A Review of Research on Recycled AggregateConcrete Filled Steel Tube

ABSTRACT

Recycled aggregate concrete filled steel tube as a new combined structural form, can effectively improve the inherent defects of recycled aggregate concrete. Existing studies are mainly theoretical analysis, experimental research and numerical simulation to investigate the mechanical properties and deformation capacity of recycled aggregate concrete filled steel tube columns. Based on the review of the current research status of recycled aggregate concrete filled steel tube columns in recent years, the basic mechanical properties, durability, seismic performance, fire and high temperature resistance of recycled aggregate concrete filled steel tube are described, and suggestions are made for future research directions.

Keywords: recycled concrete; recycled aggregate concrete filled steel tube; properties; review

1 INTRODUCTION

Concrete filled steel tube(CFST) members have the characteristics of high bearing capacity, excellent seismic performance, good plasticity and toughness, easy construction and good economic benefits. At present, many scholars have conducted research on the application of recycled aggregate concrete in structures, focusing on the force properties and design methods of recycled aggregate concrete filled steel tube(RACFST) columns, and have obtained abundant research results, laying a foundation for the optimization of the structural performance of CFST and diversified development. This paper focuses on the research progress of RACFST columns, summarizes the characteristics of recycled aggregate concrete and RACFST columns, and provides references and suggestions for the application research and future direction of RACFST columns.

2 CURRENT STATUS OF RESEARCH

2.1BASIC MECHANICAL PROPERTIES OF RECYCLED CONCRETE

Recycling of waste concrete first began in Europe, after the end of the Second World War, many cities in the war became a ruin, all over the construction waste is people rebuild their homes after the war is urgent to solve the problem, including waste concrete. After the war,

Japan, Germany, the Soviet Union and some other countries carried out research on the rational use of waste concrete [1][2][3]. Recycled coarse aggregate refers to the aggregate with particle size of 5~40 mm obtained from waste concrete after crushing and processing, and recycled fine aggregate refers to the aggregate with particle size of 0.5~5 mm obtained from waste concrete after crushing and processing [4]. When crushing waste concrete, the recycled aggregate is prone to internal cracks, and the surface of the recycled aggregate is attached with residual mortar and impurities attached to its interior, resulting in low apparent density, high porosity, high water absorption, low strength and other characteristics of recycled aggregate compared with natural aggregate[5][6][7].

Compared with ordinary concrete, POON et al [8] showed that the compressive strength of recycled aggregate concrete showed a decreasing trend with the increase of recycled aggregate replacement rate. Xiao Jianzhuanget al [9] showed that with the increase of recycled aggregate substitution rate, the compressive strength of recycled aggregate concrete has a decreasing trend in general, and when the recycled aggregate substitution rate is 50%, the compressive strength is the highest, and even higher than that of ordinary concrete.THOMAS et al [10] showed that when the recycled aggregate substitution rate is 100%, the compressive strength of recycled aggregate concrete decreases by 11% to 19%, and the split tensile strength decreased by 7%~19%. And the research of Chen Zongping[11] showed that the recycled aggregate replacement rate increased, the compressive strength of recycled aggregate concrete showed an increasing trend, the flexural strength showed an increasing trend and then decreased trend, and the modulus of elasticity showed a decreasing trend. Li Xiaozhong[12] found that the flexural strength of recycled aggregate concrete decreased by 3.9% to 26.8% when the recycled aggregate substitution rate was 100%. The reason for the difference in the research results may be the effect of the recycled concrete formulation method and water-cement ratio.

The current research on the compressive strength of recycled aggregate concrete has basically reached a consensus, and it is generally recognized that the incorporation of recycled aggregate in concrete will reduce the compressive strength. In order to make up for the shortcomings, numerous researchers have carried out studies to enhance the compressive strength of recycled aggregate concrete. Wang Peng [13] concluded that recycled aggregate concrete could obtain the desired compressive strength after adjusting the water-cement ratio, and Wang Xin et al [14] reached a similar conclusion. Qingrui Li et al [15] analyzed and found that the compressive strength of recycled aggregate concrete increased with the increase in the volume admixture of steel fibers. Wang Xi [16] found that pre-wetting of recycled coarse aggregate could solve the unfavorable effect of recycled aggregate on the collapse of recycled concrete through experiments.

