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# A REVIEW OF A CURRENT RESEARCH ON THE BONDING PROPERTIES OF CONCRETE-FILLED STEEL TUBES

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## ABSTRACT

This paper is presenting the theory and experimental results on the bonding performance of the concrete-filled steel tube (CFST) at global perspective. It is introducing the bonding mechanism of steel tube concrete with the overview of the updated status on the performance of it towards bond strength, analyzes and compares its main influencing factors methodologically. The data is gathered in the industrial usage and compared with the previous studies done by the previous researches to examine the real factors and characteristics with the bonding strength targeted. The results show that the width-thickness ratio is o of the main factors contributing to the bond strength. In general, width-to-thickness ratio is negatively correlated with the bond strength where the steel tube interface structure is helping the improvising of the bond strength. There is a negative correlation between the width-to-thickness ratio and bond strength. This paper is also highlights the pivotal role of structural configuration at the steel tube of the bond strength. There are main aspects that contribute to the bond strength such as concrete strength, concrete age, specimen dimension, slenderness ratio and other aspects. Further investigation needs to be carried out to consolidate existing information on the bonding strength and to understand the complexities involved in CFST bonding performance. In conclusion, this paper emphasizes the needs of research to be conducted to have deepen understanding and to enhance the practical applications of CFST technology and indirectly contributing to the advancements in structural engineering and construction technology applications. It is also an opportunity for researchers to investigate further the real potential of CFST technology in various branch of civil engineering.

**Keywords:**
*Concrete-filled steel tube, bonding property, bonding mechanism, bond strength, structural engineering technology*

## INTRODUCTION

As a structural form with excellent performance, concrete-filled steel tube (CFST) is a combination structure composed of steel tube and concrete, which has the advantages of high bearing capacity, good seismic performance, good plastic toughness, low engineering cost and easy construction. It can well adapt to the development trend of modern building construction (Miss Basori Bano, 2023). It can meet the needs of the development of engineering structures to long span, tall and heavy loads and withstand harsh conditions. At present, it has been widely used in structural engineering such as industrial plant, high-rise building, bridge engineering, port engineering and underground engineering (Kong Linjie and Norul Wahida Kamaruzaman, 2023).

CFST is a state of synergy between steel tube and concrete. The concrete inside the steel tube is restricted by the outer steel tube, which delays the crack development and improves the compressive strength of the concrete under three-way compression. Concrete plays a supporting role on the steel tube, so that the defects of the steel tube structure are easy to bend are improved, and the stability of the steel tube is improved. The interface bond strength of steel tube and concrete is a key factor that affects the long-term working behavior of CFST structures and their collaborative work. However, in practical application, the effect of bond strength is often ignored or weakened. In addition, it is difficult to accurately measure the slip and interface stress before the interface in the test process, and the test results are quite different. At present, the theoretical and experimental research of CFST structure is still controversial, and the theory and method are not perfect and unified.

## CONCRETE FILLED STEEL TUBE BONDING MECHANISM

The interface shear bonding force of steel tube and concrete is similar to that of steel bar and concrete (Xue & Cai, 1996a, 1996b), which is mainly composed of three parts, namely, chemical bonding force, mechanical biting force and friction force.

(1) Chemical bonding force: The effect of chemical bonding force is small, and it has a greater relationship with the nature of concrete, such as the amount of cement, water-cement ratio, etc., have an impact on it. It was found that the chemical bonding force of CFST accounted for about 5% of the shear bonding force (Qu et al., 2013; Xue & Cai, 1996a).

(2) Mechanical biting force: the inner surface of the steel tube is often rough and uneven, and the degree of roughness is very small (Xue & Cai, 1996a), about 10-2 mm, which can be called "microscopic deviation". The mechanical bite force is generated by the microscopic deviation and the concrete wedged into it. When the inner surface of the steel tube is not oiled, the bonding strength of the specimen is twice that of the oiled specimen, while the bonding strength of the specimen after mechanical grinding and rust removal is only about 53% of that of the specimen without rust removal (Shakir-Khalil, 1993; Shakir-Khalil H, 1993).

