WEP Warwick Evans Publishing

International Journal of Materials Science and Technology Studies

ISSN: 3006-7693 (Print), ISSN: 3006-3744 (Online) | Volume 1, Number 2, Year 2024
DOI: https://doi.org/10.62051/ijmsts.v1n2.06
Journal homepage: https://wepub.org/index.php/IJMSTS/index

Research progress of steel-RAC composite structures

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ABSTRACT

As a new sustainable development technology, recycled aggregate concrete (RAC) has a profound impact on the green development of construction engineering. However, due to the defects of RAC itself, it is hindered in engineering application. The steel-RAC composite structure can effectively enhance the mechanical properties of RAC and promote the application of RAC in practical engineering. Based on the recent research status of steel-RAC composite structures, including recycled aggregate concrete filled steel tube (RACFST) columns and recycled aggregate concrete - encased recycled aggregate concrete filled steel tube (RAC-encased RACFST) composite columns the axial compression, the compression performance, seismic performance and fire resistance of composite columns are reviewed in this paper, and the future research direction is proposed.

KEYWORDS

Recycled aggregate concrete; Steel tube; Composite column

1. INTRODUCTION

With the rapid development of the construction industry, concrete has become the second-largest consumer product in the world after water [1]. Still, it has also brought significant resource and ecological problems. According to statistics, the total global demand for aggregate concrete has reached 40 billion tons per year [2], and the annual global cement production is about 4 billion tons, accounting for more than 7% of the total carbon emissions [3]. Along with the huge consumption, the emission of construction waste is also very surprising. For example, China emitted 3 billion tons of solid waste from buildings in 2021, of which waste concrete accounts for about 40% [4]. Recycled aggregate (RA) is the waste concrete after crushing, cleaning, and grading treatment, according to a certain proportion and grading mixed form, which can replace natural aggregate (NA) configuration into recycled aggregate concrete (RAC). As a new sustainable technology, RAC has a profound impact on the green development of construction engineering. However, due to the adhesion of old mortar on the surface of RA, the mechanical properties such as compressive strength and elastic modulus of RAC are not as good as those of ordinary concrete [5], which is hindered in engineering applications. In order to improve the mechanical properties of RAC, some scholars proposed combining RAC with steel to form a steel-RAC structure, including recycled aggregate concrete-filled steel tube (RACFST) and recycled aggregate concrete-encased recycled aggregeta concrete filled steel tube (RAC-encased RACFST) composite column. The external steel tube effectively constrains the crack development of core RAC, thereby improving the overall bearing capacity and ductility of the structure [6]. RAC-encased RACFST composite column is a struture with a layer of reinforced RAC wrapped in RACFST. On the basis of better bearing capacity and seismic performance, RAC-encased RACFST composite column has better temperature resistance and corrosion resistance than that of RACFST. In this paper, the static compression research on steel-

RAC composite structures in recent years is reviewed and summarized, which provides reference for further research on the application of RAC in steel-concrete composite structures.

2. PHYSICAL AND MECHANICAL PROPERTIES OF RAC

RA was first used in the Second World War, and in the 20th century, the United States and the United Kingdom began to introduce RA to make RAC and apply it to buildings. Due to its mechanical properties comparable to ordinary concrete, RAC has a wide range of application prospects. After many years, there have been fruitful research results

Nixon et al [8] found through experiments that the compressive strength of RAC was reduced compared with NAC, with a maximum reduction of 20%. Pacheco et al [9] studied the basic mechanical properties such as elastic modulus and compressive strength of NAC and RAC through the compression test and found that the replacement rate of recycled coarse aggregate (RCA) had little influence on the elastic modulus and compressive strength of concrete. Wei et al [10] and Bai et al [11] considered the influence of different RA replacement rates on the compressive strength of RAC, and the results showed that with the increase of RA replacement rates, the compressive strength of RAC showed a downward trend. However, Zhang et al [12] found that the compressive strength of RAC increased with the increase of the replacement rate of RA. In general, most of the research results show that the mechanical properties of RAC are not as good as ordinary concrete, and its compressive strength decreases with the increase of RA replacement rate.

