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Experimental Study on Compressive Performance of CHS T-Joints Filled with High-Water Rapid-Setting Materials

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Abstract. In order to study the compressive performance of the CHS joints filled with high-water rapid-setting materials, the comparative test of the branch axial compression of three T-joint specimens of circular hollow steel (CHS) pipes, chord filled with concrete and chord filled with high-water rapid-setting materials were carried out. Differences in the failure mode, stress-strain distribution, ultimate bearing capacity and initial stiffness of the three joints were comprehensively compared. The test results show that the filling of the chord with different materials leads to different failure modes. Filling concrete can significantly improve the bearing capacity of the joint, but it will reduce the ductility of the joint; the failure mode of the filled with high-water rapid-setting materials is similar to that of the CHS T-joint. The joint show good ductility during the stress process, and at the same time, the ultimate bearing capacity is appropriately increased compared with the CHS T-joint.

Keywords: High-Water Rapid-Setting Material; T-Joint; Failure mode; Bear capability.

1. Introduction

The pipe truss structure, which is directly welded by the branch and the chord has been widely used because of its simple structure, convenient processing, steel saving and excellent load bearing capability [1, 2]. The research shows that the mechanical performance of the pipe truss structure depends more on the stability of the joints rather than the strength of the members themselves, and the joint failure often occurs before the members. Insufficient bearing capacity and stiffness of joints are one of the important factors restricting the development of this structure, so it is necessary to study the performance of joints under the strengthening .

Filling concrete in the chord of joints is a common reinforcement method, which helps improving the strength, stiffness and the overall load bearing capacity of the joints [3].At present, the research on CFST joints is relatively mature. Yoshinaga Sakai et al. [4]conducted axial static tests on the CHS K-joints filled with concrete. The results show that after filling with concrete, the stiffness and ultimate bearing capacity of the joints are significantly higher than those of ordinary CHS joints. Yu Chen et al. [5] studied the double-layer CHS X-joints with PVC pipe as the component, and found that the ultimate strength of the double-layer tubular X-joint was significantly increased by grouting the chord. Liu Yongjian et al. [3] studied the flexural properties of rectangular and circular steel pipe trusses filled with concrete in the chord. The results show that the concrete filled in the chord can help improve the axial stiffness of the chord, as well as the strength and overall load bearing capacity of the joints. Wu Qingxiong et al. [6] conducted a full-scale model fatigue performance study on CFST K-joints, and found that the confinement of concrete in the tube increased the radial stiffness of the chord of the CFST joints.Bin chen et al. [7] carried out static loading on two groups of T-shaped truss joint specimens with different concrete filling ranges. It was found that the scheme of partially filled concrete in the chord and fully filled concrete in the chord had little effect on the mechanical properties of the joint, but the self-weight greatly reduced. In addition, a large number of research results show that the stiffness provided by the concrete filled in the chord is too large and fails to give full play to the performance of steel. Therefore, it is an urgent scientific problem to develop a new type of truss joint which can not only improve the stiffness of the chord, but also reduce the self-weight appropriately on the basis of increasing the ultimate bearing capacity of the joint.

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High-water rapid-setting material is a new type of material newly developed and promoted to the field of construction. It has the advantages of high water-cement ratio and low price. It can not condense for a long time, does not block the pipe, and can be pumped. After mixing, it can achieve the effect of rapid setting and early strength [8, 9]. At present, the research on high-water rapid-setting materials has not been fully carried out. The existing researches mainly focus on the macroscopic mechanical properties, chemical stability and the hydration mechanism of the materials [8, 10, 11]. However, this material is often only used for backfilling of roadway walls, roadway support, leakage prevention and other projects that do not require the material strength. Its application in the construction industry needs to be studied and promoted.

In the paper, a new type of joint formed by high-water rapid-setting materials to replace concrete. and the compressive performance of T-joints filled with high-water rapid-setting materials are analyzed and studied through physical tests.

