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Laboratory Evaluation of Steel Pipe Filled with Concrete Exposed to Heat Considering the Adhesion between Concrete and Steel

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Abstract: Due to the progress of composite structures and its use in columns, consideration should be given to the slip effect between the steel and concrete component as well as the appropriate solution for the shear and shear stress transfer between the two materials and the use of maximum bearing capacity of concrete and steel in these structures.

In this study, by conducting a push-out experiment unilaterally on a CFST column with a circular cross section under heat of the furnace and cooled, to evaluate the natural bonding interaction and bond stress behavior; The slip in different samples is discussed. The parameters studied in this study are the number of shear and heat applied to the specimens before cooling. The diameter-to-thickness ratio for the circular cross-section geometry is assumed to be a constant value of 70 and a number of welded shear zeros of 0, 4 and 6, and the operating temperature of the furnace at 250, 500 and 750 °C, respectively. All specimens were 14 cm in diameter and 30 cm in height.

The compressive strength of the fixed concrete and its value is 21 MPa and the steel sheet used is ST37. Bond stress and hardness indices were evaluated for each sample. The results of the study showed that the shear parameter is the cause of the macro changes in the boundary between the steel pipe and the concrete component, which results in significant changes and significant increase in the indices, resulting in a high shear residual shear strength.

Keywords: Steel Pipe Filled With Concrete, Composite Structures, Slip, Adhesion, Fire.

INTRODUCTION

Today, the use of steel pipes filled with concrete as columns with high axial force capacity in the main seismic resistant systems in restrained or unrestrained composite frames of high-rise buildings has become very popular. These members are also used as bridge piers or the main arched members of arched bridges. CFT is also used for seismic improvement purposes to strengthen concrete columns in seismic areas. A CFT structural member has distinct benefits compared to the same steel member, reinforced concrete, or steel section buried in concrete, which makes it an effective yet economical choice for construction. How to place steel and concrete in cross section so that the strength and optimizes cross-sectional stiffness. The steel is placed in the external environment, where it bears the most effective action in tensile and flexural anchors. Also the hardness of a CFT member because steel has a higher modulus of elasticity than concrete is located farthest from the center of the cross section and has the largest share of moment of inertia, significantly must increase. Existing concrete forms an ideal core for withstanding compressive loads in common applications, delaying or often preventing local buckling of the steel (especially in rectangular concrete-filled cans). In addition, it has been shown that steel pipe encloses the concrete core, which increases the compressive strength for CFTs with a circular cross-section and also increases the ductility for CFTs with a rectangular cross-section; Therefore, it is advantageous to use CFTs for columns under high compressive strength. Unlike reinforced concrete columns that have reinforcement they are transverse, the steel pipe prevents the concrete from peeling off and the density of the reinforcement in the joint areas, especially for seismic design minimizes. So far, many experiments have shown an increase in cyclic strength, ductility and damping due to the filling of hollow pipes with concrete.

For example, Ian et al. (2019), examined the behavior of twenty concrete-filled steel tubes (CFSTs) at very cold temperatures by conducting a laboratory test with ten rectangular sections and ten CFST circles under temperatures between 30° C to -80 ° C and the effect of different temperature levels, diameter to thickness ratio (D\t), concrete grades, length to diameter ratio (L\D).

Ya Tao et al. (2016), study the cohesion behavior between steel pipe and concrete in steel pipes (CFST). A series of experiments were performed on circular and square samples, and the parameters considered in the tests are: cross-sectional dimensions, type of steel (carbon and stainless steels), type of concrete (ordinary, recycled aggregates), (concrete age and surface type (normal surface, interface with shear and surface with internal annular hardeners).

Chen et al. (2015), during studies experiments push-out on eighteen steel columns with rectangular sections filled with concrete to investigate the bonding behavior between steel pipe and filled concrete.

