

A Review of Research on Recycled Aggregate Concrete Filled Steel Tube

ABSTRACT

Recycled Aggregate Concrete Filled Steel Tube are made by replacing the core concrete in ordinary concrete-filled steel tube columns with more energy-efficient and environmentally friendly recycled aggregate concrete. This paper briefly introduces the effect of recycled aggregate concrete on the mechanical properties of concrete-filled steel tube structures. It also discusses in detail the research progress of different experts and scholars at home and abroad on Recycled Aggregate Concrete Filled Steel Tube. Finally, it is concluded that although a large amount of research work has been carried out around the application of the structural properties of recycled aggregate concrete filled steel tube, there is still a lack of systematic summary of the mechanical properties of Recycled Aggregate Concrete Filled Steel Tube, and more in-depth summaries and analyses need to be carried out. Such a deeper study of Recycled Aggregate Concrete Filled Steel Tube has certain practical significance and engineering prospects.

Keywords: recycled aggregate concrete; concrete-filled steel tube; 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 CFST structures, focusing on the force properties and design methods of recycled CFST members, and have obtained abundant research results, laying a foundation for the optimisation and diversification of CFST structures. This paper focuses on the research status of recycled aggregate concrete in CFST structures, summarises the characteristics of recycled aggregate concrete, CFST and recycled aggregate CFST, and provides a reference for the application of recycled aggregate concrete in CFST structures.

2 CURRENT STATUS OF RESEARCH

2.1 RECYCLED AGGREGATE CONCRETE

Recycling of waste concrete first began in Europe, after the end of the Second World War, many cities became ruins in the war, and construction waste everywhere was an urgent problem for people to rebuild their homes after the war, 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 cracks, and the surface of the recycled aggregate is adhered to residual mortar and the impurities adhered to it, which results in the low apparent density, high porosity, high water absorption and low strength of the recycled aggregate compared to the natural aggregate [5][6][7].

Xiao Jianzhuang, Chen Zongping [8][9] prepared 264 recycled aggregate concrete cubic specimens and 36 recycled aggregate concrete cylindrical specimens for mechanical test research, the compressive strength of recycled aggregate concrete is mainly reduced with the increase of coarse aggregate substitution rate, water-cement ratio, as analysed in the compression test of cubic specimens. When the replacement rate of coarse aggregate reaches 100%, the compressive strength of recycled aggregate concrete decreases by 30%, because the old mortar on the surface of recycled coarse aggregate releases mixing water with the hydration process. As the age increases, the long-term compressive strength of recycled aggregate concrete increases faster than that of ordinary concrete. After triaxial compression tests on recycled aggregate concrete cylindrical specimens, it was found that the modulus of elasticity, load carrying capacity, and deformation capacity of the recycled aggregate concrete specimens increased with the increase of the perimeter pressure value.

Studies by Hansen and Narud [10] and Padmini et al [11] have shown that the compressive strength of recycled aggregate concrete is related to the strength grade of the base concrete and the water-cement ratio, i.e., the use of higher strength grades of base concrete or lowering the water-cement ratio of the recycled aggregate concrete can increase the compressive strength of the formulated recycled aggregate concrete.

Faced with different differences in recycled coarse aggregate, Wang XI [12] found through experiments that pre-wetting of recycled coarse aggregate can solve the unfavourable effect of recycled aggregate on the collapse of recycled aggregate concrete. Due to the uncertainty of the source of recycled aggregate, it will lead to a great difference in the drying shrinkage of recycled aggregate concrete, Wang Q H [13] crushed dilapidated concrete with water-cement ratios of 0.3, 0.45, and 0.6 and ages of 1, 20, and 42 years respectively, and produced 60 recycled aggregate concrete specimens for the year-round shrinkage test, and proposed an ideal model for the drying shrinkage of recycled aggregate concrete, which Dry shrinkage decreases with the increase in strength of the original dilapidated concrete.

R. Sri Ravindrarajrh [14] and others studied the physical and mechanical properties of recycled aggregate concrete and obtained the relationship curves of the cubic compressive strength of recycled aggregate concrete with axial compressive strength, splitting strength,

and with static and dynamic modulus of elasticity through experimental Henrichsen and Jensen [15] found that the overall shape of the stress-strain relationship curve of recycled aggregate concrete is similar to that of normal concrete. Bairagi et al [16] found that the shape of the stress-strain relationship curve of recycled aggregate concrete varies with the rate of recycled aggregate replacement. Topqu and Günçan [17] conducted an experimental study on the stress-strain relationship of recycled aggregate concrete. strain relationship was investigated experimentally and the results showed that the compressive strength and modulus of elasticity etc. of recycled aggregate concrete decreased with the increase in the rate of recycled aggregate substitution. Rühl and Atkinson [18] found that the peak strain of recycled aggregate concrete increased with the increase in the rate of recycled aggregate substitution.

