

Testing Research of Interfacial Performance of CFST Under Thermo-mechanical Coupling Effect

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Abstract: Larger temperature difference between concrete filled steel tubular (CFST) cross section will causes bigger temperature gradient and the corresponding temperature stress, which also affects its mechanical performance and structural security. The resistance heater equipment is customized and used in environmental temperature simulation, 4 CFST specimens are tested in the temperature impact test and thermo-mechanical coupling test, and the mechanical properties and interface complex stress state are researched under different environmental temperature, which can provide certain theory and test reference for the interface optimization of CFST and ensure the long term performance under bad environment. Copyright © 2013 IFSA.

Keywords: Concrete filled steel tube (CFST), Temperature impact effect, Thermo-mechanical coupling effect, Interface performance.

1. Introduction

Concrete filled steel tubular (CFST) structure is a composite structure which is composed of two materials of steel and concrete, the special material combinations, on the one hand, which makes the limit and complementary enhancement effect, on the other hand, which derives the complexity of interface performance. Larger temperature difference between cross section of CFST will causes bigger temperature gradient, the local stress of CFST under fire effect [1-8] and solar radiation [9-13] are conducted by the numerical simulation and experimental research by domestic and foreign scholars. Engineering practice also proves that there is interface debonding phenomenon in CFST members under the complex external environment, which is bound to affect the performance and structural security of CFST. Therefore, the study of interface performance and optimization method research of CFST under complex external environment has important theoretical value and engineering practical significance.

2. Thermodynamics Theory

2.1. Heat Convection

The heat flux size of heat convection is proportional to the temperature difference (ΔT) and the contact area (A) between solid and liquid.

$$Q = Ah(T_l - T_s) \quad (1)$$

$$q = h(T_l - T_s) \quad (2)$$

$$h = 2.6(\sqrt[4]{|T_l - T_s|} + 1.54v), \quad (3)$$

where $q(W/m^2)$ is the heat flux; $h(W/(m^2 \cdot K))$ is the heat transfer coefficient, T_l and T_s are the surface temperature of solid and liquid, v is the wind speed.

2.2. Heat Conduction

Basic law of thermal conductivity-Fourier law: which can be expressed by the following formula:

$$dQ = -\lambda \frac{\partial T}{\partial n} dA \cdot d\tau$$

$$q_n = -\lambda \frac{\partial T}{\partial n} \quad (4)$$

The minus “-” express the opposite direction, when the heat flow direction and isothermal surface normal direction is at α angle, the heat flux density formula rewrite:

$$q_s = -\lambda \frac{\partial T}{\partial s} = -\lambda \frac{\partial T}{\partial n} \cos \alpha = q_n \cos \alpha, \quad (5)$$

where q_n and q_s (W/m^2) are the heat flux density of normal and any direction of isothermal, λ ($W/(m \cdot K)$) is the heat conductivity coefficient of solid, $\frac{\partial T}{\partial n}$ is the temperature gradient of normal direction of isothermal.

2.3. Thermal Radiation

According to the law of Stefan-Boltzmann, the heat flow density formula of heat transfer radiation is as follows:

$$q_r = eC_s[T_1^4 - T_2^4], \quad (6)$$

where e is the surface emissivity, q_r is the heat flow density of heat transfer radiation, C_s is the Stefan-Boltzmann constant, which is $5.66 \times 10^{-8} W/m^2$.

2.4. General Situation of Test

4 CFST short column specimens ($\Phi 165 \times 4 \times 495$) are made, the concrete mixture proportion is shown in Table 1, and the temperature sensor (PT-100 platinum thermal resistance) and strain sensor (strain gauge and homemade stress box) layouts are shown in Fig. 1 and Fig. 2, the concrete hydration heat is ensured to release during 28 days of standard curing. Basing on the idea of thermo-mechanical coupling system with water as a heat transfer medium in soil test, and combining with the size of specimen and loading device, a resistance heater is designed and made which could satisfy the

requirement of experiment, the actually figure and profile figure are shown in Fig. 3 and Fig. 4.

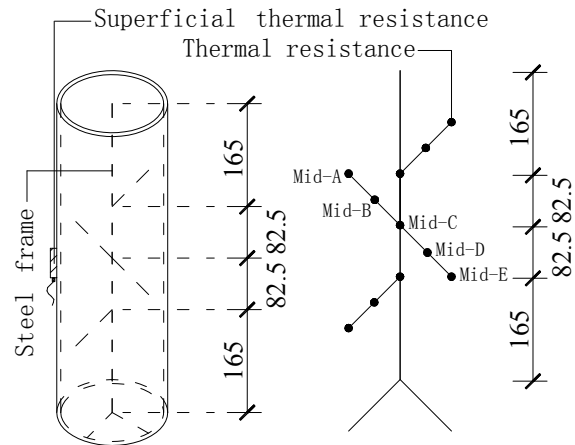


Fig. 1. Layout of temperature sensor (mm).