Kai X., Guo-Hui W., Yan-Chong P. (2015), suggested to calculate temperature distribution of concrete filled steel tube reinforced concrete (CFSTRC) column with suitable thermal properties of concrete and steel.

Recent applications have also introduced the successful use of a combination of high-strength concrete with high-strength thin-walled steel pipes as a new solution. When high-strength concrete and thin-walled pipes are used both in the CFT system, the more brittle nature of high-strength concrete is somewhat reduced due to the enclosure caused by the pipe, and the local buckling of the thin steel pipe is delayed due to the pressure exerted by the concrete. One of the most widely used composite sections in the construction industry, the columns are. When the columns are executed as a composite section, in addition to strength, energy, stiffness and ductility should also pay attention to the amount of stress transfer and how this transfer. For this reason, the combined use of hardeners and Shear Stud and its effect on the amount of bond stresses and the amount of slip of concrete and steel It has also been considered by researchers.

RESEARCH METHODS

General, the studied samples are made of 6-meter pipes with a circular geometric shape. The steel sections used are made of hollow welded pipe, which is obtained from piping steel sheets and welding operations, and the material of the sheet used in the construction of these pipes is ST37. The thickness of the consumable sheets is 2 mm and the height of the samples is 300 mm. The number of samples made is 12, which are in four groups of three samples. Each groups of 3 is made of zero, 2, 3 Shear Stud on both sides of the circular specimens. The temperature of each of the three groups of 25, 250, 500 and 750 C^{o} has been selected. Duration of load is for temperatures from 100 to 400 minutes in the oven.

Compressive strength for concrete samples with three standard cubic samples of 15 cm ×15 cm at 28 day per temperature were considered. The average compressive strength of 28 day concrete for the samples was 21 MPa. The steps in general are as follows:

1. Initially, 6-meter pipes were divided into 300 mm pieces to make samples.
2. The pipes are drilled by the machine in the position of the Shear Stud.
3. Bolts through the holes and the end is welded.
4. Concrete is made with different mixing designs and concreting is done inside the pipes.
5. For each temperature of three considered sectioning position,

➢ Test 1: Section without cutter,

- Test 2: Cross section with two rows of Shear Stud,
- Test 3: Section with three rows of Shear Stud.

6. The samples were placed in the oven at different temperatures.
7. Samples were cooled at room temperature and normal.
8. Push-out test was performed for the samples using a universal device.

   In order to connect the cutting elements to the pipe sections by welding, a person skilled in welding was hired to prevent the difference in the welds in the sections as much as possible by creating a weld by one person, and by doing so, to avoid errors as much as possible.

THE SAMPLES

The basis for naming the samples are:

- The first part is the cross-sectional geometric shape, "C" is for the circular section.
- The second part is the sample name of the thickness of the circular section.
- The third part is represents the number of Shear Stud, "s", the number of which is given after the letter "s".
- The fourth part is the temperature , "t" is the amount of temperature applied to the samples, the room temperature of 25 Co with the number 0 and then the temperatures of 250, 500 and 750 Co. All samples are given according to the classification of Table 1 and Figure 1.

Table 1: Details of laboratory samples

No.	Samples	Thickness (mm)	Number of Shear Stud	Temperature (C)	Shear Stud dimensions	Pipe height (mm)	Outer diameter of the pipe (mm)
1	c2s0t0	2	0	25	0	300	140
2	c2s0t250	2	0	250	0	300	140
3	c2s0t500	2	0	500	0	300	140
4	c2s0t750	2	0	750	0	300	140
5	c2s2t0	2	2	25	2	300	140
6	c2s2t250	2	2	250	2	300	140
7	c2s2t500	2	2	500	2	300	140
8	c2s2t750	2	2	750	2	300	140
9	c2s3t0	2	3	25	3	300	140
10	c2s3t250	2	3	250	3	300	140
11	c2s3t500	2	3	500	3	300	140
12	c2s3t750	2	3	750	3	300	140

