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Study on Compressive Behavior of Iron Tailings Sand Concrete Columns After High-Temperature Exposure

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Abstract

To investigate the compressive behavior of iron tailings sand concrete columns after high-temperature exposure, static loading tests were conducted on 5 concrete columns with different design strengths (C40, C50) and iron tailings sand replacement ratios (50%, 100%) after 60 minutes of fire exposure. The study analyzed the time-dependent temperature evolution within the specimens during heating, observed the failure modes under loading, and calculated the residual ratio of ultimate compressive strength. The experimental results showed that: Compared with natural sand concrete columns, the temperature distribution at the mid-height cross-section of iron tailings sand concrete columns exhibited minimal differences, with similar heating trends. A lower iron tailings sand replacement ratio and higher concrete strength grade resulted in a higher residual ratio of ultimate bearing capacity after high-temperature exposure. In contrast to natural sand concrete columns, the ultimate bearing capacity of iron tailings sand concrete columns decreased more significantly with prolonged fire exposure.

Keywords

Iron tailings sand concrete columns; Post-fire; Residual load-bearing capacity.

1. Introduction

Statistical data indicates that China's annual tailings production reaches approximately 1.272 billion tons, yet the comprehensive utilization rate remains below 20% [1]. Iron tailings constitute the largest proportion of these industrial byproducts, with their production volume showing a consistent annual increase[2]. The accumulation of iron tailings poses significant threats to both industrial safety and ecological environments.With China's sustained economic growth, the construction industry has experienced rapid expansion, leading to severe depletion of natural building resources - particularly the sharp decline in natural sand reserves. This critical shortage necessitates urgent identification of alternative materials[3-5]. The substitution of natural sand with iron tailings sand as fine aggregate presents an optimal solution, simultaneously addressing both the scarcity of natural sand and the recycling challenges of iron tailings.However, iron tailings sand exhibits considerable instability under elevated temperatures, suggesting potential safety risks in large-scale engineering applications of iron tailings sand concrete. During fire events, concrete structures suffer varying degrees of damage, with reinforced concrete (RC) columns being particularly vulnerable as they serve as primary vertical load-bearing elements[6-8]. Although fire-induced damage occurs, many post-fire RC columns remain serviceable after proper rehabilitation.Consequently, investigating the mechanical properties of iron tailings sand concrete columns after high-temperature exposure becomes critically important for structural safety assessments and post-fire repairs[9-10].

A comprehensive review of existing research reveals that while numerous studies have been conducted by domestic and international scholars on the mechanical properties of iron tailings sand concrete columns, the majority have focused on ambient and elevated temperature conditions. Research concerning post-fire performance remains relatively scarce and fragmented in the literature. Furthermore, the influencing factors governing the residual load-bearing capacity and stiffness of iron tailings sand concrete columns after high-temperature exposure have not been systematically elucidated. To address these research gaps, this study focuses on iron tailings sand concrete columns as the research object, with particular emphasis on investigating their axial compressive behavior after exposure to high temperatures.

2. Organization of the Text

2.1. Specimen Design and Fabrication

In accordance with the Code for Design of Concrete Structures (GB 50010-2010, 2015 edition) and considering the dimensions of the test furnace, a total of 5 concrete columns were fabricated, including 4 iron tailings sand concrete columns and 1 natural sand concrete columns for comparison. All specimens had a cross-sectional dimension of 300 × 300 × 1400 mm.