(3) Friction: Unlike reinforced concrete, the expansion of core concrete will produce extrusion pressure at the interface, thereby increasing the interface friction, that is, the friction will change with the constraints of the steel tube and the stress stage. The friction force is closely related to the micro deviation, macro deviation and concrete deformation, and together with the mechanical bite force, it bears about 95% of the bonding stress (Xue & Cai, 1996b). Among them, (Virdi & Dowling, 1980) put forward the concept of "macro deviation", due to manufacturing process and other reasons, the diameter of the steel tube at different sections will always have a deviation, this macro deviation is difficult to accurately predict, which determines the size and development of interface friction to a certain extent.

## RESEARCH STATUS OF CEMENTING PROPERTIES OF CONCRETE-FILLED STEEL TUBE

### *BONDING PROPERTIES OF CONCRETE-FILLED STEEL TUBE WITH DIFFERENT TYPES OF CONCRETE MATERIALS*

With the development of society, continuous progress of science and technology and deepening of construction industrialization, the continuous development of new materials such as aggregate for concrete are diversified, such as recycled aggregate concrete, fiber concrete (Hou Zhicheng & Norhaiza Nordin, 2022), granite and Beranang laterite aggregate concrete (Norul Wahida et al., 2023). However, concrete made of different aggregates has different bonding and sliding properties.

### *BONDING PROPERTIES OF ORDINARY CFST*

Pull out test of circular CFST has been carried out by (Virdi & Dowling, 1980), with concrete strength, interfacial bonding length, concrete age and interfacial treatment as the main parameters The pullout test of circular CFST was carried out, with concrete strength, interfacial bonding length, concrete age and interfacial treatment as the main parameters. The experimental results show that the concrete strength and interfacial bond length have less influence on the interfacial bond strength, and the interfacial bond strength decreases with the prolongation of concrete age and the increase of lubricant. Another research conducted by (Morishita Y & Tomii M, 1979) in which the section type of steel tube and the strength of concrete were used as the research parameters to carry out the test of CFSTThe section type of steel tube and the strength of concrete were used as the research parameters to carry out the test of CFST. The experimental results reveal that the bond strength of CFST is significantly affected by the section type, and the bond strength of CFST with circular section is obviously higher than that with square section. (Shakir-Khalil H, 1993) tested 56 specimens and the main parameters included section type, shear connector type, loading method, etc. The results revealed that the interface bond strength of round steel tubular concrete was higher than that of rectangular CFST. The addition of shear connectors or welded supports will produce extrusion effect and construction effect, which can effectively improve the interface bond strength. (Roeder C W et al., 1999) studied 20 large size steel tube concrete specimens and the test reveals that the concrete strength of the bond strength of the influence of the law is not obvious; for the curing age of 28d specimens, its diameter and thickness ratio changes on the bond strength of the influence is not obvious, while the age of more than 28d specimens due to the greater shrinkage of the concrete, the bond strength will be with the diameter and thickness ratio increases and decreases. According to the previous researchers, (Aly et al., 2010), the influence of loading regime, concrete strength and age as variation parameters on the bond strength of steel tube concrete was investigated. The test results show that the bond strength decreases with the use of high-strength concrete components compared to ordinary concrete components. The age period was within 100 days and there was a slight decrease in the bond strength with increase in time. Wu Jian-bin et al. (2007) conducted nine square specimens which were designed to be tested with the variation parameters of width-to-thickness ratio (w/t) and length-to-thinness ratio (l/t) of the members, and the test results revealed that the w/t was negatively correlated with the bond strength, while the increase of the l/t basically did not change the bond strength. Whereas KANG Xi-liang (2008) has worked on nine specimens which were designed for testing with the change parameters of l/t, diameter to thickness ratio (d/t), and steel content, to study the size of bond strength and slip on the interface between the steel tube interior and concrete and its change rule. The test results show that in a certain range, the bond strength increases with the increase of the l/t (12.58~17.61), and then decreases with the increase of the l/t (17.61~22.64); when the d/t varies from 28.91 to 39.75, the bond strength decreases with the increase of the d/t of the member; the bond strength increases with the increase of the steel content rate.