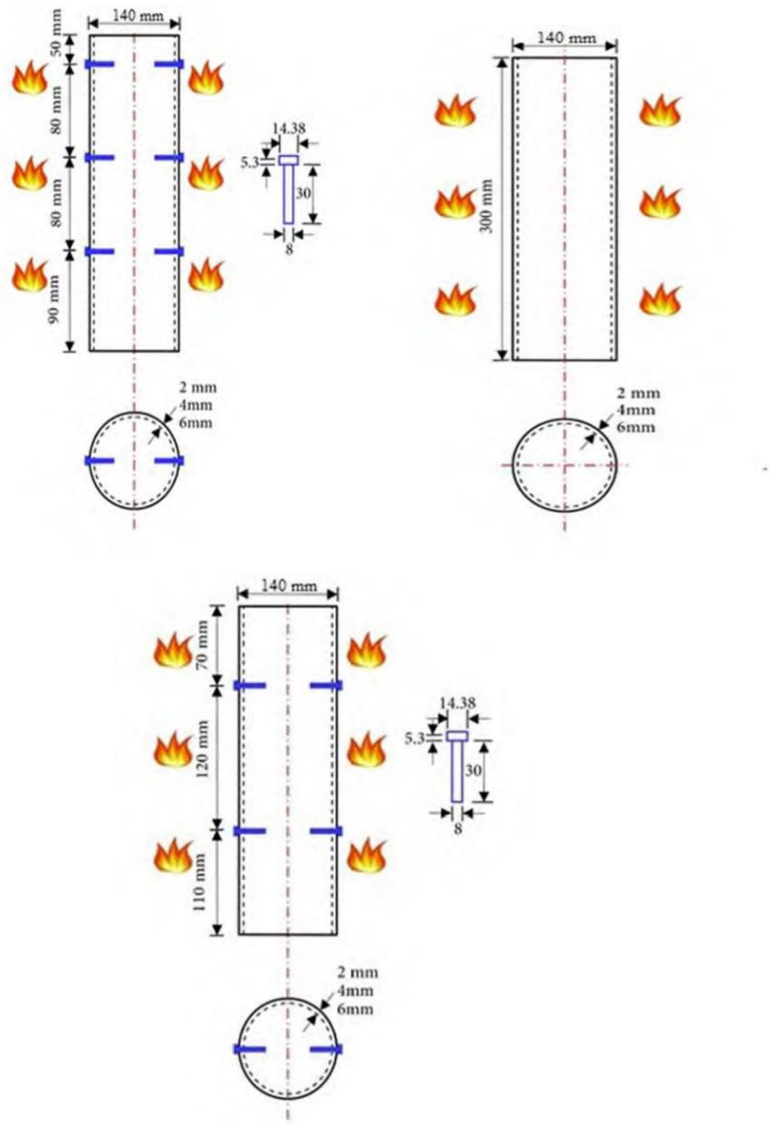

Figure 1: Drawing of the position of the Shear Stud in the studied samples.

HEATING OVEN SAMPLES

There are currently three evaluation methods for applying heat to structural members:

1. The first method is based on standard thermal conditions according to ISO 834 relationships. In this method, the design criterion is the duration of exposure of the member to ISO 834 standard temperature and the level of resistance of the member at this temperature, which should be equal to or greater than the duration of possible temperatures in the building.
2. The second method is a direct experiment on members or structures based on the theory of equality in the duration of exposure of a member to heat. In other words, it is essential that all conditions, including temperature, duration, how heat is exchanged in space, and how heat is applied to members in the test, are equal to the actual conditions at the time of fire.
3. The third method is performed by engineering calculations based on laboratory results. In this case, the evaluation is done according to the conditions and manner of exposure to heat and ventilation inside the building and the thermal characteristics of the members.

