

Confined Expansion and Bond Property of Micro-Expansive Concrete-Filled Steel Tube Columns

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Abstract: The shrinkage/expansion behavior and bond carrying capacities were investigated through 4 micro-expansive concrete-filled steel tube(MCFST) and 3 conventional concrete-filled steel tube(CFST) short columns. The results show that the temperature field in MCFST is similar to that of ordinary concrete members. Concrete core has obvious effect on shrinkage-compensating with the addition of swelling agent. Pre-stress is produced in the core concrete when it is confined by the steel tube. Both water cement ratio and expansive agent have obvious influence on expansive behaviors of MCFST. The tests also indicate that the pre-stress in core concrete can improve bond strength of core concrete and steel tube of MCFST columns and proposed a new method to improve the interface bond strength of composite structures.

Keywords: Hydration heat, shrinkage/expansion behavior, bond strength, micro-expansive.

1. INTRODUCTION

In the past few decades, CFST have been extensively used in modern structures[1]. This is because they have high strength, high ductility, construction and convenient features. The structural benefits require stress transfer between the steel and the concrete in order to ensure their composite action. In practice, this has been attained by relying on either shear connectors on the inside of the tubes or the natural bond between steel and concrete. This bond stress transfer is not well understood.

At present, the research work mainly concentrated in the interface bond in the common steel tube CFST [2-7]. Most of the research was focused on the bond strength of the specimen, and it indicated that there are many factors that would influence the bond capacity, such as the concrete compressing strength, the roughness of the concrete-steel interface, the ratio of the d/t and the interface length, etc.

Yet initial defects will be produced in the process of construction. When the structure is enduring load, the defects will develop rapidly. Charles [8] pointed out that the shrinkage of the core concrete has obvious influence on bond strength, the shrinkage will not only lead to structural defects, but will also affect the durability of concrete. For ordinary CFST, the core concrete shrinkage will lead to deterioration or separation between the two materials. Adding expansion agent in the core concrete to form the micro-expansion concrete can effectively overcome this shortcoming, micro-expansive concrete can not only compensate for concrete shrinkage, but can also produce pre-compress in concrete core. It can improve the compactness

of the core concrete and offsets the initial defects effectively [9]. This will help to improve the interface bond between steel and core concrete.

This paper focuses on the properties of hydration heat and confined expansion, which looks forward to providing dependencies for optimal design of MCFST. By adding the expansive agent to form micro-expansive concrete to improve the bond strength. In this work, first test on the steel limited expansion of micro-expansive concrete, and then on the 3 CFST and 4 MCFST push-out tests were introduced.

2. EXPERIMENTAL ARRANGEMENTS

To make the contrasts of confined expansion performance, 5 specimens with different expansive agents were produced, one of which adopted conventional concrete and the others with expansive concrete. The proportions of concrete are shown in Table 1. In alphabetical order P-0, P-8, P-12, P-15 and P-20, the expansive agent ratio (replace cement equivalently) is increasing. The coarse aggregate was gravel with a maximum size of 30 mm. The expansive agent was UEA and the high-efficient water-reducing agent was PCA-IV.

In this test, the steel has the same material parameters, all square steel tube has the same cross-section length of 180 mm and the same length of 600 mm, the condition of the specimens is shown in Fig. (1).

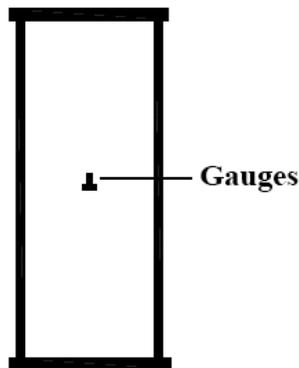
In order to observe the expansive behavior during hardening process, there are two strain gauges on each side of the specimens. As shown in Fig. (2), they can measure the longitudinal and horizontal strains at four symmetrical locations at the column middle height. Meanwhile, JMZX-215 strain gauges were embedded in the center of the specimen, which can measure transversal strain and internal temperature of the concrete core. All specimens were in the same condi-

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Table 1. Concrete Mix Proportions(Hydration Heat Specimens)

Mix Identification	Water (kg)	Cement (kg)	Expansive Agent (kg)	Sand (kg)	Gravel (kg)	Water Reducer(kg)
P-0	190	475	0	520.5	1214.5	1.425
P-8	190	437	38	520.5	1214.5	1.425
P-12	190	418	57	520.5	1214.5	1.425
P-15	190	403.75	71.25	520.5	1214.5	1.425
P-20	190	380	95	520.5	1214.5	1.425

ons, The strains and temperature are measured from 12 h age. Data are collected three or four times each day in the first seven days, with once a day in the following twenty-six days.