On the other hands, Liu Yong-Jian et al. (2010) studied regarding the longitudinal shear bond properties of 20 square and circle CFST specimens by using length-diameter ratio (l/d) and d/t as parameters. The experimental results show that the interfacial bond - slip curves of square and circle CFST specimens have similar variation rules, and the interfacial shear bond strength of circle CFST specimens is greater than that of square CFST specimens. The bond strength increased slightly with the increase of concrete age, increased with the increase of l/d, and decreased with the increase of d/t. However, the effect of concrete strength on bond strength was not significant. Xu Kaicheng et al. (2011) studied seven specimens which were designed to carry out the test by applying different proportions of butter on the inner surface as a variation parameter to obtain the magnitude and composition of the adhesion between the steel tube and the concrete. The results show that the interfacial bonding force of CFST is composed of chemical bonding force, mechanical biting force and friction force. The chemical bonding force is small and disappears immediately when there is relative slip between steel tube and concrete. Mechanical bite force accounts for 20%~30% of interface bonding force. The friction force is the main part of the interface bonding force. The average bonding strength between the inner wall of the untreated steel tube and the concrete interface is 1.2-1.3 MPa. With the increase of the ratio of the inner wall of the steel tube to the concrete, the interface bonding strength gradually decreases. Only friction exists on the interface of CFST members with all interface disadhesion, and the average bonding strength is 0.3 ~ 0.4MPa. Xu Kaicheng et al. (2012) also conducted a research consisted of nine square specimens that were designed to carry out tests with the parameters of w/t and water-cement ratio (W/C), and the results showed that the w/t and W/C were negatively correlated with the interfacial bonding strength; the ultimate bonding strength increased significantly with the increase of the wall thickness of the steel tube; and the stress and strain at the loaded end of the steel tube were always the largest and grew rapidly with the increasing of the external loads.

### *BONDING PROPERTIES OF NEW CONCRETE MATERIAL CFST*

Ke Xiaojun et al. (2015) have conducted research on the four high-strength CFST specimens were designed with concrete strength and CFST bonding length as research parameters. The results show that the bond strength between steel tube and concrete increases with the increase of concrete strength and bond length. Whereas another researcher, Wu Bin et al., (2020) have conducted another concrete bond-slip properties of circular and square red mud CFST with four varying parameters: red mud substitution rate, concrete strength, l/d ratio (embedment length) or w/t ratio, and d/t ratio. The results show that the bond limit load increases with the increase of concrete strength and steel tube l/d ratio, decreases with the increase of w/t ratio (d/t ratio), but increases first and then decreases with the increase of red mud substitution rate. Xu Jinjun et al. (2013) have been using the recycled coarse aggregate replacement rate, concrete strength grade and l/d ratio as the variation parameters for four groups of 15 circular steel tube recycled concrete specimens which were designed for various type of testing. The test results revealed that the development of interfacial bond damage advanced with the increase of recycled coarse aggregate substitution rate; the increase of interfacial embedment length was favorable for its bond-slip energy dissipation. When the l/d ratio was in the range of 1.86-2.93, the peak loads of the specimens with larger l/d ratios were all larger than those with smaller l/d ratios. Chen Zongping et al. (2013) has been investigated a group of twenty-five circular and square steel tube recycled concrete short column specimens which were designed for launching tests with five varying parameters: specimen cross-sectional form (circular and square), recycled coarse aggregate substitution rate, concrete strength grade, l/d ratio, and interface embedment length. The results show that the bond strength decreases with the increase of l/d ratio, and the bond performance of circular specimens is better than that of square specimens. For the square specimens, the bond strength increased slightly with the increase of substitution rate and concrete strength; for the circle specimens, the change of aggregate substitution rate caused a certain fluctuation of the bond strength. Guan et al. (2019) were taking the type of stone (limestone or pebble) used for sand production, the ratio of steel tube d/t, the compressive strength of concrete (C60, C80, C100), and the content of stone dust as the varying parameters, 27 specimens of CFST with mechanism sand were designed to carry out the launching test. The test results reveal that the bond strength of the mechanism sand specimens is higher than that of the natural sand specimens, the limestone mechanism sand specimens are slightly higher than the pebble mechanism sand specimens, and the bond strength decreases with the increase of the d/t ratio of the steel tube; for the mechanism sand specimens, the stone powder content has a small effect on the bond strength, and there is no uniform pattern of the effect of the concrete strength on the bond strength. Meanwhile Sha Meng et al. (2023) used sixteen specimens which were designed with the strength grade, stone powder content and steel tube w/t ratio as changing parameters. The research results reveal that the bonding strength of square steel tube limestone sand specimen is higher than that of square steel tube pebble sand specimen. The average bonding strength of square steel tube limestone sand specimen is 5.2% higher than that of pebble sand specimen, and the minimum increase is 1.2%. The largest increase was 13.7 percent. On the other side, Wang Qiuwei et al. (2022) have used eighteen square steel tube UHPC specimens which were designed with steel tube w/t ratio, height-width ratio and UHPC strength as the variation parameters to carry out the launching test. The test results reveal that the bond strength decreases with the increase of w/t ratio and height-width ratio, and when the w/t ratio is larger, increasing the UHPC strength can obviously improve the bond strength; establish the calculation model of the bond strength of square steel tube UHPC under two kinds of maintenance conditions, and the theoretical calculations are in line with the experimental data.