This research will be based on the first method. In this process, two steps are used to reach the temperature of 250° C. In the first stage, the temperature is applied from 25 ° C to 100 ° C for 1200 minutes, and in the second stage the heating continues for 40 minutes to reach 100 ° C to 250 ° C, and the samples are heated at a constant temperature of 250 ° C for 60 minutes. Then the temperature of the samples is kept at 250 ° C for one hour in the oven, after which the cooling process is carried out for 240 minutes.

For a temperature of 500° C, two steps are used. In the first stage, the temperature is applied from 25 ° C to 100 ° C for 1200 minutes, and in the second stage, the temperature is applied from 100 ° C to 250 ° C for 40 minutes, from 250 ° C to 350 ° C for 60 minutes, and from 350 ° C to 500 ° C it takes 150 minutes. Samples were heated at a constant temperature of 500 ° C for 60 minutes. Then the temperature of the samples was kept at 500 ° C for one hour in the oven, after which the cooling process was performed for 400 minutes.

For a temperature of 750 ° C, two steps are used. In the first stage, where the temperature is applied from 25 ° C to 100 ° C for 1200 minutes, and in the second stage, the temperature is applied from 100 ° C to 250 ° C for 40 minutes, from 250 ° C to 350 ° C for 60 minutes, and from 350 ° C to 500 ° C For 150 minutes, from 500 ° C to 600 ° C for 140 minutes, and from 600 ° C to 750 ° C for 200 minutes, then the samples are kept at constant temperature for 60 minutes at 750 ° C. Then the samples are kept at 750 ° C for one hour at a certain temperature in the oven, after which the cooling process is performed for 700 minutes. The Figure 2 shows the placement of CFST columns inside the oven along with a concrete cube sample and a steel tensile test specimen.

Figure 2: column CFST in the oven with samples of concrete cubes

TEST METHOD

This section describes how to perform the tests and the tools used. It should be noted that there are no standard procedures to describe the requirements and how to measure the degree of bond strength of CFST members in the ASTM Standard, so previous research in recent years published in international scientific journals was used as the basis for this research. Accordingly, the push-out test was performed with a loading speed of 0.6 mm/min and in accordance with the details to be mentioned below.

RESULTS

In this section, the effect of the number of Shear Stud on bond stress is discussed in the sample results. The number of Shear Stud in the sample is 0, 4, and 6, respectively.

Figure 3 shows (comparison of laboratory results) and Table 2 illustrates the relative changes in stiffness due to the bond between concrete and steel, the relative amount of bond stress and the relative amount of slip at maximum bond stress for samples c2s0t0, c2s2t0 and c2s3t0.

In these three samples, the standard sample was taken for comparison 2s0t0 and two samples of c2s3t0 and 0c2s2t0 were measured compared to the standard sample.

The C2s20 sample compared to the c2s0t0 sample had a relative increase in adhesion stiffness, bond stress and slip at the highest bond stress of 16, 403 and 501%, respectively 120, 590 and 505%.

Similarly, the value of the other samples to the effect of the number of Shear Stud are shown in Table 2 and Figure 3 to 6 are the comparative data and graphs of samples.

Table 2: Relative changes of indices for the number of shear parameters

Sample name	Relative amount of adhesion hardness	Relative amount of band tension	Relative amount of slip at maximum bond stress
c2s0t0	1.00	1.00	1.00
c2s2t0	1.16	5.03	6.01
c2s3t0	2.20	6.90	6.05
c2s0t250	1.00	1.00	1.00
c2s2t250	1.01	2.29	4.41
c2s3t250	1.48	3.01	4.21
c2s0t500	1.00	1.00	1.00
c2s2t500	1.07	1.87	5.34
c2s3t500	1.12	2.47	5.34
c2s0t750	1.00	1.00	1.00
c2s2t750	1.23	1.02	0.95
c2s3t750	1.49	1.70	1.30