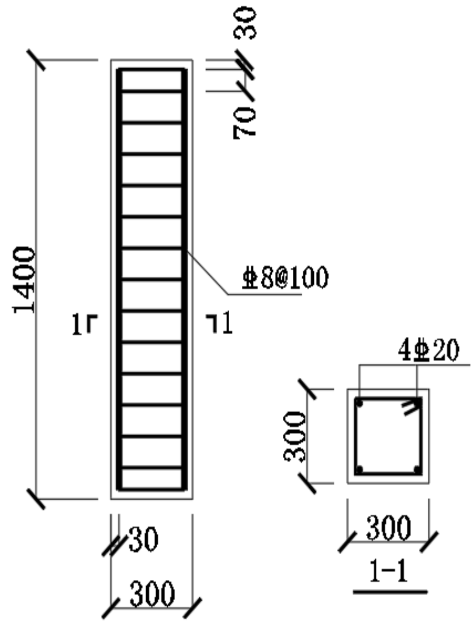

Fig. 1 Cross-sectional dimensions and reinforcement details of specimens

Table 1 Design parameters of specimens

Serial number	Strength grade	Displacement/%	Fire/min
PC40-0-60	C40	0	60
TWC40-50-60	C40	50	60
TWC40-100-60	C40	100	60
TWC50-50-60	C50	50	60
TWC50-100-60	C50	100	60

2.2. Instrumentation and Data Acquisition

2.2.1. Displacement Measurement

For the axial compression static loading test, only axial displacement was measured. Four linear variable differential transformers (LVDTs) were installed at each corner of the loading platform (southeast, northeast, southwest, and northwest) and connected to the data acquisition system. During testing, displacement data were recorded at a frequency of 10 Hz. To minimize

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measurement errors, the readings from all four LVDTs were averaged and used as the axial displacement. The arrangement of displacement transducers is illustrated in Fig. 2.

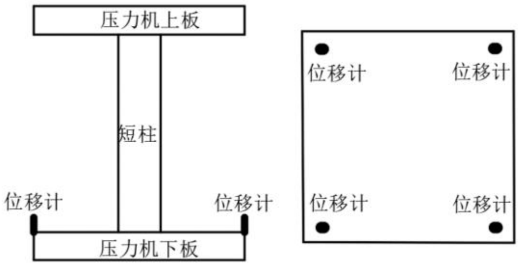


Fig. 2 Layout of displacement transducers

2.2.2. Temperature Field Measurement

Five measurement points were strategically positioned at the mid-height cross-section of each iron tailings sand concrete column. The thermocouple arrangement is illustrated in Fig. 3. The embedded thermocouples were installed using the following procedures: Internal concrete temperature measurement: Thermocouples were pre-arranged in a cruciform pattern on binding strips and securely fastened to the reinforcement cage prior to concrete pouring. Concrete surface temperature measurement: Surface-mounted thermocouples were temporarily fixed to the formwork using electrical tape, with final positioning adjustments made after formwork removal. Reinforcement temperature measurement: Thermocouples were directly attached to the longitudinal rebars to monitor steel temperature evolution. All thermocouples were connected to an Agilent 34980A data acquisition unit , configured to record temperature data at 10 Hz sampling frequency throughout the experiment.

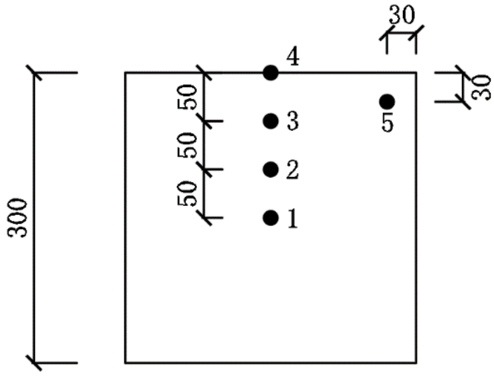


Fig. 3 Thermocouple arrangement and measurement points

3. Test Phenomena and Results

3.1. Heating and Cooling Test Observations

During the combustion process:

Early-stage vapor emission (0-13 min):

Intensive water vapor emission was observed at approximately 13 minutes of heating, persisting throughout the test duration.Incipient spalling became faintly visible during this phase.

Post-test damage assessment:

Significant spalling and surface delamination were identified, with notably more severe damage compared to specimens subjected to 30-minute fire exposure. All four column faces exhibited extensive craze cracking patterns after extraction, with measured crack widths ranging 0.1-0.4 mm.

Distinct water leaching traces and whitish discoloration (grayish-white hue) were observed on the concrete surfaces.