Another group of researchers, Lyu and Han (2019) have tested a total of 56 specimens of recycled aggregate CFST. The test was carried out with the parameters of section type (square, round), section size, RAC strength, regenerated coarse aggregate replacement rate, interface treatment (oil injection, polishing) and so on. The test results show that the section type and size are the two main factors affecting the bonding strength of steel tube and recycled concrete. The bonding behavior of recycled CFST specimens is similar to that of the inner wall of steel tube and the surface of CFST, and the replacement rate of recycled coarse aggregate has no significant effect on the bonding strength of specimens. An empirical formula for calculating the bond strength between core concrete and steel tube is presented. Another group of researchers, Lu, Liu, Li, & Tang (2018) conducted thirty-six FSSCFST specimens which were designed with concrete age (28 days and 2.5 years), steel tube thickness (2.5mm, 3.5mm, 4.25mm), and steel fiber volume percentage (0% and 1.2%) as parameters. The results show that the bond strength and slip amount of specimens increase with the increase of concrete age. The addition of steel fiber can improve the adhesion of the specimen at the early stage, but its effect gradually disappears with the increase of age. The bond strength in the same direction decreases with the increase of loading period, but the steel fiber can delay the bond strength reduction. Based on Lu, Liu, Li, & Li (2018), a total of 90 specimens which were designed with the parameters of concrete type, steel tube thickness, concrete strength and steel fiber volume percentage were tested. The results show that the bond strength of FSSCFST specimens is generally higher than that of self-compacting CFST specimens, and its value is between 0.50 and 2.51 MPa. For SCCFST and FSSCFST specimens, the bond strength increases with the increase of concrete strength or steel tube thickness, and decreases first and then increases with the increase of steel fiber volume content. The bond strength of CFST specimens can be significantly improved by self-stress, with an average increase of 42.7%. whereas Tao et al. (2016) have conducted testing with a total of twenty-four specimens which were designed to carry out the experimental study with varying parameters of section size, steel tube material, concrete type, concrete age, and interface type. The results show that the bond strength of stainless-steel tube members is lower than that of carbon steel tube members and decreases significantly with the increase of section size and concrete age. Among the different interface types, the welded inner ring on the inner surface of the steel tube is the most effective method to improve the bond strength, followed by welded shear studs. The use of expanded concrete was also effective in improving the bond strength.

## *BONDING PROPERTIES OF CONCRETE-FILLED STEEL TUBE FOR NEW PIPES*

With stainless steel instead of carbon steel, the binding strength is reduced by 32% to 69% (Tao et al., 2016). This is mainly due to the low surface roughness of stainless steel. On the other hands, Cao et al. (2023) have designed twelve UHPC-FHSST specimens with concrete strength, l/d ratio and d/t ratio as changing parameters. The results show that the bond strength of HSST and UHPC decreases with the increase of d/t ratio, l/d ratio and concrete strength. Other researchers, Wang Zhengzhen et al. (2019) have designed four groups of 19 specimens for testing. The bonding properties of FRP tubular concrete piles and CFST piles were compared according to the bonding methods (direct bonding, internal screw threads, internal shear parts and composite joint specimens), concrete types (ordinary concrete and expanded concrete), slenderness ratio of specimens and outer tube wall thickness. The results show that the bond strength of CFST specimens is obviously greater than that of FRP tube specimens under the same test conditions. Using expansive concrete, increasing the l/d ratio of the specimen and increasing the wall thickness of the outer tube can improve the bonding strength of the specimen, but the effect of using expansive concrete is the most obvious, which can increase the bonding strength by nearly 10 times. Different bonding methods can improve the bonding strength of FRP tube concrete specimens. Recent research conducted by Luo Peiyun et al. (2021)

used the orthogonal test method to design 9 specimens of welded CFST with d/t ratio, concrete strength and interfacial bonding length as parameters. The test results show that the factors affecting the bond strength and ultimate bond strength are, in order of priority, the d/t ratio of the steel tube, the concrete strength, the interfacial bond length, and the bond strength and ultimate bond strength decrease significantly with the increase of the d/t ratio of the steel tube and increase with the increase of the concrete strength.