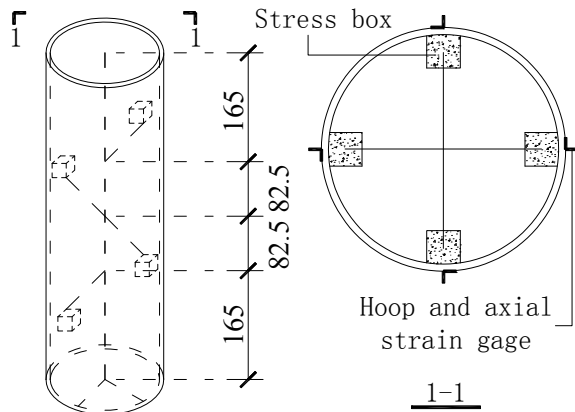


Fig. 2. Layout of strain sensor (mm).



Fig. 3. Actually figure of resistance heater.

Table 1. Mix proportion of concrete.

Admixture	Cement	Fly ash	Sand	Stone	Water	Slushing agent	Expanding agent
Kg/m ³	400	80	730	1095	144	6.24	45

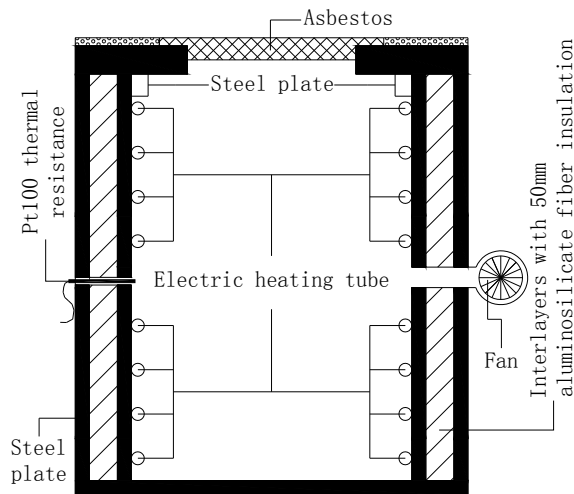


Fig. 4. Profile figure of resistance heater.

The CFST specimens are placed into resistance heater in simulation temperature stage, which are simulated from normal temperature to a temperature of 20 °C, 40 °C, 60 °C and 80 °C respectively, and specimens are removed from heat when the temperature of three sectional center points are consistent (in Fig. 1: $T_{Mid-A} = T_{Mid-B} = T_{Mid-C}$). The temperature are measured every other 15 min between the overall heating period. The temperature of steel tube and concrete are collected by CH301C-16 universal input blue screen record control instrument, the static variable temperature test device is shown in Fig. 5. At the same time, the temperature of the specimen is heat up from room temperature to the entire cross section temperature at 20 °C, 40 °C, 60 °C and 80 °C and which remain unchanged, then, the specimens are loaded with 10 t per level after preloading, and the strain of steel tube and concrete under per load level under are recorded by TS3860 static resistance strain instrument, the load device is 1500 t electro-hydraulic servo pressure testing machine. The thermo-mechanical coupling test device is shown in Fig. 6.



Fig. 5. Test device of temperature impact effect.



Fig. 6. Test device of thermo-mechanical coupling effect.

3. Test Analysis

Specimens are heated up from room temperature (RT) to a temperature of 20 °C, 40 °C, 60 °C and 80 °C, the temperature-time change curve of each measuring point of cross section in the heating stage is shown in Fig. 7; the radial, hoop and axial strain-load change curve of interface in each isothermal process (20 °C, 40 °C, 60 °C and 80 °C) are shown in Fig. 8, and the radial, hoop and axial strain-load change curve of interface in all isothermal process (20 °C, 40 °C, 60 °C and 80 °C) are shown in Fig. 9.

As shown in Fig. 7, when the specimen is in the process of temperature rising, the thermal conductivity coefficient of concrete is smaller than steel tube, thus the thermal conductivity rate of measuring point whose location is near the center of cross section lag behind the thermal conductivity rate of other location of concrete, while the temperature of each measuring point tends to be similar with the increase of heating time.