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, due to the different strengths and damage degrees of virgin concrete lead to a large difference in the performance of recycled aggregate, resulting in some differences in the conclusions reached by different researchers. However, this difference can be reduced by modifying the recycled aggregates in such a way that the compressive properties of recycled aggregate concrete will exceed those of the same type of natural aggregate concrete at some specific replacement rates. It is generally accepted that the compressive, tensile and flexural strengths of recycled aggregate concrete are reduced compared to normal concrete, but their development with age follows a similar pattern to that of normal concrete.

2.2 CONCRETE FILLED STEEL TUBE

In the long-term development process, many engineers and scholars recognise that steel tube and concrete as a separate material, have their own limitations; however, the combination of the two - CFST structure can make up for the shortcomings of the two, and can be made to further improve the performance of the force. The earliest reported use of CFST structural engineering is the 1870s British Severn Railway Bridge (Seven Railway Bridge). In the early days, the steel tube material of CFST generally used ordinary strength hot-rolled steel tube, cast tube or seamless tube, etc., and the core concrete used ordinary strength concrete. In recent decades, high-strength and high-performance materials, such as high-strength steel, stainless steel, high-strength concrete, self-compacting concrete, recycled aggregate concrete, and FRP (fiber reinforce polymer) have been gradually applied to CFST structures and related reinforcement projects.

Bradford et al [19] investigated the local buckling and post buckling of steel tubes in circular steel tubular concrete axial compression members during loading. The results of the study showed that filling the steel tube with concrete could not only improve the strength of the member section, but also delay the occurrence of steel tube buckling. In order to give full play to the combined effect between steel tube and core concrete, the paper suggests that the length-to-diameter ratio of circular CFST members should not exceed 125 for practical application.

Giakoumelis and Lam [20] carried out an experimental study of 15 short specimens of axial compression of concrete in circular steel tubes, where the main parameters examined in the specimen design were the concrete strength ($f_{cu} = 31.4-104.9$ MPa), the cross-section diameter-to-thickness ratio ($D/t = 22.9-30.5$), and the bond strength between the steel tube and the concrete. The results of the study show that the bond strength between steel tube and concrete has a slightly greater effect on the axial compressive strength of steel tube high-strength concrete, while it has a very small effect on steel tube normal-strength concrete. Bradford.M.A [21] conducted a theoretical study on the buckling mode of CFST. It was found that the core concrete can increase the local buckling stress of the members by a factor of 1.73 for circular hollow steel tubes and by a factor of 2.67 for square hollow steel tubes. Patel [22] carried out numerical simulation analysis of high strength rectangular CFST and the developed model can effectively predict the high strength rectangular steel tube considering local buckling and initial geometrical defects. concrete load-deflection curves.

Ruslan Kanishchev [23] developed a non-idealised ABAQUS model for CFST, where the boundary conditions and material properties of the model were set according to actual test conditions. In this modelling approach, the deviation of the calculated data becomes smaller compared to the normal modelling approach. The authors gave the calculation of critical stress factor based on the ABAQUS output data. Tusshar Goe [24] found that the thickness of the steel tube is positively proportional to the model load carrying capacity by building the ABAQUS model of CFST, and the damage modes of the model of short columns are basically local buckling.

Campione and Scibilia [25] carried out theoretical analyses and experimental studies on the performance of compression bending members made of steel-tube concrete and suggested simplified computational models for the load carrying capacity of compression bending members and the load-deflection relationship curves, and the results of the simplified calculations basically coincided with the experimental results.

Ding Faxing [26] found through experiments that in CFST structures, the effect of the interaction between the steel tube and the core concrete on the combined members can be disregarded when performing the overall calculation, and after theoretical analysis, a stress-strain relationship model applicable to the combined members was proposed. Yao Guohuang [27] used the finite unit method and fibre model method to calculate the load-deflection curves of CFST compression bending members, and the calculations were consistent with the test results. And the working performance of CFST compression bending was analysed to reveal the working mechanism of CFST compression bending members.