3.2. Temperature Field of Fire-Exposed Column Cross-Section

Analysis of Temperature Field in Iron Tailings Sand Concrete Columns(Fig. 4):

Thermal response characteristics:

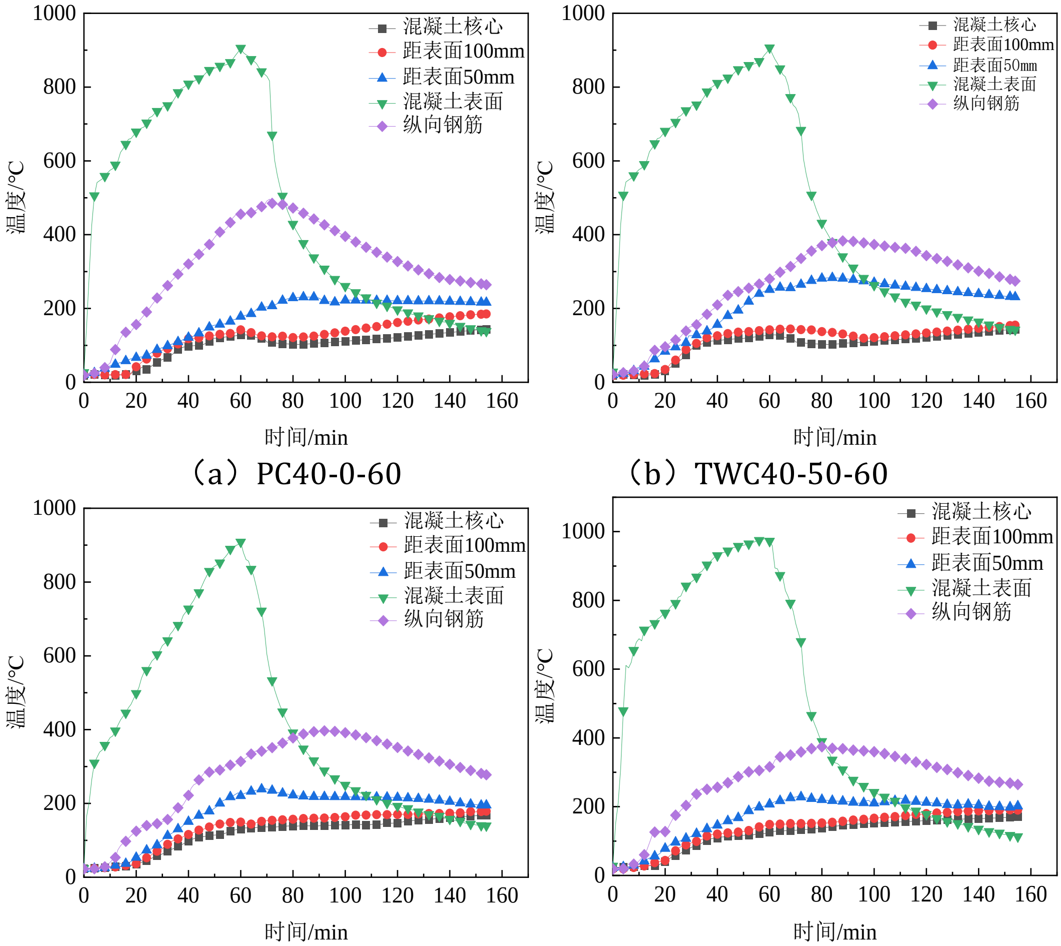
Comparison with the ISO-834 standard fire curve reveals a distinct thermal lag at all internal measurement points due to concrete's low thermal conductivity. This phenomenon is particularly pronounced at:The concrete core, Measurement points 100 mm from the surface.

Key observations:

Temperature rise initiates only after 15 minutes of fire exposure.Temperatures continue increasing throughout the cooling phase until measurement termination.Maximum temperature gradients reach 85-110°C between surface and core regions.

