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# Study on Axial Compressive Properties of Reinforced Concrete Columns with Iron Tailing Sands at High Temperatures

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## Abstract

**Open fire tests were conducted on reinforced concrete columns made of iron tailing sand with different sand dosage to analyze the fire resistance performance of reinforced concrete columns made of iron tailing sand with different sand dosage through the changes of cross-section temperature field and vertical displacement. At the same time, C30 iron tailing sand and natural sand reinforced concrete columns of the same strength were compared to compare the fire resistance of iron tailing sand and natural sand reinforced concrete columns, and to study the effect of different sand mixing rates on the axial compression performance of iron tailing sand reinforced concrete columns. Different sand mixing rates (50%, 100%) were selected as variables to study the axial compression performance of iron tailing sand concrete columns at high temperatures, and based on the corresponding theoretical research results and experimental results, the optimization design method of the fire resistance of iron tailing sand building structures was proposed to provide a theoretical basis for the substitution of natural sand by iron tailing sand concrete.**

## Keywords

**Iron Tail Ore Sand Concrete; Axial Bearing Capacity; Numerical Simulation.**

## 1. Introduction

Reinforced concrete columns, as the vertical structural system of the structure, play an important role in ensuring the bearing capacity of the building structure and the overall stiffness of the structure. One of its main raw materials, natural sand, is currently facing a shortage of resources, and the use of iron tailings sand to replace natural sand can not only effectively solve the problem of shortage of sand and gravel resources, but also provide the tailings with areas that can be utilized to improve the comprehensive utilization rate. Due to the complex composition of iron tailing sand, its mechanical properties are unstable in high temperature environment, so the study of its high-temperature mechanical properties is an important prerequisite to ensure that iron tailing sand replaces natural sand as engineering materials.

The purpose of this paper is to investigate the axial compressive properties of reinforced concrete columns made of iron tailing sand at high temperatures through numerical simulation methods, to establish a model of reinforced concrete columns made of iron tailing sand by using Abaqus finite element software, and to verify its validity, and to further elaborate the effects of length-to-finish ratio and axial compression ratio on the axial compressive properties of reinforced concrete columns made of iron tailing sand under fire. Determine the factors affecting the axial compressive performance of reinforced concrete columns of iron tailing sand under fire, and provide a reference for the study of reinforced concrete columns of iron tailing sand under fire.

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# 2. Material Preparation

## 2.1 Concrete Materials

The gravel particle size is 5~10mm and 10~25mm two graded gravel, large and small stones are configured according to the ratio of 7:5. The main performance indexes of large and small stones are shown in Table 1 and Table 2.

**Table 1.** The performance index of big stone

| gravel | sieve/mm | sieve residue/g | Submeter sieve/% | Cumulative sieve aperture/% |
|---|---|---|---|---|
| big stone | 26.5 | 155 | 3.10 | 31.0 |
| | 19 | 2760 | 55.21 | 58.31 |
| | 16 | 1500 | 30.01 | 88.32 |
| | 9.5 | 559 | 11.18 | 99.50 |
| | 4.75 | 0 | 0.00 | 99.50 |
| | 2.36 | 0 | 0.00 | 99.50 |
| | Sieve bottom | 25 | 0.50 | 100 |
| | Total | 4999 | 100 | 100 |

**Table 2.** The performance index of small stone

| gravel | sieve/mm | sieve residue/g | Submeter sieve/% | Cumulative sieve aperture/% |
|---|---|---|---|---|
| small stone | 26.5 | 0 | 0.00 | 0.00 |
| | 19 | 0 | 0.00 | 0.00 |
| | 16 | 0 | 0.00 | 0.00 |
| | 9.5 | 135 | 2.70 | 2.70 |
| | 4.75 | 4600 | 91.98 | 94.68 |
| | 2.36 | 159 | 3.18 | 97.86 |
| | Sieve bottom | 107 | 2.14 | 100 |
| | Total | 5001 | 100 | 100 |

The main performance indexes of natural sand and tailing sand are shown in Table 3 and Table 4.