3. RACFST

RACFST column is a new type of composite structure formed by filling RAC into steel tube. Because it improves the mechanical properties of RAC and opens up the structural application path of RAC, it has the application prospect of sustainable development and has been a research hotspot in recent years.

3.1. Axial Compression Performance

Wang et al [13] compared the axial compressive performance of RACFST columns and reinforced RAC columns under the same amount of steel, the results showed that the RACFST columns have better axial compressive performance. Yang et al [6] found that the axial compression failure pattern of RACFST columns was similar to that of ordinary concrete-filled steel tube (CFST) columns. Xiao et al [14] used RCA as the main research parameter to conduct axial compression tests on RACFST columns with circular steel tubes, and the results showed that the ultimate axial compression capacity of RACFST columns decreases with the increase of RCA replacement rate. Through the axial compression test, Chen et al [15] found that the bearing capacity of RACFST columns increases with the increase of steel tube constraint index. According to the test results and calculation data, Ke et al [16] proposed to adopt a unified strength theoretical formula for the design of RACFST columns.

3.2. Eccentric Compression Performance

Yang et al [17] studied the eccentric compression performance of RACFST thin columns with rectangular steel tubes and found that eccentricity, slenderness ratio and RA replacement rate had significant effects on the bearing capacity of the specimen, and derived a formula for calculating the bearing capacity of columns. Zhong et al [18] studied the eccentric performance of RACFST columns with circular stainless steel tubes and evaluated the applicability of N-M curves to RACFST columns with circular stainless steel tubes under the compression, and bending action specified in EN 1994-1-1, ANSI/AISC 360–16 and AS/NZS 5100, among which the prediction results of ANSI/AISC 360–16 were the most conservative.

3.3. Seismic Performance

Huang et al [19] completed the low-cycle repeated test of six RACFST columns, and the study showed that the replacement rate of RCA had a slight impact on the seismic performance of RACFST columns, and proposed an improved damage model based on the Miner principle. Wang et al [20] conducted quasi-static tests under constant axial force and horizontal reciprocating load with six RACFST medium-length columns and found that the energy dissipation capacity and deformation capacity of the specimens increased with the increase of the slenderness ratio. Huang et al [21] studied the effects of steel ratio and axial compression ratio on the seismic resistance of RACFST columns, and the results showed that the larger the steel ratio or the smaller the axial compression ratio, the better the seismic resistance of the specimens.

In summary, RACFST column has the same mechanical properties as CFST columns, and the replacement rate of RA, steel ratio, eccentricity and slenderness ratio have obvious effects on the mechanical properties of RACFST columns.

4. RAC-ENCASED RACFST

Compared with CFST columns, due to the outer layer of reinforced concrete, concrete-encased CFST composite columns show better structural performance and application flexibility, especially in high-rise buildings and Bridges. Before the study of RAC-encased RACFST composite columns, a large number of scholars have studied concrete-encased CFST composite columns, which lays a foundation for the study of RAC-encased RACFST composite columns. Therefore, this chapter also introduces the current research status of RAC-encased RACFST composite columns and concrete-encased CFST composite columns.

4.1. Axial Compression Performance

Kang et al [22] and Cai et al [23] considered the strength of concrete, stirrup ratio, longitudinal reinforcement ratio, cross-section shape and steel ratio, and carried out axial compression tests of concrete-encased CFST composite columns. It is found that the steel ratio, the strength of concrete and the stirrup ratio are the main factors affecting the axial compression performance of concrete-encased CFST composite column, and the bearing capacity of composite column increases with the increase of steel ratio. Han et al [24] used the finite element model to analyze the mechanical properties of concrete-encased CFST composite columns under axial compression, considered material nonlinearity and the interaction between concrete and steel, compared concrete-encased CFST composite columns with CFST and reinforced concrete, and proposed a simplified formula for predicting the ultimate bearing capacity of concrete-encased CFST composite columns. Wu et al [25] established a finite element model of concrete-encased CFST composite columns, simulated and analyzed the working state of the composite columns under axial compression, and found that the effective flexural stiffness was the key to safely predicting the anti-buckling ability of composite long columns. Ke et al [26] conducted an axial loading test on five RAC-encased RACFST composite columns and found that the core RACFST gradually played a role when the reinforced RAC outside the tubes reached its limit. The ductility of the composite column is improved with the increase of the stirrup ratio, and the damage develops slowly in the later stage. Cai et al [27-28] analyzed 20 RAC-encased RACFST composite columns under axial pressure and found that the interaction between RACFST and external reinforced RAC had a significant impact on the axial compressive capacity and stiffness of the composite columns.