2. Specimens Design

2.1 Specimens design

Three sets of joint specimens are designed, namely CHS T-joint specimen JD1, concrete-filled CHS T- joint specimen JD2, and CHS T-joint specimen filled with high-water rapid-setting materials JD3. The number, dimension and other parameters of each test piece are shown in Table 1.

Table 1. Joint specimen parameters.

Specimen name	Chord size (mm)	Branch size (mm)	Chord length (mm)	Branch length (mm)	High-water rapid-setting material strength (MPa)	Concrete strength
JD1	125*6	50*6	800	300	--	--
JD2	125*6	50*6	800	300	--	C25
JD3	125*6	50*6	800	300	10.2	--

2.2 Material test

The interception position, specific shape and size of the tensile specimen are all in accordance with the detailed regulations in "Sampling Position and Sample Preparation for Mechanical Properties Test of Steel and Steel Products" (GB/T 2975-2018). The material properties test results are shown in Table 2. The chord of joint specimen JD2 is filled with concrete with the strength grade of C25. According to the compressive test of the standard test block produced, the compressive strength of the concrete cube is 28.3Mpa, and the elastic modulus is 29500Mpa. The chord of the joint specimen JD3 is filled with high-water rapid-setting materials with a water-cement ratio of 1:1, and three groups of 50*50*100mm3 standard test blocks are configured on the test site. The mechanical characteristics of the high-water rapid-setting materials in this paper were selected for the material cured for 7 days under the natural film curing condition. After the compressive test of the high-water rapid-setting material test block, the compressive strength is 10.2Mpa, and the elastic modulus is 12044.1Mpa.

Table 2. Mechanical properties of steel tubular.

Cutting site	Steel marking	Nominal wall thickness (mm)	Measured wall thickness (mm)	Measured material properties			
				Yield Strength (MPa)	Ultimate strength (MPa)	Elongation (%)	Elastic Modulus ($*10^3$MPa)
Chord	number 20	6	5.54	372	521	27.4	194.2
Branch	number 20	6	5.72	368	488	26.8	199.6

3. Test plan

3.1 Loading system

In the test, the axial loading device of the branch is a hydraulic jack with a range of 500kN, and the axial force loading device of chord is a mechanical jack with a range of 320kN. When installing, ensure that the chord of the joint is level and stable, and the branch is perpendicular to the ground.The face is in even contact with the loading end. Both ends of the chord are hinged, and the pressure in both directions must be strictly centered. The structural layout is shown in Fig. 1 and Fig. 2

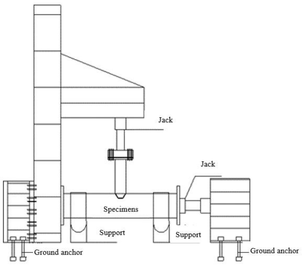

Figure 1. Test arrangement.

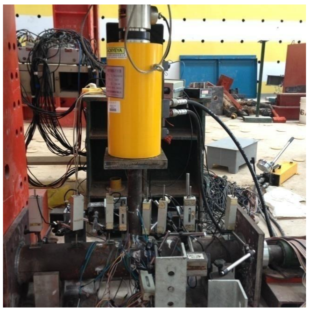

Figure 2. Filed test arrangement.

3.2 Loading scheme

In this experimental design, the axial force of the chord is 120kN. In order to ensure the smooth development of the test work and eliminate the gap between the loading equipment and the loading end, the preload value is set before the formal loading, and the value is 5% of the estimated ultimate bearing capacity. In the early stage of formal loading, the load of each stage is 100kN, and in the later stage of loading, the load of each stage is 50kN.The load of each level is maintained for 5 minutes. When the load displacement has an obvious nonlinear relationship, the displacement control loading is adopted to load until it is damaged. When the load is reduced to 65% of the peak load, the loading is stopped. After the test, unload evenly and stop collecting data.