**Fig. (1).** 5 specimens.**Fig. (2).** Strain gauges arrangements.

To make the contrasts of bond carrying capacities and load-slip relationships of CFST specimens with those of MCFST ones, 7 kinds of concrete mixes are designed. The proportions of concrete are shown in Table 2. The mixes 'a', 'b' and 'c' are poured with common concrete and their water-cement ratios are 0.35, 0.4 and 0.45, respectively. The mixes 'b', 'd' and 'f' have the same water-cement ratio but expansive agent ratio is increasing. In alphabetical order 'e',

'f' and 'g', the expansive agent accounts for 12% of the cement materials based on the mixes 'a', 'b' and 'c'.

When pouring the specimens, the steel tube was erected on the flat steel plate, and then pouring the concrete through the funnel, the concrete is cast to about 20mm below the top end of the specimen. In this paper, the steel has the same material parameters, all square steel tube has the same cross-section length of 160 mm and the same length of 600 mm.

Push-out test arrangements are shown in Fig. (3). The use of computer controlled electro-hydraulic testing machine feeding stage loading. In the early phase, each stage loads of about 1 / 10 of the ultimate loads, the loading speed about 500N / s, and maintains 3 minutes. When the nonlinear sliding between the steel tube and concrete core has taken place, loading speed becomes 200N / s. Two transducers are symmetrically attached to the steel tube to measure the slip between the concrete and steel tube. Load value directly read outs in test machine, from which we can draw the P-S curve. The parameters of the specimens are shown in Table 3.

3. HYDRATION HEAT OF CONCRETE CORE

Fig. (4) shows the time-dependent temperature during hydration stage for each specimen. It is clear that the hydration heat rises rapidly in the beginning period and the peak comes after a day's pouring. The top temperature of the concrete core is about 6.5°C higher than that of the room. With the heat dissipating, the temperature of the concrete core is close to the surrounding temperature 2 days later. Fig. (3) indicates that the peak of the curve drops with the increase of expansive agent. This may be due to the fact that the amount of cement declines as that of expansive agent increases, which weakens hydration process on a certain degree. The hydration heat of the MCFST rises rapidly in the beginning and then drops to near the room temperature, which is similar to that of ordinary concrete members [10].

4. EXPANSIVE/SHRINKAGE BEHAVIOR

Figs. (5 and 6) show the expansive behaviors of the concrete and steel tube respectively for specimens 'b', 'd' and 'f'. It can be seen that the shrinkage of the concrete core for the CFST specimen occurs from 4 days while concrete core of the MCFST is kept in compression when in the curing stage. This can be seen that the micro-expansive concrete can not only compensate for the conventional shrinkage but also produces the pre-stress in the core concrete. The trans-

Table 2. Concrete Mix Proportions(Push-out Test Specimens)

Mix Identification	Water (kg)	Cement (kg)	Expansive Agent (kg)	Sand (kg)	Gravel (kg)	Water Reducer(kg)
a	160	457.2	0	619	1149.6	1.425
b	190	475	0	520.5	1214.5	0
c	190	422.5	0	572	1215.5	0
d	190	437	38	520.5	1214.5	0
e	160	402.2	55	619	1149.6	1.425
f	190	418	57	520.5	1214.5	0
g	190	371.8	50.7	572	1215.5	0

versal strains increased obviously before 8-day age and almost remain same after 15-day age.

dependent on the expansive agent ratio. The constrained expansion increases with the quantity of expansive agent.

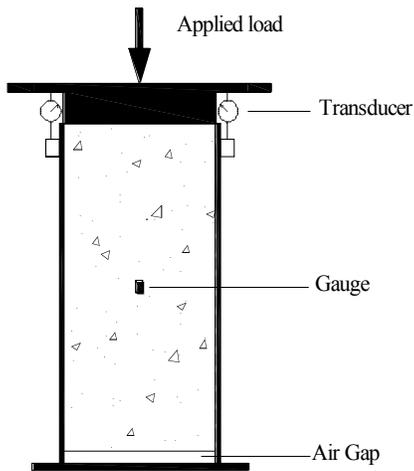


Fig. (3). Push-out test arrangement.

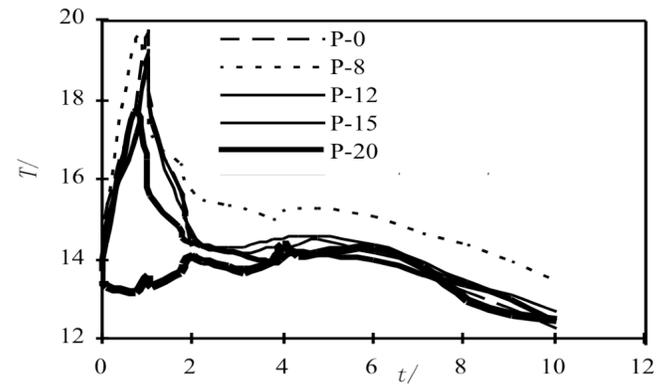


Fig. (4). Measured temperature versus time relationship.