As shown in Fig. 8 and Fig. 9:

1) The axial load-strain curves of CFST specimens in constant temperature (20 °C, 40 °C, 60 °C and 80 °C) are similar to the axial load-strain curves of CFST specimens in normal temperature, which includes three stages: elastic stage, elastic-plastic stage and plastic stage.

2) The radial strain amplitude changes of concrete in the conditions of 11 °C, 20 °C and 80 °C are larger than theirs in the conditions of 40 °C and 60 °C, and the elastic stage of load-strain curve in the condition of 40 °C is shorter.

3) The elastic stage of hoop strain-load curve of concrete in the conditions of 20 °C and 40 °C are longer, and the hoop strain in the condition of 80 °C has smaller change, while the hoop strain change trend in the conditions of 11 °C and 60 °C are somewhere between the above two cases.

4) The elastic stage of axial strain-load curve of concrete in the conditions of 20 °C, 40 °C and 60 °C are longer, while the axial strain changes in the conditions of 11 °C and 80 °C are smaller.

5) In the condition of 40 °C, the hoop strain and axial strain of concrete are larger, and the radial strain is smaller; in the condition of 80 °C, the radial strain and hoop strain of concrete are larger, and the axial strain is smaller; if only to consider the limit

(radial effect) of steel tube on concrete, the 11 °C, 20 °C and 80 °C temperature are the best environmental temperature for structural performance.

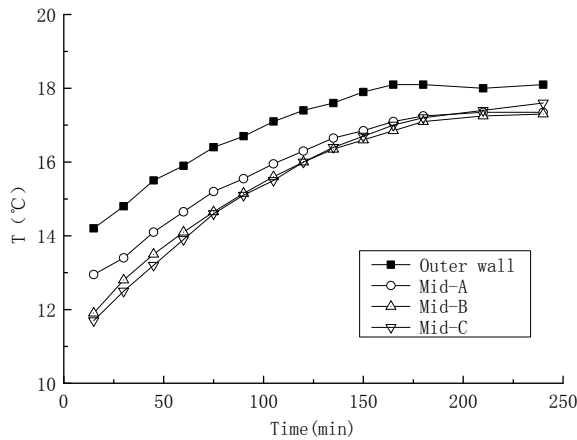


Fig. 7 (a). Heating stage from RT to 20 °C.

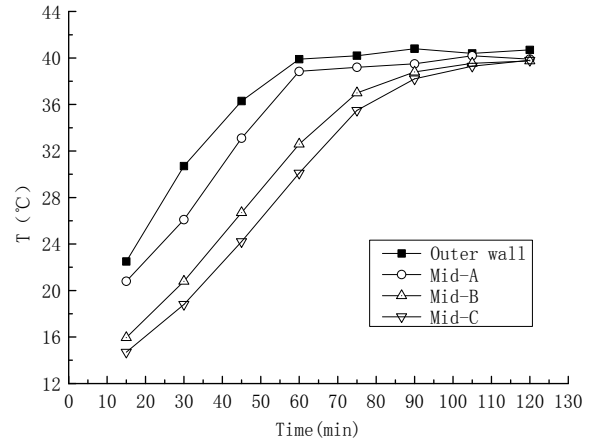


Fig. 7 (b). Heating stage from RT to 40 °C.

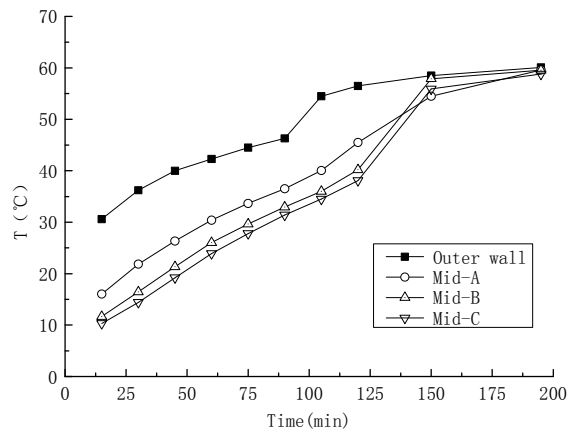


Fig. 7 (c). Heating stage from RT to 60 °C.