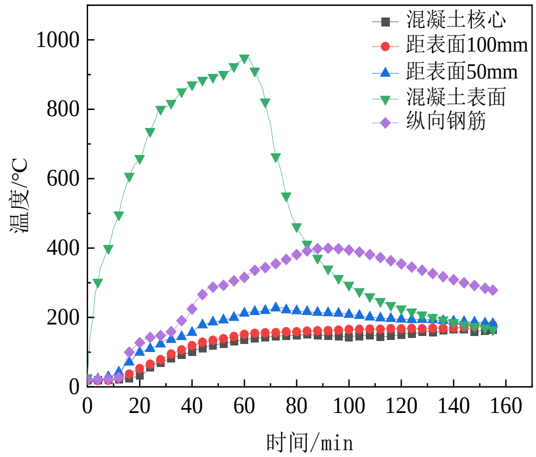
Effect of iron tailings sand replacement ratio (0%, 50%, 100%):

The replacement percentage demonstrates negligible influence on the thermal distribution.Critical thermal transition at 100°C: Evaporation of pore water creates a distinct temperature plateau.Heating rate reduces to <0.5°C/min during this phase. Plateau duration varies from 8-12 minutes depending on specimen thickness.



（a）PC40-0-60 （b）TWC40-50-60

（c）TWC40-100-60 （d)TWC50-50-60



（3）TWC50-100-60

Fig. 4 Temperature-Time Curves at Specified Cross-Section Locations

3.3. Analysis of Load-Displacement Curves

The load displacement curve obtained from the axial compression test is shown in Figure 5. Through comparison, it is found that the trend of the load displacement curve changes is basically the same. At the beginning of loading, the curve shows linear growth with a slow rate. When loaded to 500kN, it is changed to displacement loading, and the curve briefly twists. Then the curve continues to show linear growth with an accelerated rate. When approaching the peak load, the curve begins to slow down, the displacement increases rapidly, and the load tends to stabilize; After reaching the peak load, the load no longer increases and the displacement continues to increase.

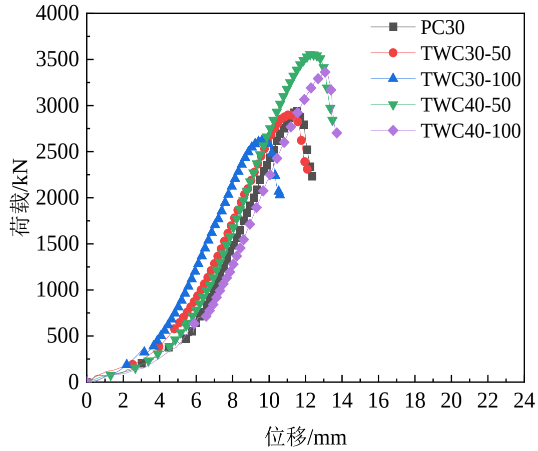


Fig. 5 Load displacement curve of axial compression specimen

4. Conclusion

1) Compared with natural sand concrete columns, the temperature field difference in the cross-section of iron tailings sand concrete columns is relatively small, and the heating trend is consistent; When the concrete strength is the same, the degree of cracking increases with the increase of fire time and iron tailings replacement rate; When the duration of exposure to fire and the substitution rate of iron tailings sand are the same, the higher the strength grade of concrete, the more severe the cracking of iron tailings sand concrete columns.

2) Improving the strength grade of concrete is beneficial for enhancing the ultimate bearing capacity of iron tailings sand concrete columns after high temperature exposure for 60 minutes. For specimens with iron tailings sand replacement rates of 50% and 100%, the concrete

strength increased from C40 to C50, and the residual rate of ultimate bearing capacity increased by 8.3% and 13.3%, respectively.

3) Reducing the substitution rate of iron tailings is beneficial for improving the ultimate bearing capacity of iron tailings concrete columns after high temperature. After being exposed to fire for 60 minutes, the replacement rate of iron tailings sand decreased from 100% to 50% for specimens with concrete strengths of C40 and C50, and the residual rate of ultimate bearing capacity increased by 8.4% and 6.3%, respectively.

Acknowledgements

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