Fig. (6) also shows that in the same geometrical dimensions of the steel tube, the micro-expansive behavior is mainly

The expansive behaviors of the steel tube for specimens ‘e’, ‘f’ and ‘g’ are shown in Fig. (7). It is clear that the water-cement ratio has obvious influence on the confined expansion of the MCFST columns. The constrained expansion reduces with the increase of water-cement ratio. This is because more energy will be consumed in filling pores due to the existence of pre-stress. Meanwhile, the compressive

Table 3. Summary of Test Specimens and Results

Specimen	D (mm)	L (mm)	T (mm)	F_N (kN)	τ_u (Mpa)	S(mm)
a	160	600	4	142.5	0.41	1.348
b	160	600	4	132	0.38	0.917
c	160	600	4	126.4	0.36	0.345
d	160	600	4	171.3	0.49	1.474
e	160	600	4	193.5	0.55	1.433
f	160	600	4	182	0.52	1.615
g	160	600	4	174.1	0.49	0.427

strength reduces with the increase of water-cement ratio, which leads to the increase of elastic deformation and creep deformation, therefore the restriction expansion rate reduces [11].

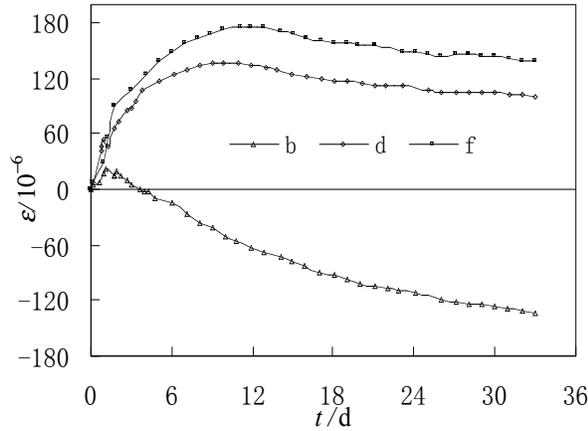


Fig. (5). Time-dependent transversal strain plot of concrete core for specimens b, d and f.

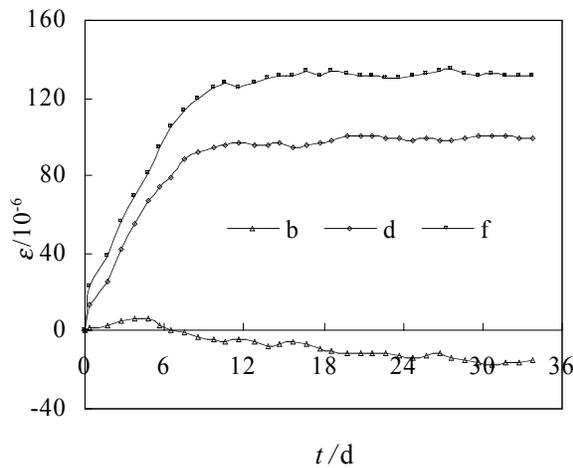


Fig. (6). Time-dependent transversal strain plot of steel tube for specimens b, d and f.

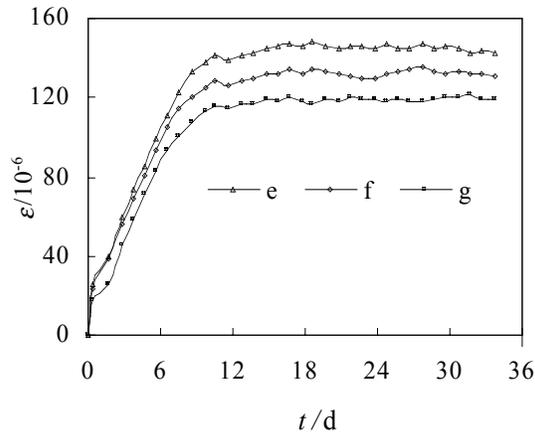


Fig. (7). Time-dependent transversal strain plot of steel tube for specimens e, f and g.

5. PUSH-OUT TESTS OF SPECIMEN

The bond strength is defined in the following equation:

$$\tau_u = \frac{F_N}{4DL} \tag{1}$$

where F_N is the applied load at which the bond failure occurred. D and L are the square steel tube cross-section length and the concrete-steel interface length, respectively. The test results are summarized in Table 3.

At the beginning of loading period, little sound can be heard and no displacement occurs. The slip increases with the increasing of the applied load, both in linear growth. For most of the specimens, a sudden brittle sound can be heard when bond failure reaches and then rigid body motion between the concrete and the steel begins with increasing slip displacements. The typical bond failure of specimen is shown in Fig. (8).



Fig. (8). The typical bond failure of the push-out test.