Fourteen specimens were designed with the ratio of section W/t, concrete strength, type of ribbed reinforcement and grade of stainless steel as varying parameters by Dai et al. (2022). The results show that the ratio of section W/t, the strength of concrete and the grade of stainless steel have significant effects on the ultimate bonding stress of the specimens. In addition, Han et al. (2022) were regenerated the stainless steel tube where the concrete specimens bond slip test is carried out, and its results show that with CFST specimens, the bond strength of stainless steel tube regenerated concrete specimens is lower, which is mainly due to the smooth surface of stainless steel tube, and the larger shrinkage and deformation of core concrete. At the same time, the formula for calculating the bond strength of stainless steel tube regenerated concrete specimens is proposed, and a finite element model is established for comparison and verification. Previous researchers, Y. Chen et al., (2017) were used height-to-diameter ratio, D/t ratio and concrete strength as changing parameters, 32 stainless steel hollow steel tube specimens were designed to carry out repeated push-out tests. The results reveal that the shear failure load decreases gradually with the increase of repeated push-out tests. The ratio of height to diameter, ratio to D/t and strength of concrete have no significant effect on shear resistance. The comparison also shows that the existing rules on bond strength of carbon CFST design code are not applicable to stainless steel CFST specimens. Song et al., (2023) were designed fifteen specimens with the target temperature, high temperature duration, elliptic section length and section type (ellipse, circle and square) as the variable parameters. The results show that high temperature and its duration have a significant effect on the post-fire bond strength of the specimens, and the post-fire bond strength of the specimens increases with its increase. The bond strength of elliptical specimens is generally lower than that of circle and square specimens when the same concrete strength grade and interface contact area are equal.

## *BONDING PROPERTIES OF CONCRETE-FILLED STEEL TUBE UNDER SPECIAL CONDITIONS*

Z. Chen et al. (2022) were designed a total of 40 samples (20 round and 20 square columns) with different high temperature, mass replacement rate of regenerated coarse aggregate and cross-section shape as research parameters. The results show that high temperature and mass replacement rate of regenerated coarse aggregate have different degrees of influence on bonding behavior and interface damage resistance. By analyzing the bond property and interface damage resistance, it is found that the round specimen is generally stronger than the square specimen. Previous researchers, Chen Zongping et al., 2017) were using the concrete strength, temperature and anchoring length as parameters, 17 samples of high-strength square CFST were designed to carry out high-temperature tests. The results show that the bond strength is inversely proportional to the anchoring length, and increases first and then decreases with the increase of constant temperature. With the increase of constant temperature, the development of adhesive damage of the specimen is late and slow. The energy dissipation capacity of interfacial bonding increases with the increase of concrete strength and decreases with the increase of ergodic temperature. Previous researchers (Chen Zongping et al., 2020; Chen Zongping & Zhou Ji, 2020) were designed a total of 44 steel tubular high-strength concrete specimens (22 circle and 22 square) with the varying parameters of concrete strength, maximum temperature, anchoring length, constant temperature duration and cooling method. The results show that with the increase of the maximum temperature, the interface bonding properties of the two types of steel tube specimens are significantly different after cooling by water spray at high temperature, and the performance indexes of the circular steel tube specimens are better than that of the square steel tube specimens. The bond strength of the square specimen is more affected by the constant temperature time and increases with the constant temperature time. With the increase of anchoring length, the interface bond strength decreases, which has greater influence on the shear bond stiffness and energy dissipation capacity of the circle specimen. The shear bond stiffness of the specimens with two types of cross section is opposite. Compared with the naturally cooled specimens, the water-cooled specimens have lower bond strength and shear bond stiffness, and better energy dissipation capacity. Increasing the strength of concrete can improve the bond strength. Based on fire exposure time, section type, section size, interface L/D (L/W) ratio, concrete type, fly ash type and concrete curing conditions, 64 specimens were tested (Tao et al., 2011). The results show that fire has a significant effect on bonding strength. After 90 minutes of fire exposure, it is usually observed that the bond strength of the specimens decreases. However, when the exposure time was extended to 180 minutes, the bond strength recovered somewhat. Other researchers, Parsa-Sharif et al. (2023) used the exposure temperature, L/D ratio, D/t ratio, grade of cementing material and type of concrete (pumice lightweight concrete and ordinary concrete) as the research variables to carry out an experimental study on pumice lightweight CFST members. The results show that at 200℃, 400℃ and 600℃, the bonding capacity of light CFST specimens remains relatively unchanged (negligible increase or decrease), and decreases by 84% and 94%, respectively. The bond strength increases with the increase of L/D ratio and decreases with the increase of D/t ratio. In most high temperature environments, high water-cement ratio test parts have greater bonding strength; At a high temperature of 600℃, the bonding capacity of ordinary concrete specimens is about 8 times that of light concrete specimens. Chen Jun et al. (2018) highlighted that the main parameters, such as constant temperature, L/D ratio and D/t ratio, were used to test specimens at constant high temperature. The results show that the average bond strength is significantly affected by constant temperature in the study range of 20℃~900℃. The average bond strength decreases first, then increases and then decreases with the increase of constant temperature, and the decrease range is up to 90%. The average bonding strength decreases with the increase of L/D ratio, and the decrease range is up to 50%. The D/t ratio has little effect on the average bonding strength, and the reduction range is less than 10%. Bahrami & Nematzadeh (2021) presented that the bonding behavior of lightweight CFST specimens containing rock wool waste under high temperature load was studied. It was found that the bonding strength decreased significantly under high temperature environment, but the addition of rock wool could alleviate this trend. Yan et al. (2019) carried out tests with different low-temperature temperatures, concrete D/t ratio, concrete strength grades, L/D ratio, and cross-section types as the varying parameters, and the results showed that the ultimate bond strength decreases with increasing D/t ratio at low temperatures, which is higher in circular than square members, and the value is greater for low-strength concrete; whereas, the effect of L/D ratio on it is small.