3.3 Measurement scheme

Considering the symmetry of the joint, 5 groups of rosettes are arranged in the joint domain, among which 5 groups of rosettes A1~A5 are arranged at the upper wall of the chord at a distance of 15mm from the weld. In order to further observe the deformation of the joints during the test, four groups of displacement gauges were symmetrically arranged on the upper surface of the chord of the node during the test. The specific test point layout is shown in Fig. 3.

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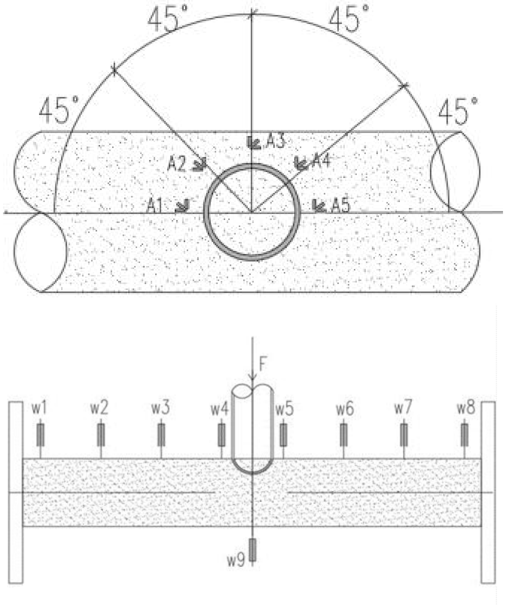

Figure 3. Test point layout.

4. Test result

4.1 Failure mode

(a) Specimen JD1 (b) Specimen JD2 (c) Specimen JD3

Figure 4 Failure modes of specimens

As shown in Fig 4,the center of the upper surface of the chord at the weld is obviously dented and deformed, and the chord also has a large overall deformation, and the joint failure performance is the failure mode of plastic deformation on the surface of the chord.JD2 has a significant strengthening effect on the chord, and the internal concrete restrains the deformation of the chord and assumes part of the pressure from the branch. When the branch damaged, it has obvious buckling deformation, but there is no obvious depression on the surface of the main at the joint. The damage in the whole process does not occur near the joint domain, which belongs to the pipe fitting failure. The failure mode of the joint belongs to the branch buckling failure mode.For JD3,in the initial stage of loading, high-water rapid-setting materials bears the pressure from the branch and constrains the deformation of the chord.When the load further increases, the high-water rapid-setting materials reach the local bearing limit and is fractured and crushed, the bearing capacity gradually decreases, and local depression deformation occurs on the surface of the chord.Due to the uneven concave settlement on the surface of the chord, the end of the branch is eccentrically loaded. When the branch buckles as a whole, the failure mode is local crushing of the filling material and concave failure of the chord surface.

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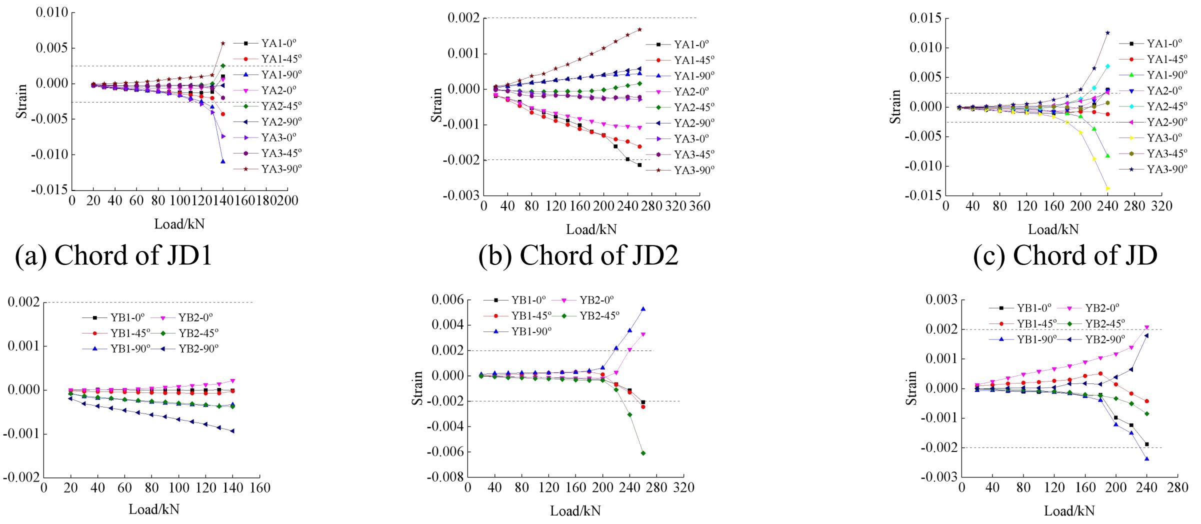
4.2 Joint domain strain analysis