The load-slip relationships of specimens 'b', 'd' and 'f' are shown in Fig. (9), it can be seen that the bond carrying capacity of the CFST is lower than that of MCFST. The failure loads for specimens 'b', 'd' and 'f' are 132, 171.3 and 182 KN, the bond strengths are 0.38, 0.49 and 0.52 Mpa, respectively. It indicates that expansive/shrinkage behaviors of the concrete are important factors of the bond strength.

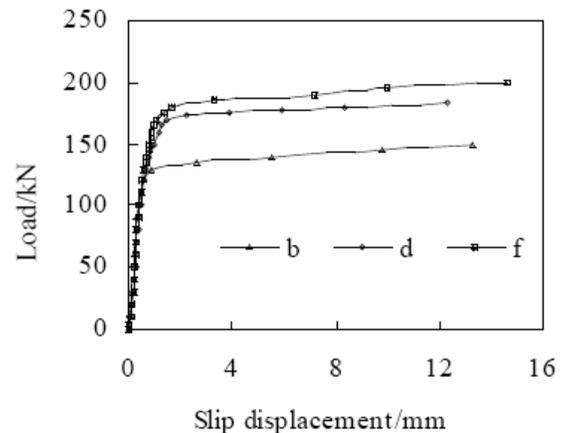


Fig. (9). Load-slip displacement curve for specimens b, d and f.

The different expansive agent ratio in the concrete can produce different pre-stresses in the concrete. The characteristics of the load-slip curves between the CFST and MCFST have obvious difference. In the curves' linear part, MCFST specimens have longer slip displacement and slip at a higher rate before failure load than do CFST specimens.

The load-slip relationships of specimens 'e', 'f' and 'g' are shown in Fig. (10). For these specimens, any parameters of specimens are the same except the water-cement ratio. The failure loads for specimens 'e', 'f' and 'g' are 193, 182 and 171.3 KN, the bond strengths are 0.55, 0.52 and 0.49 Mpa, respectively. Obviously, bond strength reduces with the increasing water-cement ratio of the concrete. This is due to the fact that bigger water-cement ratio results in smaller constrained expansion in the concrete, which induces lower bond strength.

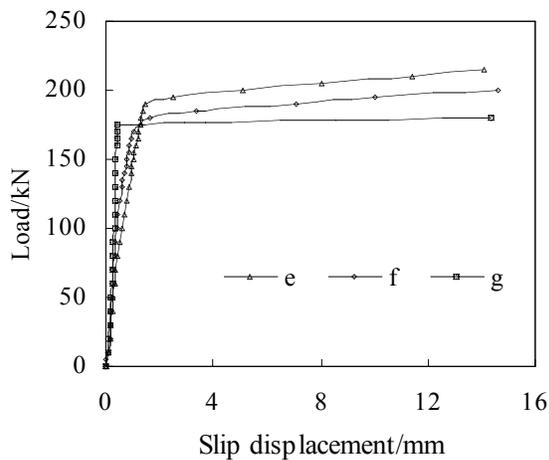


Fig. (10). Load-slip displacement curve for specimens e, f and g.

The load-strain relationships for specimen 'e' are shown in Fig. (11), which is typical for all the specimens. The steel tube strain increases from the top to the base at certain load level. This is due to the interface bond through which the load transfers from the concrete to the steel tube, as Shakir-Khalil [2] has pointed out.

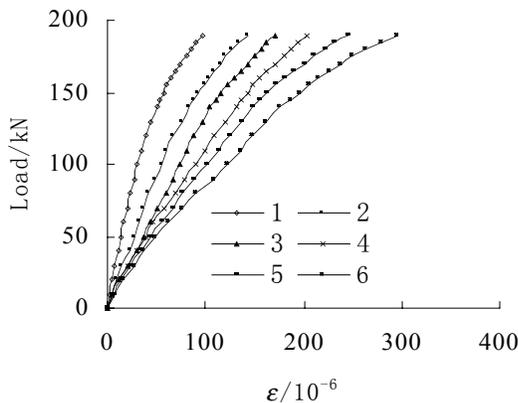


Fig. (11). Load-strain relationships for specimen e.

CONCLUSION

The hydration heat of the MCFST is similar to that of ordinary concrete members. It rises fast in the beginning and then drops to the approximate room temperature.

Through the expansion behaviors and push-out tests, we can get the conclusions as follows:

For MCFST specimens, both mixture ratio of expansive agent and water-cement ratio have an important influence on the constrained expansion in the concrete. Generally, the transversal strain of the steel tube increases before 8-day age and almost remains constant after 15-day age.

The push-out test results show that bond strength of MCFST specimens is 1.36~1.38 times as that of the CFST ones. The constrained expansion rate is an obvious factor for the bond strength of the MCFST specimens. The bond strength increases with the increasing expansion rate in the concrete.

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CONFLICT OF INTEREST

None

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