In summary, different researchers and scholars have concluded that the shape of the stress-strain relationship curve of recycled aggregate concrete is similar to that of ordinary concrete, but its peak strain increases and its modulus of elasticity decreases compared with that of ordinary concrete. Regarding the influence law of recycled aggregate on the strength of recycled aggregate concrete, the performance of recycled aggregate varies greatly due to the different strengths and damage degrees of old and broken concrete, which leads to some differences in the conclusions reached by different researchers. But this difference can be reduced by modifying the recycled aggregate. It is generally believed that the compressive

strength, tensile strength and flexural strength of recycled aggregate concrete are reduced compared to ordinary concrete, but their developmental pattern with age is similar to that of ordinary concrete.

2.2 MECHANICAL PROPERTIES OF RECYCLED AGGREGATE CONCRETE FILLED STEEL TUBE COLUMN UNDER COMPRESSION

At present, research scholars have conducted a large number of experimental studies on the mechanical Behaviour of RACFST members, but due to the short development time of recycled aggregate concrete, the research on RACFST is still limited compared to ordinary CFST members.

Related researchers [17][18] believe that concrete waste can be made into a good performance of the aggregate, and the recycled aggregate concrete of CFST also exists with ordinary CFST consistent "interaction". RACFST can not only meet the structural needs, but also the steel tube and recycled aggregate concrete can complement each other and play the role of complementing each other's strengths and weaknesses. However, the bearing capacity of RACFST is lower than that of ordinary CFST, and the mechanical properties of recycled aggregate concrete are lower than those of ordinary concrete under the same mix ratio.

2.2.1MECHANICAL PROPERTIES AND ANALYSIS OF AXIAL COMPRESSION

Chen[19] investigated the mechanical properties of RACFST short columns with different cross-sectional forms through axial compression tests, analyzed the effects of recycled coarse aggregate substitution rate and hoop coefficient on its mechanical properties, and the results showed that:the peak stress of RACFSTincreased with the increase of recycled coarse aggregate substitution rate.Konno et al [20][21] investigated the RACFST axial stressed members, and the results showed that the stiffness and bearing capacity of steel tube restrained recycled aggregate concrete were lower than that of steel tube restrained plain concrete, which was mainly due to the reduction of strength and modulus of elasticity of recycled aggregate concrete compared to plain concrete.WANG et al [22], based on the model equations of CFST proposed the modulus of elasticity of circular RACFST taking into account the replacement rate of mortar and recycled aggregate and the compressive strength equations; in the calculation of ultimate load carrying capacity, the American AISC360-10 and Japanese AIJ2008 specifications were underestimated by 20%~25%, and the European standard EC4 and the national standard GB50936-2013 (2014) were underestimated by 5.8%, 6.8%, and 3.8%, respectively.YANG et al.[23] analyzed that with the increase of substitution rate, the column bearing capacity decreases:European Standard EC4 bearing capacity calculation results are more in line with the test values; and based on the design formula of CFST, a simplified design formula for RACFST members under different conditions is proposed.SANGEETHA et al.[24] showed that increasing the length-to-finish ratio, the mechanical properties of RACFST columns decrease. Zhang Xianggang et al.[25] showed that the ductility of square columns is less than that of circular columns, and the length to slenderness ratio has a greater effect on the bearing capacity of square section columns,In the calculation of bearing capacity and stiffness, the domestic codes are more in line with the test results.