Zhou Guangshi [28] found that in CFST under eccentric loading, the tight hoop force in the dangerous section is not uniform, which is very difficult in making theoretical calculations. The effect of hoop force can be disregarded when using compression collapse theory to calculate the critical force. A formula for calculating the critical force of CFST is proposed based on the experimental data, and the accuracy of its proposed formula in the calculation of commonly used columns in engineering is demonstrated with reference to the data from relevant tests at home and abroad.

Nie and Xu Guigen [29] carried out a shear test study on square CFST column nodes, after analysing the characteristics of shear force-shear deformation curves of a large number of specimens, the shear force process can be divided into four stages of cooperative work,

co-work, yielding reinforcement and ultimate deformation, and the shear force is shared by the steel tube web and the node core area concrete, in which the core concrete is in planar Shear and compression bar mode contributes to the shear bearing capacity, considering the role of these three, the calculation model of the nodal shear bearing capacity of square CFST column is established, and the calculation results of this model are more consistent with the test results. Li Bin [30] and others carried out eccentric compression test of square CFST specimens, mainly considering the influence of three parameters: concrete strength, eccentricity, length and slenderness ratio, and the results show that: eccentric compression specimens by eccentricity and length and slenderness ratio of the influence of obvious, with the increase of eccentricity and length and slenderness ratio of the limiting bearing capacity decreases, and the strength of the concrete has no significant effect on the stress performance of eccentric compression specimens.

In summary scientifically and rationally designed CFST is actually an economical form of high performance structure. CFST uses the interaction between steel tube and core concrete in the stress process, that is, the restraining effect of the steel tube on the core concrete, so that the core concrete is in a three-way stress state, so that its strength has been strengthened, and plasticity and toughness have been improved. Among them, the core concrete strength, steel strength, length to slenderness ratio, eccentricity and other influencing factors have a significant impact on the load carrying capacity of CFST columns, so each of the above factors should be fully taken into account in the engineering application.

2.3 RECYCLED AGGREGATE CONCRETE FILLED STEEL TUBE

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

researchers [31][32] believe that concrete waste can be made into good performance aggregate, and recycled aggregate concrete from steel tube also has the same "interaction" with ordinary CFST. Recycled CFST can not only meet the structural needs, but also complement each other with steel tube and recycled aggregate concrete, so as to complement each other's strengths and weaknesses. However, the bearing capacity of recycled CFST 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.

Yang [33] found a gradual trend of decreasing structural modulus of elasticity and bearing capacity with increasing core recycled aggregate concrete substitution rate by conducting experimental studies on 24 compression bending members. Recycled aggregate CFST short columns with the same dimensional parameters. The modulus of elasticity and bearing capacity are lower than that of ordinary CFST. It is also pointed out that the damage of the middle-length column members of recycled aggregate CFST belongs to the overall buckling damage like ordinary CFST, and the load carrying capacity of the members gradually decreases with the increase of eccentricity. At the same time, the assumption of sinusoidal half-wave curve, flat section assumption and mechanical model applicable to ordinary CFST are also applicable to the theoretical analysis of compression bending members of recycled

CFST. Using the finite element method and the fibre model method, the load-deflection curves of members in compression bending were analysed, and a simplified calculation model of the load carrying capacity of beams and columns was proposed.

Chen [34] investigated the mechanical properties of recycled aggregate CFST short columns with different cross-sectional forms through axial compression tests to analyse the effects of recycled coarse aggregate substitution rate and hoop coefficients on their mechanical properties, and the results showed that: the peak stress of recycled aggregate CFST increased with the increase of recycled coarse aggregate substitution rate.

Lyu W Q, Han L H [35] conducted an experimental study on the bonding properties of steel tube and recycled aggregate concrete, and explored the influence mechanism of chemical bonding, micro bonding and macro bonding on the bond strength. The analysis results showed that the section type and section size were the two main parameters affecting the bonding strength of the steel tube to the RAC core; and the bonding properties of the recycled aggregate concrete of the steel tube were similar to those of the CFST; The empirical formula for calculating the bond strength between core concrete and outer steel tube is proposed.

Chengkui Huang [36] found that the initial self-stress increased the ultimate bearing capacity of steel tube self-compacted concrete and extended the elastic working range, but had little effect on the damage mode of the specimens. Feng Yu [37] investigated the mechanical behaviour of self-compacted CFST columns with recycled coarse aggregate under eccentric compression, and the experimental results showed that the damage modes of the specimens were related to the aspect ratio. . The long column was destabilised and the short column was strength damaged.

Konno et al [38][39] investigated the axial force members of steel tube restrained recycled aggregate concrete 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 in the strength and modulus of elasticity of recycled aggregate concrete compared to that of plain concrete.