## *BONDING PROPERTIES OF CONCRETE-FILLED STEEL TUBE WITH DIFFERENT INTERFACE STRUCTURES*

(Xue & Cai, 1996b) The surface roughness of the steel tube has a significant effect on the interface bond strength, and it is proportional to the roughness. (Dong et al., 2020a)16 large square specimens were designed with steel tube construction measures and concrete types as parameters. The results show that the stud and round bar have a higher cost performance in improving the bonding strength, and the combination of stud and round bar has a better effect. The combination of circular reinforcement and vertical reinforcement significantly improves the bond strength and energy dissipation capacity. The recycled concrete specimens have better bonding properties than ordinary CFST. (Dong et al., 2020 b) Eighteen large-diameter specimens with different structures and concrete types were designed for testing. The results show that the interface of tubes with special structures can improve the bonding properties, and the concrete strength is proportional to the bonding strength.

(Wang et al., 2022) Eighteen specimens were designed with the varying parameters of surface roughness, interface length, concrete age, contact pressure, interface long-term load and modified load. The results show that the bond strength is proportional to the surface roughness of the steel tube, and decreases with the increase of concrete age and interface long-term load. The interfacial length has little effect on the final bonding strength, but it is not conducive to the uniform distribution of bonding stress along the interfacial length. (Chen Lihua et al., 2015) Based on the concrete strength and the height of the pattern bump, 9 samples with internal pattern were designed and tested. The results show that the ultimate bond strength can be significantly improved by the introduction of the pattern steel tube, and the strength is proportional to the height of the pattern bump and the strength of the concrete. And the regression formula of characteristic bond strength can fit the experimental results well. (Dai et al., 2022)14 square stainless-steel specimens were designed with the ratio of cross-section width to thickness, concrete strength, type of ribbed reinforcement and grade of stainless steel. The results show that the addition of ribbed reinforcement can significantly improve the bonding properties.

## MAIN FACTORS AFFECTING THE BONDING PERFORMANCE OF CONCRETE-FILLED STEEL TUBE

Through the comprehensive analysis of domestic and foreign research results on the bonding properties of CFST, it can be seen that the research results have a large dispersion, and a mature theory has not been formed. Concrete type, concrete strength and shrinkage properties, steel tube section shape and section size (diameter, diameter to thickness ratio, slenderness ratio), steel tube inner surface structural measures are the main factors affecting the interface bonding properties.