In conclusion, due to the incorporation of recycled aggregates, the ductility of recycled aggregate concrete is better and possesses good energy dissipation capacity, while the

specimen composite modulus of elasticity, bearing capacity and compressive strength are lower than that of ordinary CFST specimens. The specimen bearing capacity varies with the recycled aggregate substitution rate with disagreement due to the influence of the water-cement ratio in the formulation of recycled aggregate concrete, and is also affected by factors such as old mortar and original damage accumulation. The load carrying capacity and deformation capacity are strongly influenced by the steel content and the length-to-finish ratio. The mechanical indexes of the specimens were predicted conservatively by different codes; for foreign standards, EC4 was predicted better, and for domestic standards, Zhang Xianggang et al [25] carried out a multi-code comparison and recommendations. However, the calculation formulae for different environments and parameter changes need to be further studied and improved. The mechanical properties of specimens with different sources and different initial strengths of recycled aggregates are also less studied. The tests are mostly focused on short-term static load tests of columns, and even less involved in the study of mechanical properties and durability performance of long-term loaded specimens.

2.2.2 BIAS MECHANICAL PROPERTIES

Ma Hui[26] Recycled aggregate concrete was poured into steel tubes with steel profiles and subjected to eccentric compression tests, the results of which were analyzed and found that this type of composite column had high initial stiffness and the falling section was smooth after the peak load, indicating good ductility. The transverse deformation along the column height direction also conformed to the sinusoidal half-wave curve, which increased by 14% when the substitution rate was 100%. Chen Zongping et al [27] showed that the mechanical Behaviour and damage morphology of RACFST biased long columns were similar to that of steel tube plain concrete biased long columns, and the effects of length to slenderness ratio and eccentricity distance on their mechanical properties were more significant, while the recycled aggregate substitution rate had a lesser effect on their mechanical properties. Xiang Xing Eddie [28] through the self-compacting recycled aggregate concrete filled steel tube short column bias test research, found that the recycled aggregate substitution rate of self-compacting recycled aggregate concrete filled steel tube short column bias bearing capacity effect is not very significant, but the peak strain effect is more significant; steel content rate on the bias bearing capacity is more obvious. According to the experimental data based on the unified theory and the empirical coefficient method, respectively, a suitable formula for calculating the bias bearing capacity of self-compacting recycled aggregate concrete filled steel tube short columns was proposed.

In summary, the steel tube has good adhesion properties with the core concrete. Buckling damage occurred in the biased specimen and bulging deformation was produced to the biased side. The specimens showed flexural slip lines from the end, and the ultimate load required for the occurrence of bias damage was smaller than that required for axial damage, while the specimen load carrying capacity was mainly affected by the eccentricity and the length-to-slender ratio. There are relatively few studies on the bias performance of RACFST columns, and the bias performance of the specimens under the factors of recycled aggregate concrete strength, steel strength, steel content and different environments need to be further investigated.

2.2.3PURE BENDING PROPERTIES

There are fewer existing pure bending test studies, and Yang Youfu [29][30] was the first to investigate this aspect, and conducted a comparison test between eight RACFST members

and two ordinary CFST members. The results show that the mechanical properties of RACFST pure bending members are similar to those of ordinary CFST pure bending members, and the ultimate bending moment and stiffness of the members decrease with the increase of the replacement rate of recycled aggregate. As for the theoretical analysis and numerical simulation, Yang Youfu[31] analyzed and simulated the load-deformation relationship curves of pure bending members by using the fiber model method and ABAQUS. The interaction between steel tube and recycled aggregate concrete during the stressing process and the cross-section stress distribution law were revealed.

In summary, the existing research on pure bending performance has made some progress but there are also major problems. First of all, there are fewer related experimental studies, and it is difficult to draw more systematic test conclusions. In terms of theoretical analysis, the study of mechanical property changes in the whole process of member bending is not sufficient.