Ma Hui[40] Recycled aggregate concrete was poured into steel tubes with steel profiles and subjected to eccentric compression tests, the results of which were analysed and found that this type of composite column had high initial stiffness and a smooth falling section after the peak load, indicating good ductility. The transverse deformation along the column height direction also conformed to the sinusoidal half-wave curve, and increased by 14 per cent when the substitution rate was 100 per cent.

An He [41] tested and developed a suitable finite element model for medium-length columns of recycled CFST using stainless steel tube size, recycled aggregate substitution rate, specimen height, and concrete strength as influencing factors. The available experimental data were compared with EN 1994-1-1 [42], AS/NZS 5100 [43] and AISC 360 [44] specifications, and it was found that the prediction accuracy of EN 1994-1-1 was high.

Chen Juan and Zeng Lei [45] analysed the effects of recycled aggregate substitution rate, silica fume, mineral admixture and steel fibre on the mechanical properties of recycled aggregate CFST short columns, and the results of the study showed that with the increase of recycled aggregate substitution rate, the load carrying capacity decreases and the peak deformation increases, but the method of mixing mineral admixtures as well as steel fibres can help to improve the mechanical properties of recycled aggregate CFST short columns.

Zhang Xianggang[46] conducted an experimental study on the mechanical properties of recycled aggregate CFST axial compression long columns through tests, and the test results showed that: the ductility of recycled aggregate CFST axial compression long columns is better, which is due to the support of the core concrete to the external steel tube; however, the ductility of the square specimens is weaker than that of the circular specimens; and the bearing capacity of the specimens decreases with the increase in the length and slenderness ratios.

Chen Zongping et al [47][48] conducted 30 recycled aggregate CFST long columns in bias test, and the results showed that the mechanical behaviour and damage morphology of recycled aggregate CFST bias long columns were similar to that of steel tube normal concrete bias long columns, and the effects of length to slenderness ratio and eccentricity distance on their mechanical properties were more significant, while the effects of recycled aggregate substitution rate on their mechanical properties were smaller.

Meng Er from [49] designed and produced eight square steel tube regenerated concrete frame for low week repeated loading test research, the study shows that: regenerated concrete hollow block infill wall can be used as the first line of seismic defence of square steel tube regenerated concrete frame; square steel tube regenerated concrete columns - regenerated concrete deep bending beams frames of the damage characteristics of the damage is mainly presented by the deep bending beams in order to occur mainly in shear damage.

Through the axial compression and bias compression tests on steel tube self-compacting recycled aggregate concrete short columns, Eddie Xiang Xing [50] found that the effect of recycled aggregate substitution rate on the axial compression and bias compression of steel tube self-compacting recycled aggregate concrete short columns is not very significant, but the effect of the peak strain on both of them is more significant; the effect of the steel content rate on the axial compression and bias compression bearing capacity is more obvious. Based on the experimental data, the axial and bias bearing capacity formulas for steel tube self-compacting recycled aggregate concrete short columns are proposed according to the unified theory and empirical coefficient method, respectively.

The research on recycled aggregate CFST members mainly focuses on axial compression and bias compression mechanical properties. Due to the different sources of recycled aggregates lead to the greater variability of mechanical properties of recycled aggregate concrete, and different scholars selected different ranges of experimental variation parameters, resulting in different conclusions about the effect of recycled aggregate substitution rate on the mechanical properties of recycled aggregate CFST members, such as some scholars believe that the axial compressive capacity of the short column of recycled aggregate CFST decreases with the increase in the substitution rate of recycled aggregates, while some scholars believe that the recycled aggregate replacement rate has no significant effect on the axial compressive load capacity of CFST short columns. However, in general, the damage pattern of recycled aggregate CFST members is similar to that of ordinary CFST

5 CONCLUSION

Recycled aggregate concrete filled steel tube makes use of the interaction between steel tube and recycled aggregate concrete to make up for the shortcomings of recycled aggregate

concrete performance, achieve complementary advantages, and provide an effective way for waste concrete resourcing. However, the bonding performance, seismic performance and durability of Recycled Aggregate Concrete Filled Steel Tube are rarely studied in depth, thus laying a theoretical foundation for the promotion of the wide application of this combined structure in actual projects. The solution of the above problems as soon as possible will lead to the formation of technical regulations for recycled aggregate concrete filled steel tube, which will make a greater contribution to the reuse of waste concrete and the sustainable development of resources.

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