### *STRENGTH GRADE OF CONCRETE*

Previous researchers (Do Hong Ngying et al., 2021; Ke Xiaojun et al., 2015; Lu, Liu, Li, & Li, 2018; LUO Peiyun et al., 2021; Xu Kaicheng et al., 2012; Xue & Cai, 1996b; Yuan Wei-bin & Jin Wei-liang, 2005) show that increasing the strength of concrete can reduce the ultimate bond stress of concrete, but aggravate the shrinkage of concrete. On the other notes, several group of researchers (Y. Chen et al., 2017; Liu Yong-jian et al., 2010; Virdi & Dowling, 1980) show that the bond strength is not obviously affected by the concrete strength. After high temperature, lightweight concrete specimens with smaller cement grades show greater bonding ability (Parsa-Sharif et al., 2023). Whereas another researchers, Yan et al. (2019) concludes that at low temperatures, smaller concrete strength grades show greater bond capacity. As for the influence of concrete strength, domestic and foreign scholars have not reached a unanimous conclusion. The reason may be that the mechanical bite force between high-strength concrete and steel tube is stronger than that between low-strength concrete, but high-strength concrete has large shrinkage, which will reduce the tightness between it and steel tube, resulting in reduced friction. Perhaps there are other uncertain factors, and the influence of concrete strength still needs a lot of in-depth research by domestic and foreign scholars.

### *WIDTH TO THICKNESS RATIO (DIAMETER TO THICKNESS RATIO)*

(Kang Xi-liang, 2008) The bond strength is related to the D/t. When the D/t is 28.91~39.75, the bond strength is negatively related to the D/t. (Cao et al., 2023; Chen Jun et al., 2018; Han et al., 2022; LIU Yong-jian et al., 2010; LUO Peiyun et al., 2021; Parsa-Sharif et al., 2023; WU Jian-bin et al., 2007; XU Kaicheng et al., 2015; Yan et al., 2019) The existing research shows that W/t (D/t) radio is one of the main factors affecting the bonding stress of CFST.

Scholars have basically reached a consensus that the W/t (D/t) radio is negatively correlated with bond strength. This is mainly because the smaller the W/t (D/t) radio, the stronger the constraining effect of the steel tube on the concrete, the greater the normal force on the contact interface, and the greater the bonding strength. However, this value is not the smaller the better, when below a certain limit value, the bond strength should not change significantly. Theoretically, there should be an optimal value interval, in which the bond strength is negatively correlated with the ratio of width and thickness, and the change is regular. However, how to determine the optimal value interval and which factors are related still need to carry out a lot of experimental research or simulation analysis.

### *SLENDERNESS RATIO / LENGTH-DIAMETER RATIO*

Kang Xi-liang (2008) emphasized that the bond strength is positively correlated with the slenderness ratio (12.58~17.61) within a certain range, and negatively correlated with the slenderness ratio (17.61~22.64) beyond this range. This is mainly because the bond strength is mainly provided by friction, when the slenderness ratio exceeds a certain critical value, the impact of the slenderness ratio on the friction between the steel tube and concrete becomes less obvious. In addition, Xu Jinjun et al. (2013) highlighted that when the ratio of length to diameter of recycled CFST specimens is in the range of 1.86~2.93, the peak load of the specimens with large length-diameter ratio is greater than that of the specimens with small length-diameter ratio. Chen Zongping et al. (2013) stated that the bond strength of recycled CFST specimens is negatively correlated with the length-diameter ratio. This statement is in line with the other researchers, Cao et al. (2023) where the bond strength of high strength steel tube (HSST) and ultra-high performance concrete (UHPC) is negatively related to the length-diameter ratio. Chen Jun et al. (2018) also stated that under constant high temperature conditions, the average bond strength is negatively correlated with the length-diameter ratio, and the decrease range is up to 50%. Whereas other researchers, Wu Jian-bin et al. (2007) stated that the change of bond strength was not significant with the increase of slenderness ratio. Yan et al. (2019) also highlighted that at low temperature, the ultimate bond strength is less affected by the change of L/D value. According to the research of domestic and foreign scholars, the influence of slenderness ratio on bond strength has not yet reached a unified conclusion, and further experimental and theoretical research is still needed.

### *CONCRETE AGE*

Previous researchers, (Aly et al., 2010; Wang et al., 2022) have shown that a negative correlation between concrete age and bond strength. Tao et al. (2016) Age has a significant effect on bond strength, and there is a negative correlation between the two. However, for full-size specimens with a normal concrete age of more than three years, the value drops to negligible. (Lu, Liu, Li, & Tang, 2018) Age has a significant effect on the bonding properties of FSSCFST specimens. With the increase of age, the bond strength and the corresponding peak slip are increased, and the bond strength is increased by 37.5% on average.