2.2.4DURABLE PERFORMANCE

Chen Mengcheng et al. [32] showed that, with the increase of load, the specimen surface floating rust spalling, the specimen occurred bulging cracking, and ultimately the waist drum type damage; the degree of corrosion increases, the specimen damage from the middle to the end of the expansion; steel tube corrosion mainly caused the specimen effective cross-section size reduction, so as to make the steel tube on the constraint effect of the recycled aggregate concrete is reduced, resulting in the reduction of the specimen load carrying capacity, stiffness and ductility. Huang Hong et al. [33] showed that Faraday's law of electrochemical corrosion is feasible for the simulation of steel tube corrosion. The corroded specimen under the action of load, first appeared obvious weld cracking, and ultimately bulging damage pattern, and the greater the degree of corrosion, the more serious the corresponding regenerated aggregate concrete damage: under the condition of bias, with the deepening of the degree of corrosion, the specimen stiffness in the early stage, the late ductility and the ultimate load carrying capacity decreased; increase the eccentric distance, the specimen stiffness and load carrying capacity decreased, and relative compression ratio increased.

Lu Junkai [34] conducted experimental study and finite element numerical simulation of freeze-thaw cycles on solid RACFST column and hollow RACFST column. The study showed that:Freezing and thawing had a greater effect on the modulus of elasticity of the hollow steel tube and a smaller effect on the solid RACFSTcolumn; while water saturation had a greater effect on the freezing deformation of the solid RACFSTcolumn. The solid RACFSTcolumns can effectively resist the circumferential freezing deformation. The tightening force generated by the temperature change has little effect on the RACFST structure and can be disregarded in the actual process.

Due to the indoor or finite element numerical simulation to consider the state of the more ideal, resulting in rapid indoor testing and engineering reality is obviously a large gap, how to simulate the actual engineering situation to reduce the difference is worth thinking about.

2.2.6SEISMIC PERFORMANCE

Zhang Xianggang [35] and others showed that RACFST columns have better hysteretic return properties and energy dissipation capacity. When the specimen was damaged, the equivalent viscous damping coefficient hc ranged from 0.323 to 0.360. Wang Chenggang et al. [36] showed that increasing the steel content ratio was favorable to the specimen's deformation, energy dissipation capacity, and load carrying capacity; the increase of the length-to-finish

ratio was favorable to the deformation and energy dissipation enhancement, while the load carrying capacity was decreased; and the increase of axial compression ratio was decreased in the deformation and energy dissipation capacity while the load carrying capacity was improved.CHEN et al.[37] showed that axial compression ratio had a significant effect on the seismic performance of members, and the axial compression ratio was increased. CHEN and others showed that the axial pressure ratio has a significant effect on the seismic performance of members, and at low axial pressure ratio (≤0.31), the specimens have good seismic capacity. Meng Er from [38] recycled concrete hollow block infill wall can be used as the first line of seismic defense for square RACFST frames. The recycled aggregate substitution rate has no significant effect on the specimen ductility, energy dissipation capacity and stiffness degradation.

Tang [39] and others carried out low-cycle repeated loading tests on RACFST columns, and used the finite element method to study the effects of length-to-diameter ratio, diameter-to-thickness ratio and axial compression ratio on the seismic performance of RACFST columns. The test results and calculations show that compared with ordinary recycled concrete columns, the RACFST columns exhibit excellent seismic performance and deformation capacity, which indicates that the RACFST structures can be used as engineering structural elements in seismic zones.

In conclusion, the seismic performance of RACFST columns is mainly affected by the length-to-finish ratio, axial compression ratio, shear span ratio and steel content rate. The enhancement of steel content rate on each mechanical index of the specimen is more obvious. The increase of recycled aggregate substitution rate increased the deformation capacity of specimens, while the bearing capacity decreased. However, in these seismic performance experimental studies, the influence of some key factors on the damage deterioration level under seismic action has not been explored; the existing analyses are mainly focused on the members, while the overall seismic performance of the structure is not adequately studied. In the theoretical analysis and numerical calculation work, the existing physical model of damage deterioration of RACFST columns under seismic action is not yet perfect, and further experimental research and theoretical analysis work is required.

2.2.7 FIRE AND HIGH TEMPERATURE RESISTANCE

Yang [40] and Chen Zongping[41][42] conducted a series of post-high-temperature axial compression short column force performance tests. The tests showed that the damage process and damage morphology of RACFST after high temperature were similar to those of ordinary CFST columns. With the increase of recycled aggregate substitution rate. The bearing capacity of square RACFST specimens after high temperature is reduced. The bearing capacity of round RACFST specimens did not change much; and with the increase of temperature, the bearing capacity of RACFST specimens showed a different situation of decline.