The variation law of strain at each measuring point of the joint with the increase of load was further analyzed, and the load-strain variation curve was drawn (Fig. 5). Since 5 groups of rosettes A1~A5 are symmetrically arranged on the surface of the chord along both sides of the weld, the data of 3 groups of rosettes (A1~A3) are used to draw curves during data analysis.

When the load level is small,the surface strain of the JD1 chord increases slowly,and the steel is still in an elastic state at this time. The chord A3-0° strain gauge first reaches the dotted line position, that is, the strain εu=0.002, which indicates that the load at the end of the joint branch is mainly supported by the upper surface of the chord. Continuing to load the chord and the strain increases rapidly. At this time, the upper surface of the chord has been partially buckled, and the joint region is concave and deformed.The maximum tensile and compressive strain of the branch is only about 0.001, which means that the axial force of the branch is completely transmitted to the joint chord. It is in an elastic state without reaching the yield strength.

The JD2 is in an elastic state during the whole test process, and the chord include the inner filling concrete jointly bear the load transmitted by the branch.The branch shows a small strain state before the failure of the member. When the branch is buckled, the axial force of the branch is no longer centered, and the strain of the branch sharply increases after continuous loading. No joint failure occurs in the whole process, and the corresponding test phenomenon is the buckling of the branch.

When the load reaches the local compressive strength of the material, the inner filling material of JD3 is crushed, the upper surface of the chord cannot support the load transmitted by the branch and a depression occurs, and the chord strain then reaches the tensile and compressive yield strain εu=0.002, the strain level of the branch is still small at this time. Continued loading after the joint failure makes the branch buckling under eccentric compression, so that the strain also reaches the yield strain. Compared with the joint specimen JD1 and the joint specimen JD2, the joint specimen JD3 not only shows the ductility of the empty steel pipe joint, but also exhibits the characteristics of the joint common bearing of the inner filling material and the chord.



(a) Chord of JD1 (b) Chord of JD2 (c) Chord of JD

(d) Branch of JD1 (e) Branch of JD2 (f) Branch of JD3

Figure 5.Strain of specimens chords and braces

4.3 Load-displacement curve

The concrete filled in the chord of the specimen JD2 greatly improved the stiffness of the chord, and the chord did not show local depression and overall bending when it was damaged. Therefore, the displacement gauge arranged on the upper surface of the chord did not collect obvious data. The following does not discuss load-displacement curve and initial stiffness of the joint specimen JD2. The variation law of strain at each measuring point of the joint with the increase of load was further analyzed, and the load-strain variation curve was drawn (Fig. 6). Since 5 groups of rosettes A1~A5

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are symmetrically arranged on the surface of the chord along both sides of the weld, the data of 3 groups of rosettes (A1~A3) are used to draw curves during data analysis.Extract the two groups of strain rosettes (B1~B2) near the weld at the root of the branch to draw the load-strain curve.

