International Journal of Infrastructure Research and Management
Vol. 12 (2), December 2024, pp. 25 - 34

STUDY ON THE INFLUENCE OF COARSE AGGREGATE TYPES ON THE BONDING PROPERTIES OF HIGH-STRENGTH CONCRETE-FILLED STEEL TUBE

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ABSTRACT

This paper presents the results on the influence of coarse aggregate types on the bonding properties of high strength concrete filled steel tube. In order to study the difference of interface bonding properties between square and circle steel tube high-strength concrete with different coarse aggregate types, a total of 18 specimens were designed and prepared for steel tube push-out tests. The variation parameters of concrete strength grade, coarse aggregate type and steel tube section shape are mainly considered for the tests. Through the experiments, the failure patterns of samples are observed, analyzed and recorded. The load-displacement curve and characteristic point parameters are sketched and analyzed too. Whereas the factors affecting the failure process and bonding properties of the concrete-filled steel samples are studied. The results show that for square specimens, the ultimate bond strength and residual bond strength of natural crushed stone specimens are the largest, and the residual bond strength of crushed pebble specimens is the smallest. For circle specimens, the ultimate bond strength of natural crushed stone specimens is the highest, and that of crushed pebble specimens is the least. Under the condition that the bond area is close to the same (the difference of bond area of specimens is less than 10%), the ultimate bond strength of the square specimen is mostly higher than that of the circle specimen, and the residual bond strength of the circle specimen is higher than that of the square specimen. Thus, it can be concluded that the ultimate bond strength and residual bond strength are vary depending on the concrete strength grade and coarse aggregate types.

Keywords:
Coarse aggregate type; concrete filled steel tube; bond property

INTRODUCTION

As a kind of structural material, concrete filled steel tube (CFST) has the advantages of high strength, excellent durability, good resistance to wind and earthquake, etc., and has been widely used in the field of construction engineering and infrastructure. Moreover, the characteristics of large heat capacity and good thermal insulation performance of concrete filled steel tube can effectively reduce the energy consumption of buildings, improve the energy-saving performance of buildings, and meet the requirements of modern buildings for energy conservation and environmental protection. In recent years, the application of concrete filled steel tube in the field of energy saving and environmental protection buildings has gradually increased. With the continuous development of science and technology and the progress of engineering technology, the application prospect of concrete-filled steel tube in the future will be broader. In addition, there is a need to investigate the influence of coarse aggregate types of high strength concrete filled steel tube due to limited source of knowledge available.

The bond mechanism of concrete-filled steel tube (CFST) is complicated, there are many uncertain factors affected by various parameter variables, and different types of concrete materials have different bond properties. In recent years, scholars have conducted a lot of research on the bonding properties of concrete-filled steel tube specimens of different types of concrete materials, such as ordinary concrete (Norul Wahida et al, 2023a; Wang et al., 2022), recycled aggregate concrete (Norul Wahida Kamaruzaman, 2023b; Chen et al., 2022; Lyu & Han, 2019; Zhao et al., 2021), high-strength concrete (Cao et al., 2023; Dong et al., 2020a, 2020b), steel fiber concrete (Li et al., 2020; Lu et al., 2018; Kong

Linjie, 2023), machine-made sand concrete (Guan et al., 2019; SHA Meng et al., 2023), ultra-high performance concrete (Xie et al., 2023), etc., and obtained rich test results, which laid a good foundation for promoting the application of concrete-filled steel tube.

However, as a common natural material in nature, there are few researches on the bonding properties of concrete-filled steel tube (CFST), and their application scope is relatively small. At present, the pebbles and crushed pebbles in the river are mainly made into sand by machine production and applied in the engineering field. In addition, the application of filler materials with roadbed engineering, construction of horticultural roads and landscaping works. These engineering application scenarios are far from giving full play to the advantages of pebbles and crushed pebbles. In this paper, based on the performance advantages of concrete-filled steel tube composite structure, in order to expand the application scenarios of pebbles and crushed pebbles, crushed pebbles, natural pebbles and natural gravel are taken as coarse aggregates, and the bonding properties of concrete-filled steel tube specimens made of different coarse aggregates are compared to provide references for expanding their application scope.

