Experimental Research on the Bond-Slip Behavior of Red Mud Concrete Filled Square Steel Tubes

Bin Wu1, 2, *, Zhuoying Tan1, Yongdan Zhang2, Zhonghua Zhao3, Chengxue Liu3

1School of Civil and Resource Engineering, University of Science and Technology Beijing, China
2Department of Construction Engineering, Liaoning Provincial College of Communications, Shenyang Liaoning, China
3Shenyang Urban Construction University, Shenyang Liaoning, China

*Corresponding author e-mail: 66084537@qq.com

Abstract. In order to study the bond slip behavior of red mud concrete-filled square steel stubs, fifteen red mud concrete filled square steel tubes short column specimens were designed for the push-out test. Five parameters including replacement rate of red mud mass, concrete strength, embedment length, length diameter ratio, width to thickness ratio were regarded as variable parameters in the experiment. Through experiment, the load-slip curves of red mud concrete filled square steel tubes were obtained and analyzed. The results show that the load slip curves of red mud concrete filled square steel tubes can be classified into five stages: no slipping section, ascending section, descending section, re-ascending section and re-descending section. The bond strength increases first and then decreases with the increase of red mud substitution rate. When the substitution rate of red mud is 5%, the bond strength reaches the maximum. When the substitution rate of red mud is 20%, the bond strength is equivalent to that of normal concrete filled steel tube.

1. Introduction

Red mud concrete [1] is a new environmental protection and energy saving material, which is made of waste red mud produced by aluminum industry after grinding and drying instead of part of cement. However, by the study of the relevant scholars, red mud concrete has certain defects that are poor durability, high water absorption, slightly higher radiation than ordinary concrete, etc, which affects its popularization and application in Engineering [2-7]. In order to overcome the defects of red mud concrete, this paper proposes the concept of red mud concrete filled steel tube, combines the steel pipe with red mud concrete, forms red mud concrete filled steel tube, makes use of the advantages of concrete filled steel tube to improve the defects of red mud concrete. Because of the interfacial slip between the steel tube and the red mud concrete, the reliability of the interface between the steel tube and the red mud concrete is considered, therefore, before studying the static performance of red mud concrete filled steel tube, at the beginning, we discuss the problem of bond slip between steel tube and red mud concrete interface. For this purpose, the launching tests of 15 red mud concrete filled square steel tubes are carried out to explore the bond slip behavior of red mud concrete filled square steel tubes interface.
2. General situation of experiment

2.1. Experimental materials and mix ratio

The yield strength \( f_y \), tensile strength \( f_u \) and elastic modulus of the steel tube \( E_s \) are determined according to the document [8] are listed in Table 1.

| NO. | Steel B×t(mm) | \( f_y \) (MPa) | \( f_u \) (MPa) | \( E_s \) (GPa) |
|-----|---------------|----------------|----------------|---------------|
| 1   | 120×3(3.5)    | 403.3          | 484.9          | 206           |

The cement adopts Yatai P.O42.5 ordinary portland cement, the coarse aggregate is continuous graded broken stone whose maximum particle size is 20mm; the fine aggregate is medium sand; the water is common tap water; the red mud is alumina red mud from Bayer process of Weiqiao Company in Beihai, Shandong; the admixture is an high efficiency water reducing agent ADVA-109 of Grace, USA; the quality substitution rate of red mud is respectively is 0%, 5%, 10%, 15%, 20%; The concrete mix proportion according to document [9] are listed in Table 2.

| NO. | Red mud | Cement | Fine aggregate | Course aggregate I | Course aggregate II | Water | Water-reducing admixture |
|-----|---------|--------|----------------|---------------------|---------------------|-------|-------------------------|
| RMC-0 | 0       | 360    | 780            | 216                 | 862                 | 162   | 3.6                     |
| RMC-5 | 18      | 342    | 780            | 216                 | 862                 | 162   | 3.9                     |
| RMC-10 | 36      | 324    | 780            | 216                 | 862                 | 162   | 4.3                     |
| RMC-15 | 54      | 306    | 780            | 216                 | 862                 | 162   | 4.7                     |
| RMC-20 | 72      | 288    | 780            | 216                 | 862                 | 162   | 5.3                     |

2.2. Design and manufacture of specimens

15 specimens were designed totally, considering five parameters that are red mud replacement rate, concrete strength, embedment length, length diameter ratio and width to thickness ratio, seeing in Table 3. When we pour of the specimen, place square steel tubes on a flat steel plate, pour the red mud concrete hierarchically. When the red mud concrete is poured to the 40mm of the top of the steel pipe, the concrete pouring is stopped and the top surface is flattened. At the same time, the cubic of red mud concrete specimens were made under the same condition as the red mud filled steel tube test. The partly specimens of the cast are shown in Figure 1.