4.2. Enccentric Compression Performance

Yang et al [29] studied the performance degradation law of RAC-encased RACFST composite columns under small eccentric compression, taking the replacement rate of recycled coarse aggregate, eccentricity and slenderness ratio as parameters. The results showed that reducing the slenderness ratio was conducive to improving the ultimate bearing capacity, ductility and energy dissipation capacity of composite columns. Guo et al [30] found through the eccentric test of the RAC-encased RACFST composite column that regardless of the eccentricity, the compressive bar always yielded before the concrete in the compression zone was crushed. Ke et al [31] analyzed the effects of the replacement ratio of RA, eccentricity, steel ratio and slenderness ratio on the eccentric compression performance of RAC-encased RACFST composite columns with circular steel tube. The results show that the bearing capacity of composite columns decreases with the increase of eccentricity, and increases with the increase of steel ratio and the decrease of slenderness ratio.

4.3. Seismic Performance

Li et al [32] conducted seismic experiments on four concrete-encased CFST columns and one ordinary high-strength concrete column under cyclic and reciprocating loads. They found that the outer reinforced concrete was the main part to bear the horizontal force by analyzing the test results. The more the strength difference between the concrete inside and outside the steel tube, the better the ductility of the composite column. Huang et al [33] explained the mechanism of improving ductility under a high axial compression ratio. Based on the existing tests, a finite element model of the composite column was established, and the influence of parameters such as axial compression ratio and steel tube constraint coefficient on the ductility coefficient of the composite column was analyzed.

4.4. Fire Resistance

Li et al [34] and Tang et al [35] respectively carried out a numerical simulation on the mechanical properties of concrete-encased CFST composite columns after fire, and analyzed the main factors affecting the bearing capacity of the composite columns. The analysis results showed that the section size and slenderness ratio had a great influence on the bearing capacity of the composite columns under fire. Xu et al [36] studied the fire resistance of concrete-encased CFST composite columns on one side and found that the existence of the inner core concrete effectively prevented the local buckling of the steel tube, while the outer concrete protected the steel tube under high temperature.

In summary, the static compression performance and durability of RAC-encased RACFST composite columns are similar to that of concrete-encased CFST composite columns, and due to the outer reinforced concrete, the mechanical properties of composite columns are not only affected by the steel ratio, strength of concrete, eccentricity and slenderness ratio but also affected by the stirrup ratio. At present, there are few researches on the RAC-encased RACFST composite columns, which need to be further enriched in order to broaden the application of RAC in engineering.

5. SUMMARY

This paper reviews and summarizes the research progress of steel-RAC composite structures, discusses the factors affecting the static compression performance and durability of RACFST and RAC-encased RACFST composite columns, and puts forward the future research direction. The details are as follows:

(1) Steel-recycled concrete composite structures have the feasibility of engineering application, and their mechanical properties are close to those of ordinary concrete structures.

(2) The mechanical properties of RACFST and RAC-encased RACFST composite columns are all affected by concrete strength, steel content of steel tube, eccentricity and slenderness ratio. Since a layer of reinforced concrete is wrapped outside the RAC-encased RACFST composite column, its mechanical properties are also affected by the reinforcement ratio and stirrup ratio, among which the stirrup ratio plays a more obvious role.

(3) At present, there are few researches on RAC-encased RACFST composite columns, which need to be further enriched.

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