METHODOLOGY

The design of the specimen takes into account three parameters: coarse aggregate type (crushed pebble, natural pebble, natural stone), concrete strength grade (C65, C75, C85), and steel tube section shape, according to the principle of approximately equal bonding area (the difference of specimen bonding area is less than 10%). 18 specimens of square and circle straight welded steel tubes with different side lengths and diameters were selected for testing. Steel tube length 400mm, thickness 4mm. The upper and lower ends of the steel tube are determined as the loading end and the free end. A 50mm space is reserved at the free end without pouring concrete, and a 10mm wide notch is opened by mechanical machining. The steel sheet is consolidated with the internal concrete through the notch as a whole, which is used as a measuring point for measuring the slip amount of the free end concrete.

Figure 1: Coarse aggregate used in the test

Push-out test

RMT-301 rock and concrete mechanics test system was used to load the specimens. In order to obtain the load slip curve of the whole process of the test, the test adopts the displacement-controlled loading system, and the loading rate is 0.3mm/min. When the test load reaches about 10mm at the free end, the load does not change significantly, and the test is considered to be over.

ANALYSIS

Test phenomena

After the formal loading starts, the loading end and the free end of the steel tube specimen slip almost simultaneously. At the initial stage of loading, with the increase of load, the slippage keeps increasing, and the relationship between load value and slippage is almost linear. The slip rate of the loading end is faster than that of the free end, and the slip amount is larger. During the sliding process of the specimen, the sound of concrete crushing like electrostatic "squeaking" is emitted from time to time. At this point, the load rises rapidly. With the further increase of slip and load, the natural pebble and crushed pebble specimens will break out the "dong dong" sound, and the "dong dong" sound of natural pebble specimens is larger than that of crushed pebble specimens. The "thumping" sound of the square steel tube specimen is larger than that of the crushed pebble specimen. The natural gravel specimen did not make a "knock" sound. After that, the load peak point (square specimen) or inflection point (circle specimen) appeared, and the load value and slip amount showed a nonlinear relationship, the load value of the square specimen appeared a decreasing stage, the circle specimen remained stable or increased slightly, and the slip difference between the loading end and the free end gradually decreased until the synchronization was maintained, and the core concrete was pushed out. After the loading was finished, the loading pad was removed, and it was observed that the core concrete at the loading end was concave inward, and the concrete "crushed" occurred along the loading pad, the outer wall of the steel tube did not bulge significantly outward, and the hollow part of the steel tube at the free end did not buckle.

Load-slip curve

Figure 2 shows the load-slip curve of square and circle representative specimens. It can be seen that the curves of the loading end and the free end are approximately the same. Summary and analysis of curve characteristics and reference results (KE Xiaojun et al., 2015; SHA Meng et al., 2023; Wang et al., 2022; XU Jinjun et al., 2013), the curve can be simplified into a fast-rising section, a falling section (an inflection point rising section) and a horizontal section.

Straight ascending section

In the process of pushing out the specimen, the slip first occurs at the loading end of the specimen and gradually develops to the middle and free end of the specimen with the increase of the load. The interface bonding force is composed of chemical bonding force, mechanical biting force and friction force on the contact interface. Because the dry shrinkage of high strength concrete is larger than that of ordinary concrete, the chemical bonding force is smaller. At the initial stage of loading, the adhesive force is mainly provided by chemical bonding force and mechanical biting force. With the increase of slip, the chemical bonding force is gradually lost, and the mechanical bite force and friction force between the interfaces are gradually increased. When the combined force reaches the maximum, the pushing load reaches the ultimate load.