Yutuo et al. [43] on hollow tube columns showed that the outer steel tube and the corners of the member concrete temperature is the highest, the inner steel tube and the surrounding recycled aggregate concrete temperature is the lowest, the maximum temperature difference in the cross-section reaches 445℃; after the fire, the specimen residual bearing capacity by the calculation of the length and the time of the fire is greatly affected: the residual capacity with the replacement rate of recycled aggregates, the load eccentricity, the calculation of the length and the time of the fire is reduced; with the increase in the strength of recycled aggregate concrete and steel increases; with the increase in hollow ratio is a decreasing trend.

strength of concrete and steel; it tends to increase and then decrease with the increase of hollowing ratio. Jin Deyu et al. [44] showed that the specimen fire surface warming rate is faster, and the farther away from the fire surface, the slower the temperature gradient changes, the specimen ultimate bearing capacity is affected by the steel content rate, concrete strength, steel strength and the fire time, and the hollowing rate and recycled aggregate substitution rate have less influence.

In conclusion, the damage of specimen is accelerated after high temperature, the mechanical indexes are degraded obviously, and the enhancement of specimen deformation and energy-consuming capacity mainly relies on the promotion effect of steel tube by high temperature. Under the rapid cooling of water spraying, the small increase of steel strength by the "quenching" reaction is not enough to compensate for the decomposition damage of recycled aggregate concrete, so that the specimen bearing capacity decreases, but the ductility and energy consumption will be better than natural cooling. The RACFST columns have better fire resistance, for the shorter and thicker specimens and high strength of the constituent materials, under the same external conditions, it is more favorable to fire itself. The residual bearing capacity of the specimen increases and then decreases with the increase of the hollow ratio, because the recycled aggregate concrete content decreases when the hollow ratio is higher, and the steel content decreases when the hollow ratio is lower. Most of the existing work is the experimental study of RACFST after high temperature, and it is necessary to carry out the experimental study of specimen performance change under high temperature or fire, and numerical simulation and theoretical analysis, so as to form a reliable and practical design method.

3CONCLUSION

RACFST makes use of the interaction between steel tube and recycled aggregate concrete to make up for the lack of recycled aggregate concrete performance, to achieve complementary advantages, and to provide an effective way for waste concrete resource utilization. The main conclusions include the following aspects:

(1) The axial compression and eccentric compression performance of RACFST columns can meet the requirements of the mechanical properties of structural members in actual engineering structures, and their stress characteristics are basically similar to those of ordinary CFSTcolumns.

(2) Sensitive factors of specimen mechanical properties are mainly steel content, length-to-fineness ratio, recycled aggregate concrete strength and recycled aggregate substitution rate, and shear damage mainly occurs in short columns, and bending damage occurs in long columns.

(3) Freezing and thawing cycles and acidic corrosion mainly degrade the restraining properties of steel tubes, leading to the reduction of ultimate column capacity, pre-stiffness and post-ductility. The RACFST columns showed excellent seismic capacity and energy dissipation capacity in the proposed static tests such as low circumferential repeated loading, which can be used in the structural design and construction in seismic zones. The high temperature reduces the load carrying capacity of the columns, while the deformation properties are mainly determined by the yield capacity of the steel tubes only.

(4) There are still more problems in the existing research on RACFSTcolumns. In terms of theoretical analysis, the existing results are not systematic enough. Failed to study the influence of aggregate properties on specimen performance. In the experimental study, the lack of analysis of the overall structure and the failure of multiple factors under the action of

RACFST performance research and other issues, the follow-up work must be in-depth discussion of these issues. The bond performance, impact resistance, and creep performance of RACFST columns are rarely studied, and more in-depth research is needed. The solution of the above problems as soon as possible will lead to the formation of technical regulations for RACFST, which will make a greater contribution to the reuse of waste concrete and the sustainable development of resources.

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