the specimen decreased with the increase of the steel fibre dose. The average crack width of the specimens decreased with the increase of steel fibre doping at the level of reinforcement stress 360 MPa. At the stress levels of 320 MPa and 360 MPa, the steel fibre and nanometre fibre showed good synergistic crack resistance.

The crack control of the specimens with steel-Nano hybrid fibre was also better than that of the specimens with steel fibre alone or with nanometre fibre alone at higher reinforcement stress levels (360 Mpa). Compared with the previous axial tensile tests[18] of steel-polypropylene hybrid fibre, which showed a negative mixing effect at higher steel stress levels, the steel-Nano hybrid fibre showed better crack control at higher steel stress levels, and the most significant crack control effect was achieved at 0.10% nanometre fibre and 1.5% steel fibre.

## 3 Conclusions

After preliminary test and later data analysis, the following conclusions are obtained:

The addition of steel-Nanometre hybrid fibre can significantly change the crack shape, increase the number of cracks, and effectively prevent the crack penetration.

The addition of steel-Nanometre hybrid fibre significantly increases the initial crack load of the specimen, and the maximum increase is 58.9% higher than that of plain concrete.

The average crack spacing of the specimen decreases obviously with the addition of steel-Nanometre hybrid fibre.

Before the yield of reinforcement, the average crack width of the specimen is basically positively correlated with the reinforcement stress. Under the high reinforcement stress level(360MPa), the crack control effect of the specimen mixed with steel-Nanometre hybrid fibre is also better than that of the specimen mixed with single fibre.

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