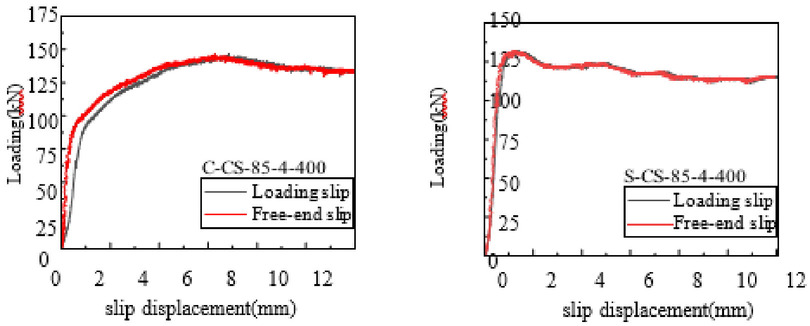

Figure 2: Load-displacement curves of specimens

Down section (inflection point up section)

When the ultimate load is reached, the steel tube wall is squeezed by the core concrete and tends to bulge outwardly. If the steel tube wall has insufficient action on the concrete hoop, and it bulges outwards, the mechanical biting force and friction resistance will decrease. The effect of square specimen on concrete hoop is weaker than that of circle specimen. For this reason, the bond strength of the square specimen decreases, and the load-slip curve of the circle specimen shows a declining section, while the load-slip curve of the circle specimen shows a slightly stable rising section, but the slope of the curve decreases gradually.

Horizontal segment

With the continuous loading, the interface bonding force is mainly balanced by friction resistance and tends to be stable, and the load-slip curve is horizontal or close to the horizontal line. Characteristic value of load-slip curve

See the literature (Shakir-Khalil H, 1993; Virdi & Dowling, 1980), combined with the literature (CHEN Zongping & ZHOU Ji, 2020), defined the interfacial shear stress corresponding to Pu and Pr as the ultimate bond strength τu and the residual bond strength τr Based on load-slip curve, test characteristic values of specimens are shown in Table 1 and Table 2. Among them, the load value corresponding to the peak point of the curve is the ultimate load Pu, and that corresponding to the approximate horizontal segment is the residual load Pr.

Table 1: Test characteristic values of square concrete-filled steel tube specimens

Specimen number	P_u/kN	P_r/kN	τ_u/MPa	τ_r/MPa
S1	96.54	91.29	0.62	0.58
S 2	112.38	83.61	0.72	0.53
S 3	100.92	81.54	0.64	0.52
S 4	140.28	72.18	0.89	0.46
S 5	113.52	94.14	0.72	0.60
S 6	100.95	91.29	0.64	0.58
S 7	119.52	94.83	0.76	0.60
S 8	132.69	113.58	0.85	0.72
S 9	137.64	104.01	0.88	0.66

The design requirements for the interface bond strength of concrete filled square steel tube are different in different countries and regions. Japan AIJ requires that the bond strength of rectangular concrete-filled steel tube is 0.15MPa (Recommendations for Design and Construction of Concrete Filled Steel Tubular Structure, 1997); The British BS5400 (Steel Concrete and Composite Bridges: Part 5: Code of Practice for the Design of Composite Bridges: BS 540025: 2005, 2005) and the European EC4 (Eurocode 4: Design of Composite Steel and Concrete Structures: Part 1-1:General Rules and Rules for Buildings: BS EN 1994-1-1:2004, 2004) both stipulate that its value is 0.40MPa. It can be seen from Table 1 that τu and τr of square tubular high-strength concrete with different coarse aggregate types meet the requirements of relevant specifications.

Table 2: Test characteristic values of circle concrete-filled steel tube specimens

Specimen number	P_u/kN	P_r/kN	τ_u/MPa	τ_r/MPa
C1	73.95	105.51	0.45	0.64
C 2	81.57	142.89	0.49	0.86
C 3	71.655	170.86	0.51	0.81
C 4	104.19	141.66	0.63	0.85
C 5	92.13	138.84	0.55	0.84
C 6	87.6	125.67	0.53	0.76
C 7	143.58	149.7	0.86	0.90
C 8	98.58	136.98	0.59	0.83
C 9	86.31	139.59	0.52	0.84

There is no uniform design standard value of bond strength between circle steel tube and concrete interface in the world, such as the design value in Asia is 0.225MPa (Recommendations for Design and Construction of Concrete Filled Steel Tubular Structure, 1997), and the design value in Europe is 0.40 MPa (Eurocode 4: Design of Composite Steel and Concrete Structures: Part 1-1: General Rules and Rules forBuildings: BS EN 1994-1-1:2004, 2004. It can be seen from Table 2 that τ_u and τ_r of circle tubular high-strength concrete with different coarse aggregate types meet the requirements of relevant specifications.