2.3. Loading device and loading system

The test is carried out by the 200t microcomputer controlled pressure test machine of Liaoning Provinclal Transportation College. The loading mode of displacement control is adopted, and the loading rate is 0.01mm/s. When loading, a 60mm thick steel backing plate is placed on the red mud concrete surface at the load side, the size of which is slightly smaller than that of the steel tube. During the test, the red mud concrete at the loading side is compressed, the steel tube of the free end is pressed, the red mud concrete is pushed out from the steel pipe, and the loading device is shown in Figure 2.
### Table 3. Experimental parameters of specimens

| NO. | B/mm | t/mm | h/mm | r   | Concrete strength | $f_{cu}$ /MPa | Embedded length L/mm | L/B | B/t |
|-----|------|------|------|-----|-------------------|---------------|----------------------|-----|-----|
| S-1 | 120  | 3.5  | 450  | 0%  | C50               | 52.5          | 410                  | 2.93| 34.3|
| S-2 | 120  | 3.5  | 450  | 5%  | C50               | 60.4          | 410                  | 2.93| 34.3|
| S-3 | 120  | 3.5  | 450  | 10% | C50               | 58.3          | 410                  | 2.93| 34.3|
| S-4 | 120  | 3.5  | 450  | 15% | C50               | 53.8          | 410                  | 2.93| 34.3|
| S-5 | 120  | 3.5  | 450  | 20% | C50               | 50.1          | 410                  | 2.93| 34.3|
| S-6 | 120  | 3.5  | 300  | 5%  | C50               | 60.4          | 260                  | 1.86| 34.3|
| S-7 | 120  | 3.5  | 300  | 15% | C50               | 53.8          | 260                  | 1.86| 34.3|
| S-8 | 120  | 3.5  | 450  | 5%  | C30               | 42.4          | 410                  | 2.93| 34.3|
| S-9 | 120  | 3.5  | 450  | 15% | C30               | 36.2          | 410                  | 2.93| 34.3|
| S-10| 120  | 3.5  | 300  | 5%  | C30               | 42.4          | 260                  | 1.86| 34.3|
| S-11| 120  | 3.5  | 300  | 15% | C30               | 36.2          | 260                  | 1.86| 34.3|
| S-12| 120  | 3.0  | 450  | 5%  | C50               | 60.4          | 410                  | 2.93| 40  |
| S-13| 120  | 3.0  | 300  | 5%  | C50               | 60.4          | 260                  | 1.86| 40  |
| S-14| 120  | 3.0  | 450  | 5%  | C30               | 42.4          | 410                  | 2.93| 40  |
| S-15| 120  | 3.0  | 300  | 5%  | C30               | 42.4          | 260                  | 1.86| 40  |

2.4. **Content of measurement and layout of measuring point**

Before the test, the strain gauge were pastes in the outer wall of the steel tube and measure the strain of steel tube in the whole process of testing. The distribution of bond stress is obtained by strain gradient of steel tube. When opening small holes on the side wall of the steel tube and pouring red mud concrete, steel bars are embedded into red mud concrete and make it extend out, install displacement meter, measure the relative slip between steel tube and red mud concrete, which are as shown in Figure 3.
3. Result and discussion

3.1. Test phenomenon
At the beginning of loading, there is no relative slip between square steel tube and red mud concrete. With the increasing growth of load at loading end, when the load reaches 11% to 14% of the limit load, the end of the load begins to slip; when the load increases further, the slip also increases further and can hear the sound of “shasha”; at this time, load slip curve is basically linear growth; When the sound of “kaka” can be heard, the load reaches the limit. Then the load descends about 10%, then rises again, then drops after the turning point. Generally, the decline is limited and the final curve tends to be stable. When the slip is between 4 and 5mm, the test is stopped. At this time, the steel pipe does not yield and overall the slip of concrete occurred without appearing to be crushed.