**Table 3.** The performance index of natural sand

| Sieve size/mm | | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | Sieve bottom /g | Total /g |
|---|---|---|---|---|---|---|---|---|---|
| First sieving | Subtotal sieve residue /g | 7 | 111 | 76 | 65 | 98 | 62 | 79 | 498 |
| | Subtotal sieve balance /% | 1.41 | 22.29 | 15.26 | 13.05 | 19.68 | 12.45 | 15.86 | |
| | Cumulative sieve residue /% | 1.41 | 23.70 | 38.96 | 52.01 | 71.69 | 84.14 | 100 | |
| Second sieving | Subtotal sieve residue /g | 6 | 92 | 77 | 65 | 101 | 68 | 90 | 499 |
| | Subtotal sieve balance /% | 1.20 | 18.44 | 15.43 | 13.03 | 20.24 | 13.63 | 18.04 | |
| | Cumulative sieve residue /% | 1.20 | 19.64 | 35.07 | 48.10 | 68.34 | 81.97 | 100 | |
| Average value | Cumulative sieve residue /%/% | 1.31 | 21.67 | 37.02 | 50.06 | 70.02 | 83.06 | 100 | |
| fineness modulus | | 2.59 Zone II grading | | | | | | | |

 

**Table 4.** The performance index of iron tailings sand

| Sieve size /mm | | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | Sieve bottom /g | Total /g |
|---|---|---|---|---|---|---|---|---|---|
| First sieving | Subtotal sieve residue /g | 8 | 30 | 31 | 83 | 139 | 112 | 95 | 498 |
| | Subtotal sieve balance /% | 1.61 | 6.02 | 6.22 | 16.67 | 27.91 | 22.49 | 19.08 | |
| | Cumulative sieve residue /% | 1.61 | 7.63 | 13.85 | 30.52 | 58.43 | 80.92 | 100 | |
| Second sieving | Subtotal sieve residue /g | 8 | 27 | 36 | 57 | 149 | 95 | 127 | 499 |
| | Subtotal sieve balance /% | 1.60 | 5.41 | 7.21 | 11.42 | 29.86 | 19.04 | 25.45 | |
| | Cumulative sieve residue /% | 1.60 | 7.01 | 14.22 | 25.64 | 55.50 | 74.54 | 99.99 | |
| Average value | Cumulative sieve residue /% | 1.61 | 7.32 | 14.04 | 28.08 | 56.97 | 77.73 | 100 | |
| fineness modulus | | 1.79 Zone III Gradation | | | | | | | |

## 2.2 Concrete Mixing Ratio

According to the "Regulations for the Design of Ordinary Concrete Mix Ratio" (JGJ55-2011) [2], the calculation of concrete mix ratio is carried out. On the basis of the calculated mix ratio, keep the water-cement ratio unchanged, and adjust the concrete sand rate to make the mix meet the requirements of the ease of use. The final concrete mix ratio is shown in Table 5.

**Table 5.** Mix ratio of concrete

| Strength grade | Content/(kg/m$^3$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | concrete | Iron tailing sand | clinker | coal ash | mineral powder | stone | water | additive |
| PC30 | 836 | - | 240 | 67 | 84 | 982 | 188 | 8 |
| TC30-50 | 371 | 371 | 240 | 67 | 84 | 982 | 188 | 8 |
| TC30-100 | - | 621 | 240 | 67 | 84 | 982 | 188 | 8 |

# 3. Research Methodology

## 3.1 Specimen Design

According to the current Code for the Design of Concrete Structures (GB50010-2010) (2015 version) [3], and with reference to the dimensions of the test furnace, four iron tailing sand concrete columns with a cross-section size of 300 × 300 × 3500 (mm) and one natural sand concrete column are fabricated. The hoop reinforcement of the test columns is HRB400 grade steel bars with a diameter of 8 mm and a spacing of 200 mm, with an encrypted zone spacing of 100 mm and an encrypted interval of 600 mm; the compressive longitudinal reinforcement is four HRB400 grade steel bars with a diameter of 20 mm. The thickness of the column protective layer is 30mm, and the sample design diagram of the test column is shown in Fig. 1.

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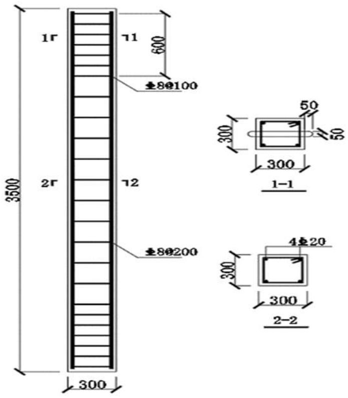


**Fig. 1** Cross-sectional dimensions and reinforcement of test columns

Considering concrete strength and iron tailing sand as variables, the specimen design parameters are shown in Table 6. Where "T" denotes iron tailing sand column and "P" denotes natural sand column.

**Table 6.** Test column design parameters

| Serial number | Strength grade | Admixture /% | Axial pressure ratio |
|---|---|---|---|
| P1 | C30 | 0 | 0.7 |
| T1 | C30 | 50% | |
| T2 | C30 | 100% | |

## 3.2 Specimen Design

Stress-strain relationship of concrete with iron tailing sand Stress-strain relationship of concrete with iron tailing sand.