ANALYSIS OF INFLUENCING FACTORS OF BONDING PROPERTIES

Influence of coarse aggregate type on the bonding properties of square steel tube specimens

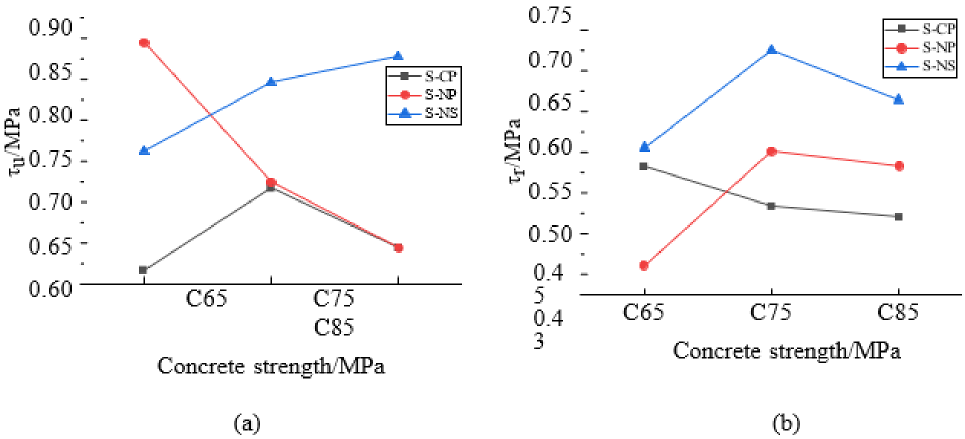

Figure 3: Influence of coarse aggregate type on the bonding properties of square steel tube specimens

The type of coarse aggregate has significant influence on the bonding properties of square specimens. It can be seen from Figure (a) that the ultimate bond strength of the natural gravel specimen is the largest, while that of the crushed pebble specimen is the smallest. The ultimate bond strength varies with the change of coarse aggregate type. When crushed pebbles are used as coarse aggregate, the ultimate bond strength increases first and then decreases with the increase of concrete strength grade, and the difference between the minimum value and the maximum value is 16.4%. When natural pebble is used as coarse aggregate, the ultimate bond strength decreases with the increase of concrete strength grade, and the difference between minimum and maximum value is 39.0%. When natural gravel is used as coarse aggregate, the ultimate bond strength decreases with the increase of concrete strength grade, and thedifference between the minimum value and the maximum value is 15.2%.

It can be seen from Figure (b) that the residual bond strength of the natural gravel specimen is the largest, while that of the crushed pebble specimen is the smallest. There are two different changes of residual bond strength with the change of coarse aggregate type. When crushed pebbles are used as coarse aggregate, the residual bond strength decreases with the increase of concrete strength grade, and the difference between the minimum and maximum value is 12.0%. When natural pebbleand natural gravel are used as coarse aggregate, the residual bond strength increases first and then decreases with the increase of concrete strength grade, and the difference between the minimum value and the maximum value is 30.4% and 19.8%,respectively.

Influence of coarse aggregate type on the bonding properties of circle steel tube specimens

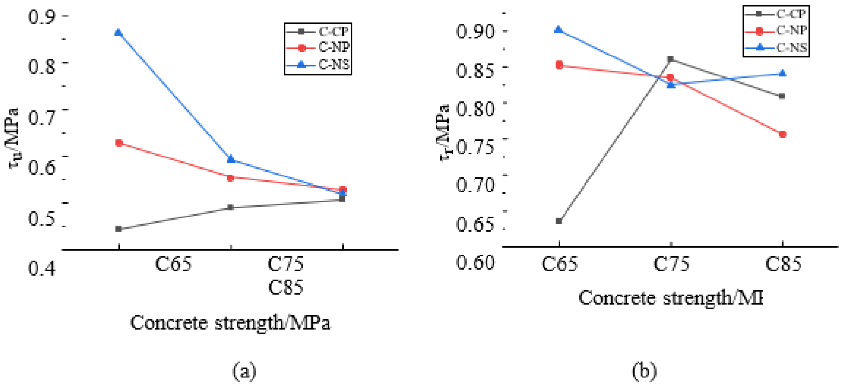

Figure 4: Influence of coarse aggregate type on the bonding properties of circle steeltube specimens