As far as the existing research is concerned, the effect of age on bond strength has not yet been recognized. In the author's opinion, the bond strength may be related to the type of concrete, for ordinary concrete, the bond strength is negatively correlated with the age, which is due to the shrinkage of the concrete caused by the two materials are not bonded tightly enough to cause a decrease in friction. For special functional concrete, its age and bond strength is positively correlated, such as the use of expansion concrete, with the increase in age, the bond strength also increased.

## *INTERFACE STRUCTURE OF DIFFERENT STEEL TUBES*

A researcher, Shakir-Khalil H (1993) has squeeze and build-up effects can be created by the increased installation of shear connectors or welded bearings, which have a positive effect on improving bond strength. Whereas another researchers, Wang et al. (2022 and Xue & Cai (1996b) had mentioned that the surface roughness of the steel tube had a significant effect on the bond strength, which was highly positively correlated. Whereas Chen Lihua et al. (2015) stated that the use of patterned steel plates instead of ordinary steel pipes significantly increases the ultimate bond strength; the ultimate bond strength is positively correlated with the height of the patterned projection and the concrete strength. Other researchers, Tao et al. (2016) highlighted that the different interface types for steel tubes, all had a positive effect on increasing bond strength. The order of prioritization for comparing the final effects was welded inner rings on the inner surface of the steel tube, welded shear studs, and application of expanded concrete. This is in line with the research on different structural measures for square and circular steel tube concrete setups were carried out respectively, and the results showed that the structural measures for the steel tube interface all have positive effects on improving bond strength and energy consumption capacity (Dong et al., 2020a, 2020b). To summarize the existing studies, the steel tube interfacial configuration is advantageous for improving the bond strength. The influence of the inner wall roughness and shear bond on the interface bonding performance is very obvious. The rougher the inner wall is or the shear bond is set, the greater the adhesive strength and energy dissipation capacity will be.

## *SECTION TYPE AND SIZE*

Morishita Y & Tomii M (1979) were first found that the bond strength varies with the cross-section shape of the member, specifically from square→octagonal→circular and increases gradually. There is a study conducted by Shakir-Khalil H (1993) of square, polygonal, and circular steel tube specimens concluded that the adhesion of circular steel tubes was greater than that of polygonal and greater than that of square. Chen Zongping et al. (2013) had compared the interface bonding and sliding performance test of recycled CFST, the bonding performance of circle specimens was better than that of square specimens. On the other side, Tao et al. (2016) highlighted that for specimens of the same cross-sectional size, circular columns have higher bond strength than square columns. The bond strength between carbon steel tube members and stainless steel tube members decreases significantly with the increase of section size. Post-fire square, circular, and elliptical steel tube concrete bond-slip tests were conducted, and it was found that the bond strength of elliptical cross-section specimens was generally lower than that of circular and square specimens for specimens with different cross-section types but the same concrete interfacial contact area (Song et al., 2023).
It is found through the test that the specimens with circular section can obtain greater bond strength than those with square section, which is also the conclusion that the analysis of factors affecting the bond strength of CFST has reached a unified understanding. This is mainly because the stiffness of the four corners of the square steel tube is much greater than that of the four sides. Under pressure, only the four corners can effectively constrain the concrete, while the four sides will flex and expand under the pressure. Only when the concrete is close to the circle will it exert the greatest restraint effect. Therefore, concrete filled steel tube with circular section has the strongest bonding property.

## CONCLUSIONS

In this paper, the research results related to the bonding properties of CFST specimens are reviewed. The main conclusions are summarized as follows:

(1) W/t (D/t) radio is one of the main factors affecting the bond strength. Generally, the w W/t (D/t) radio is negatively correlated with bond strength.

(2) The interfacial structure of steel tube is favorable to improve the bonding strength. Interfacial bonding performance is affected by the roughness of the inner wall of the steel tube and shear bonding is very obvious, the rougher the inner wall or set up with shear bonding, the greater the bonding strength, the greater the energy dissipation capacity.

(3) Specimens with circular section can obtain greater bond strength than those with square section. There is still no uniform conclusion on the influence of concrete strength, concrete age and the slenderness ratio of specimens on bond strength, and further research is still needed.

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