The stress-strain relationship for iron tailing sand concrete was used as proposed by Hongzhen Kang [4]:

$$y=\begin{cases}\alpha_a x+(3-2\alpha_a)x^2+(\alpha_a-2)x^3 & x\le 1\\ \dfrac{x}{\alpha_d(x-1)^2+x} & x>1\end{cases}$$

Where: x=ε/εp,y=σ/σp,fcconcrete compressive strength,αa is the shape parameter of ascending section,αd is the shape parameter of descending section. In this test, the strength of iron tailing sand concrete is C30, and the above relation is used.

## 3.3 Modeling

The reinforcement skeleton is embedded in the concrete beam, the concrete is simulated by eight-node linear hexahedral unit, and the reinforcement is simulated by two-node linear 3D truss unit, and the numerical model is established by ABAQUS, as shown in Fig. 2.

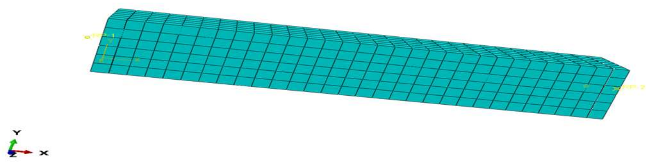

**Fig. 2** Numerical simulation model of concrete column with iron tailing sand

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## 4. Simulation Results

Through numerical simulation, the force performance curves of the columns at different sand mixing rates were obtained. The bearing capacity, deformation and damage mode of the columns were analyzed in comparison with ordinary concrete columns of the same grade. The results show that the reinforced concrete columns with iron tailing sand have good load bearing performance and the deformation gradually increases after the load bearing capacity reaches the peak value. A numerical simulation model was developed through ABAQUS to derive the simulated compressive load capacity.

According to the comparison between the simulated compressive load capacity of reinforced concrete columns of iron tailing sands and the simulated compressive load capacity of ordinary reinforced concrete columns, line graphs are plotted, as shown in Fig. 3, Fig. 4.

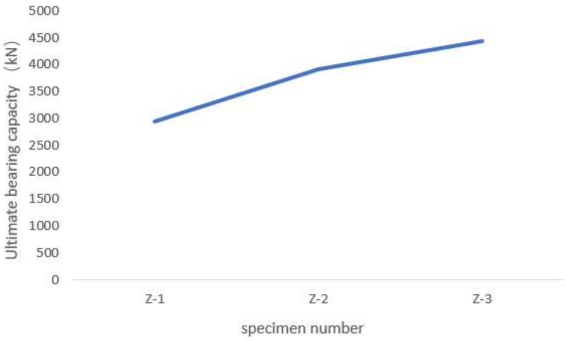


**Fig. 3** The compressive bearing capacity of ITSC

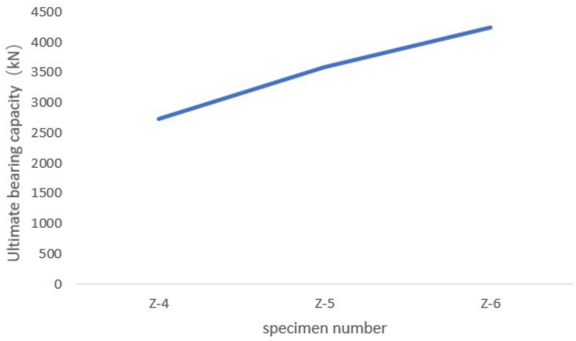


**Fig. 4** The compressive bearing capacity of PC

According to the folding line and data shown in the figure, the iron tailing sand concrete has a higher ultimate bearing capacity than ordinary concrete with the same strength grade. The curve trend is roughly the same, and the value difference is within a reasonable range, the laboratory test results are often higher than the finite element simulation results, the test value is greater than the simulation value is more because in the calculation of the compressive strength of the concrete used in the value is more conservative, and its real bearing capacity retains more, so it is greater than the simulation value, but still within a reasonable range. Provide a partial theoretical basis for advancing the application of iron tailing sand in engineering practice. This implies that in engineering structures that require higher performance, the use of high strength concrete with appropriate sand mixing ratio can be considered to improve the safety and reliability of the structure.

## 5. Conclusion

(1) The ultimate compressive load bearing capacity of concrete columns with iron tailing sand replacing natural sand is approximately the same compared with that of ordinary concrete columns, and based on the analysis of compressive load bearing capacity, it is appropriate to replace natural sand with iron tailing sand.

(2) There is not much difference in the performance trend of three kinds of high-strength concrete after high temperature, and the modulus of elasticity of ordinary concrete with iron tailing sand is obviously larger than that of natural sand concrete.

(3) Increasing the length and slenderness ratio will reduce the residual bearing capacity of the columns after high temperature, and the degree of influence gradually increases with the growth of the fire time.

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