It can be seen from the figure that the type of coarse aggregate has a significant effecton the bond performance of the circle specimen. It can be seen from Figure (a) that the ultimate bond strength of the natural gravel specimen is the largest, while that of the crushed pebble specimen is the smallest. The ultimate bond strength varies with the change of coarse aggregate type. When crushed pebbles are used as coarse aggregate, the ultimate bond strength increases with the increase of concrete strength grade, and the change range of maximum and minimum values is only 14.0%. When natural pebbles and natural gravels are used as coarse aggregates in the concrete filled steel tubes, the ultimate bond strength of the concretes were decreases with the increase of concrete strength grade. The maximum and minimum values change by 18.9% and 66.4%, respectively. It can be seen from Figure (b) that the variation law of residual bond strength with coarse aggregate type is relatively discrete, and the variation law of specimens with various coarse aggregate types is different. The residual bond strength of crushed pebble specimens varies greatly with the strength grade of concrete, up to 35%. The residual bond strength of natural pebble and natural gravel specimens varies little with the strength grade of concrete, and the range is less than 10%.

Influence of coarse aggregate type on the bonding properties of steel tube specimens with different section shapes

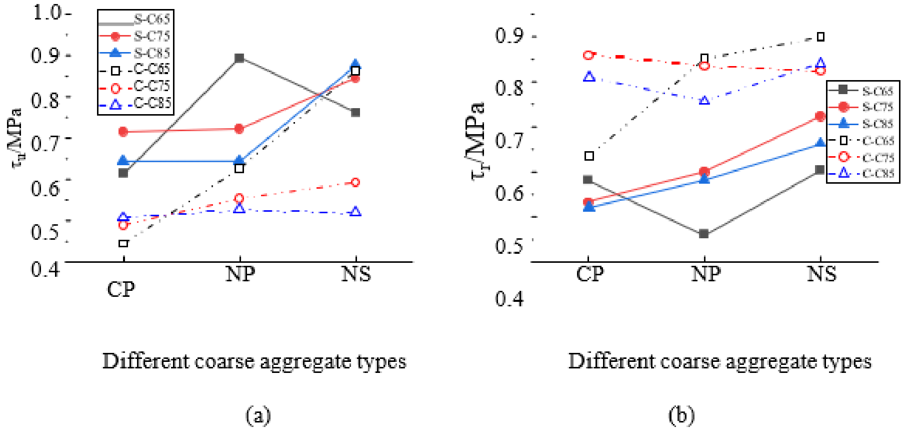

Figure 5: Comparison of bonding properties of steel tube specimens with different sections by coarse aggregate type

It can be seen from Figure (a) that the ultimate bond strength of square specimens is mostly higher than that of circle specimens for different coarse aggregate types. With the change of different coarse aggregate types, the limit bond strength of square and circle specimens is relatively discrete, and there is no obvious law to follow. It can be seen from Figure (b) that the residual bond strength of the circle specimen is higher than that of the square specimen for different coarse aggregate types. The residual bond strength of the square specimen generally increases with the change of the coarse aggregate using crushed pebble, natural pebble and natural stone, while the change of the circle specimen is more discrete and there is no obvious rule to follow.

CONCLUSION

For square specimens, the ultimate bond strength and residual bond strength of natural crushed stone specimens are the largest, and the ultimate bond strength and residual bond strength of crushed pebble specimens are the smallest. Whereas, for circle specimens, the ultimate bond strength of natural crushed stone specimens is the largest, and that of crushed pebble specimens is the smallest. Under the condition that the bond area is close to the same (the difference of the bond area of the specimens is less than 10%), the ultimate bond strength of the square specimen is mostly higher than that of the circle specimen, and the residual bond strength of the circle specimen is higher than that of the square specimen. For square and circle specimens, the ultimate bond strength and residual bond strength vary discretely with the concrete strength grade and coarse aggregate type.

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