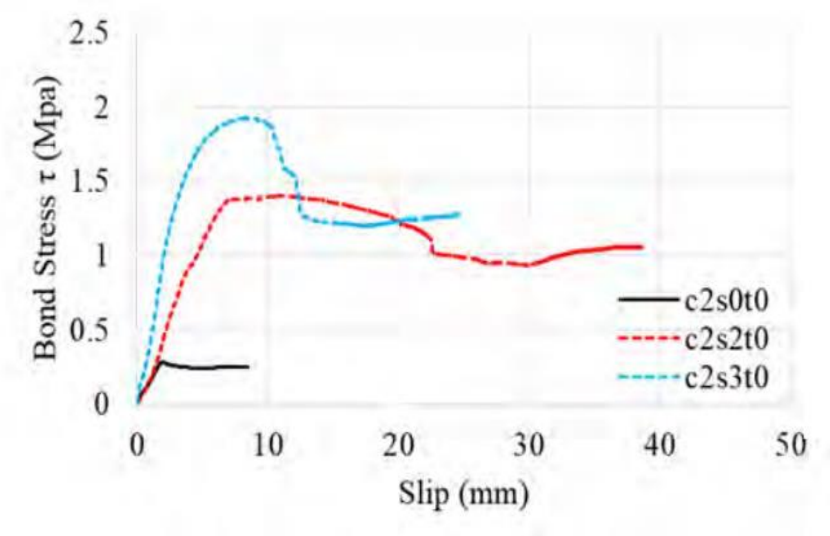

Figure 3: Comparison of band stress-slip diagrams of samples c2s0t0, c2s2t0 and c2s3t0

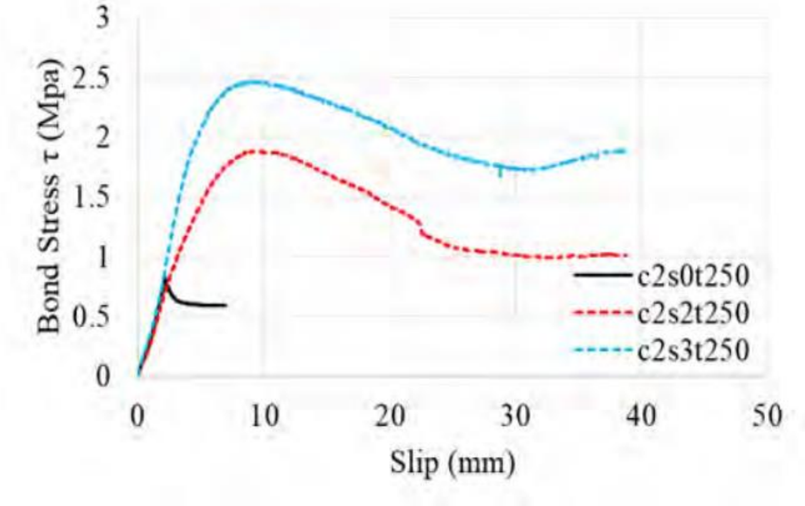

Figure 4: Comparison of band stress-slip diagrams of samples c2s0t250, c2s2t250 and c2s3t250