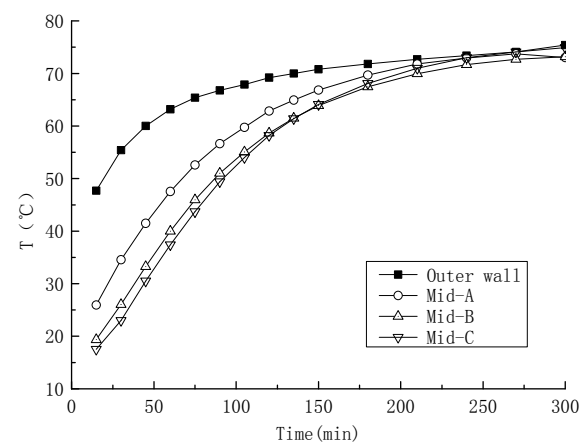


Fig. 7 (d). Heating stage from RT to 80 °C.

Fig.7. Temperature-time change curve of sectional measuring points in heating stage.

4. Conclusions

The CFST specimens are tested under axial compressive load in the conditions of different temperature on the basis of the relevant theories of temperature stress, and the strain-load relationship in interface are experimentally studied under different temperature, and the conclusion are as follows:

1) The change of radial stress is most sensitive to the change of environmental temperature, which show different characteristics in each temperature level and present the characteristic of rapid change; the variation law of hoop stress and axial stress is basic same, while which show the opposite characteristics in the condition of 11 °C and 60 °C.

2) If only to consider the radial effect alone, the reasonable service temperature range is from 11 °C to 20 °C, that is the temperature variation is within 9 °C;

if only to Consider the three directions of radial, hoop and axial stress completely, the reasonable service temperature range is from 11 °C to 40 °C, that is the temperature changes is within 29 °C; and the interface state is complex when the serving temperature above 60 °C, between 60 °C and 80 °C, that is the temperature variation is from 49 °C to 51 °C, and the harm in temperature fast rising is greater than its in temperature strong cooling.

3) The CFST members show good work performance under temperature range of 9 °C-29 °C. When the temperature range is more than 49 °C-51 °C, the interface properties and the mechanical properties are severely affected because the thermal sensitivity of steel. The climate situation does not normally occur in the region of middle latitude, and which is close to the fire performance research category when the service temperature is beyond a certain temperature range.