In the initial stage of loading, the load at the end of the branch of the two specimens increases almost linearly with the increase of the sag displacement of the chord. When the sag displacement of the chord is 2~3% of the pipe diameter of the chord, the load increase of the joint specimen is slowed down due to the plasticization of the chord joint domain, and then the curve becomes a horizontal trend, which reflects good ductility. When the joint specimen JD3 fails, the deformation value of the chord can reach the deformation value of the pipe wall yielding of the joint specimen JD1, but the ultimate bearing capacity of the joint specimen JD3 is greatly improved compared with that of the joint specimen JD1, which reflects the high bearing capacity and stiffness of steel pipe joints filled with high-water rapid-setting materials.

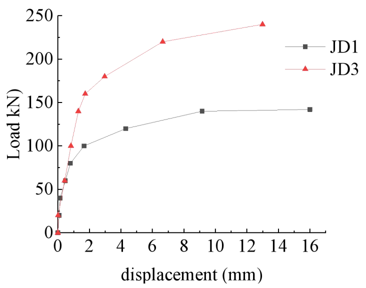

Figure 6.Load-displacement curve

4.4 Ultimate Bearing Capacity and Initial Stiffness

According to the ultimate strength criterion and ultimate deformation criterion [16,17], the ultimate axial compressive bearing capacity and initial stiffness of the T-shaped joint of the round steel pipe are determined. The detailed results are listed in Table 3.

Table 3. The test results of specimens

Specimen number	P_r/kN	K_i/(kN/mm)	M/(kg)
JD1	120	79.34	18.456
JD2	220	--	42.826
JD3	190	109.61	28.496

Note: Pr is the test value of axial compression bearing capacity of the specimen; Ki is the stiffness of the test curve; M is the self-weight of the specimen.

According to the experimental results, the following conclusions can be drawn:

(1) The ultimate bearing capacity of joint specimen JD2 is 83.33% higher than that of joint specimen JD1, and the ultimate bearing capacity of joint specimen JD3 is 58.33% higher than that of joint specimen JD1. From the perspective of self-weight, the self-weight of joint specimen JD2 is 132.04% higher than that of joint specimen JD1, and the self-weight of joint specimen JD3 is 54.35% higher than that of joint specimen JD1. It can be seen that the joint specimen JD3 has the appropriate bearing capacity compared with the CHS joint, and effectively reduces the self-weight of the structure compared with the CFST joint.

(2)The initial stiffness of the joint specimen JD3 is 38.15% higher than that of the joint specimen JD1,indicating that filling the chord with high-water rapid-setting materials can effectively improve the initial stiffness of the joint specimen. However, the failure of the joint specimen JD2 starts from the buckling failure of the branch, so when the joint fails, the chord does not have obvious plastic deformation,so that the initial stiffness is not considered.

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5. Conclusion

(1) The failure mode of joint specimen JD3 is similar to that of joint specimen JD1, which belongs to local plastic failure of chord surface. Under the local pressure of the branch, the chord and the internal filling material is constrained to form a stressed whole. Before the crushing of the filling material, the two work together, and the whole process shows sufficient ductility.

(2) It can be seen from the strain distribution of the chord and branch in the joint area that the steel near the weld is mainly compressed, and the strain increases rapidly when the load reaches the ultimate strength of the joint. The growth law of strain in the whole process well verifies the joint failure mode and bearing characteristics summarized in conclusion (1).

(3) The ultimate bearing capacity and initial stiffness of joint specimen JD3 are significantly higher than that of JD1. Although the ultimate bearing capacity of joint specimen JD2 is greatly higher than that of JD1, because its failure starts from the buckling failure of branch, the filled concrete material is not fully utilized, and the ductility of failure process is poor.

(4) By comparing with the other two types of T-joints, it is concluded that the strength-quality ratio of T-joints filled with high-water rapid-setting materials remains at a high level. It shows that the T-joint truss structure filled with high-water rapid-setting materials can reduce the self-weight of the structure on the premise of ensuring the bearing capacity, which proves the feasibility of this kind of joint design.

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