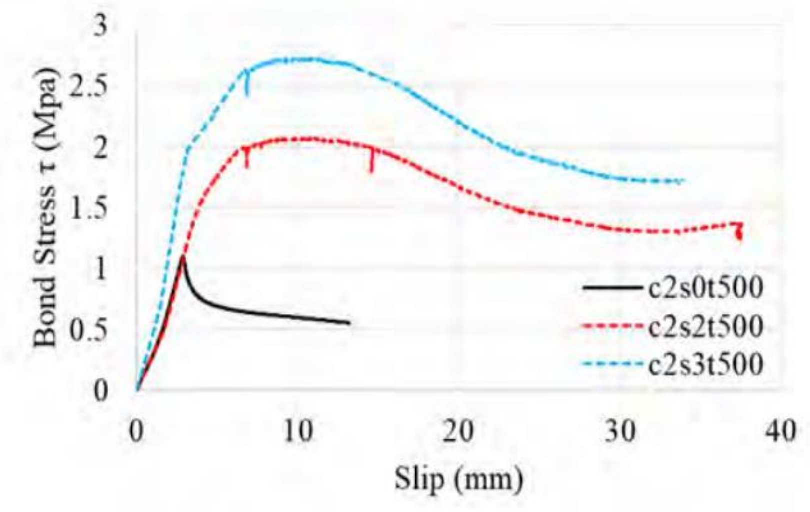

Figure 5: Comparison of band stress-slip diagrams of samples c2s0t500, c2s2t500 and c2s3t500

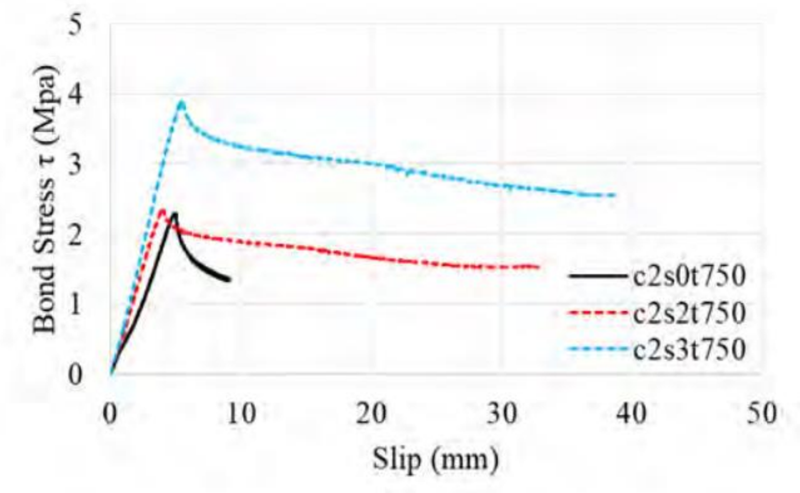

Figure 6: Comparison of band stress-slip diagrams of samples c2s0t750, c2s2t750 and c2s3t750

According to a laboratory study of post-fire behavior of columns CFST, the following results can be provided with a cutter:

1. Changing the indicators in the non-contactor condition compared to 4 contactors and 6 contactors increased the bond stiffness by 1 to 120% and the bond stress increased by 2 to 590%.
2. The shear parameter is also the cause of macro changes in the boundary between the steel pipe and the concrete component, so that it causes noticeable changes and a significant increase in the indices and causes a residual shear strength after high slip.
3. Failure mode in non-shear samples is unobstructed sliding between concrete and steel, but in shear samples it causes local compaction and crushing of concrete around the screw and local buckling of the steel pipe outwards around the screw.

DISCUSSION AND CONCLUSION

In general, the studied samples are 6 meters long tubes with a circular geometry, and the used steel sections are hollow tubes of ST37 material. The thickness of the spent plates is 2 mm and the height of the samples is 300 mm. The number of samples taken is 12, and they are in four groups of three. Each group of 3 consisted of 0, 2, and 3 sides of the circular samples. The temperature of each of the three groups is determined, and the number of incisors is 0, 250, 500 and 750 ° C. The temperature loading time ranges from 100 to 400 minutes in the oven. By performing a one-way push-out test on a CFST column with a circular cross-section that has been heated and cooled by a furnace, to evaluate the natural bonding interaction and bond stress behavior- Slip is discussed in various examples. The parameters studied in this study are the number of Shear Stud and the temperature applied to the samples prior to cooling.

It was observed that the change of indices in the state without cutter compared to 4 Shear Stud and 6 Shear Stud caused an increase in bond stiffness by 1 to 120% and an increase in bond stress by 2 to 590%. It is unobstructed, but in specimens with Shear Stud, it causes local compaction and crushing of the concrete around the screw and local buckling of the steel pipe outwards around the screw.

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