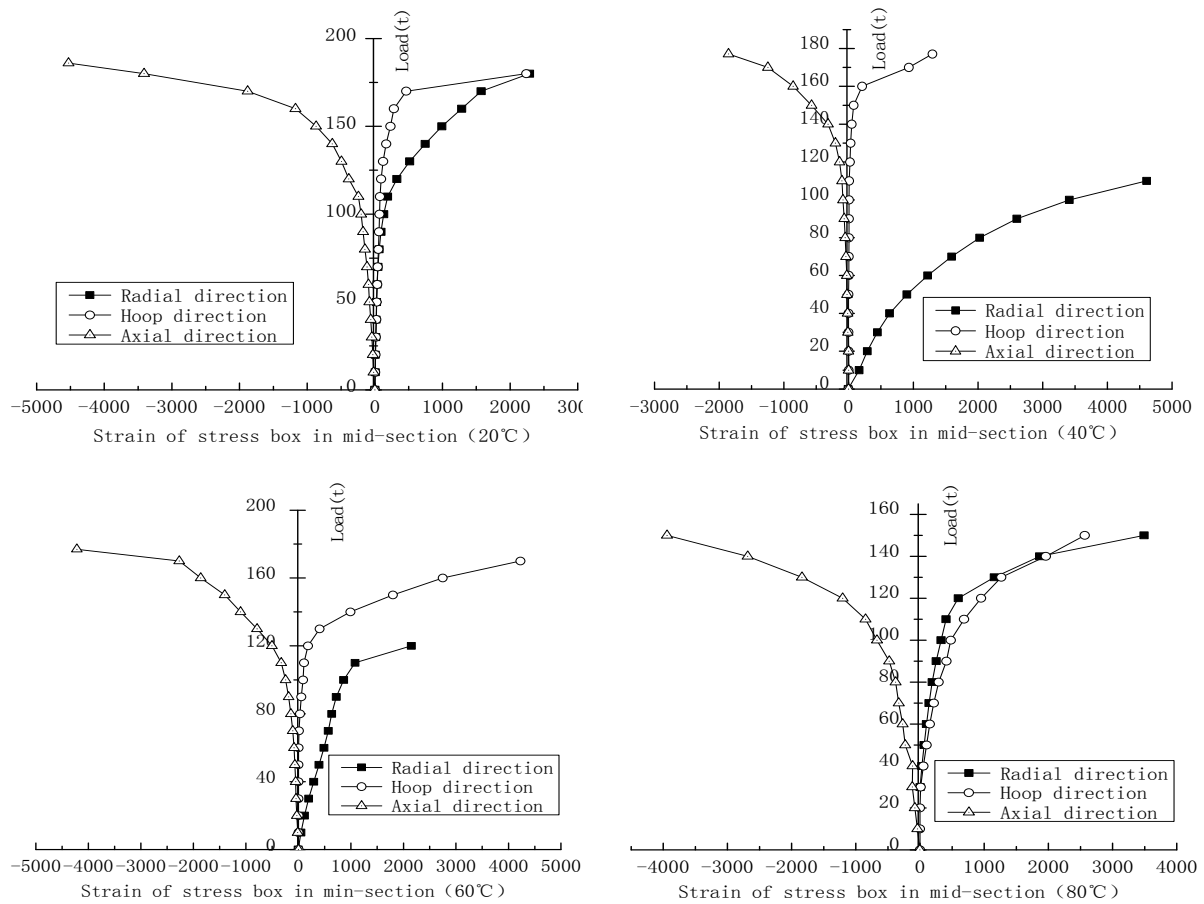


Fig. 8. Interface strain-load curve.

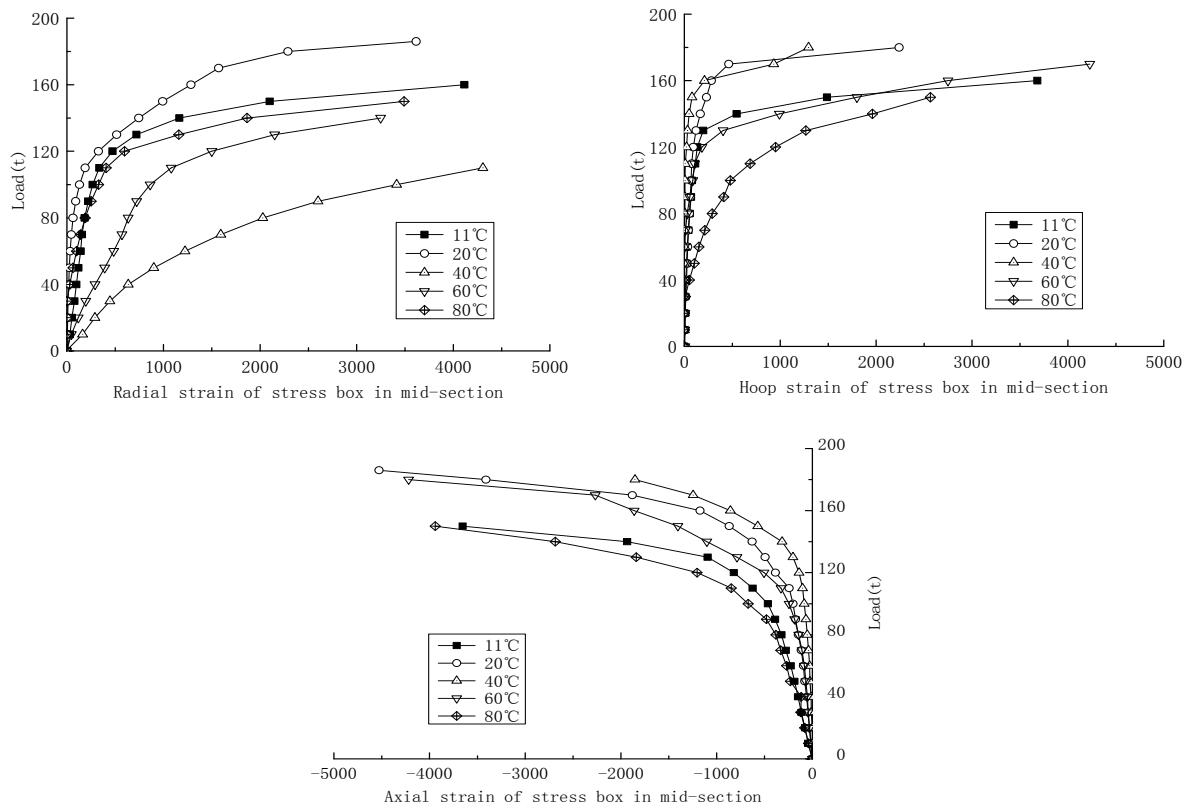


Fig. 9. Interface strain-load curve (Left-radial strain; Mid-hoop strain; Right-axial strain).

5. Acknowledgments

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