3.2. Load-slip curve
The load slip curves of the specimens are measured during the loading process, as shown in Figure 4. As we can see from Figure 4, the loading end of the specimen is similar to the load slip curve of the free end. The free end begins to slip at the end of the loading end. And when the slip amount at the loading end is larger than the free end slip and the load reaches about 90% of the ultimate load, the free end produces slip.

![Fig 3. Trepanning and layout of strain gauges of red mud concrete filled steel tube](image)

![Fig 4. Load-slip curves](image)
The load slip curves of steel pipe red mud concrete can be roughly divided into 5 stages, that are no slip section, ascending section, descending section, two ascending section and two descending segment. Because of the chemical cementation force between the steel tube and the red mud concrete, there is no slip section. As the load increases, when the load reaches the sum of the mechanical bite force and the chemical cementation force between the steel tube and the red mud concrete, the load reaches the peak, the curve is in the rise section, and then the load is suddenly reduced by about 10%, and the curve is at descending segment. then the curves are into the two ascending segment, but the increase is not more than the peak point. When the chemical cementation force and the mechanical bite force are lost, the bond between the steel tube and the red mud concrete is mainly based on the friction between the two, and the curve is slower and the curve is at the re-fall. From table 3 and Figure 4, it is found that the bond strength increases first and then decreases with the increase of red mud substitution rate. When the red mud substitution rate is 5%, the bond strength reaches the maximum. When the red mud substitution rate is 20%, the bond strength is equal to that of the standard concrete.

4. Conclusion

Through the above research, we have drawn conclusions as follow.

(1) The anti slip ability between steel pipe and red mud concrete is mainly provided by mechanical biting force, chemical cementation force and friction force.
(2) The load slip curves of red mud concrete filled steel tube can be roughly divided into 5 stages which are no slip section, ascending section, descending section, two ascending section and two descending segment.

(3) The bond strength between the steel pipe and the red mud concrete interface increases first and then decreases with the increase of red mud substitution rate. When the red mud substitution rate is 5%, the bond strength reaches the maximum. When the red mud substitution rate is 20%, the bond strength is equivalent to the standard concrete filled steel tube.

Acknowledgments
This work was financially supported by National Natural Science Foundation of China (51574015), Liaoning Province Natural Science Foundation fund (20170540493), Liaoning province PHD startup fund (20170520139) and School-level research projects of Liaoning Provincial College of Communications (Lnccybky201701).

References
[1] Rudraswamy M.P, Dr.K.B.Prakash. AN EXPERIMENTAL INVESTIGATION ON THE EFFECT OF ALTERNATE WETTING AND DRYING ON THE PROPERTIES OF CONCRETE PRODUCED BY RED MUD [J]. International Journal of Advanced Research, 2014, 2 (1): 473—484.

[2] D.Linora Metilda, C.Selvamony, R.Anandakumar,A.Seeni. Investigations on optimum possibility of replacing cement partially by red mud in concrete [J]. Scientific Research and Essays, 2015, 10 (4): 137—143.

[3] Pratik Deshmukh. Efficient Use of Aluminum Industry Waste (Red Mud) for High Quality Self Compacting Concrete [J]. International Journal of Advanced Research, 2015, 3 (12): 759—764.

[4] Liang Naixing, Zhang Dengliang. Analysis of Mechanical Properties of Cement Red Mud Concrete [J]. Journal of Xi'an Highway University, 1995, 15 (3): 1—4.

[5] Liang Naixing, Zhang Dengliang, Yan Zuxing. Strength mechanism of cement red mud concrete [J]. J. Xi'an Univ. of Arch.a Tech, 1996, 28 (2): 147—151.

[6] Yan Zuxing. The Application and Research of Cement-red Mud Concrete [J]. Concrete, 2000, 132 (10): 18—20.

[7] Liu Chun, Yin Guoxun. Research About Producing a Process Kind of Concrete with Sintering Red Mud [J]. China Resources Comprehensive Utilization, 2007, 25 (3): 17-19.

[8] GB/T228—2002 Metallic materials tensile testing at ambient temperature [S]. Beijing: Standard Press of China, 2002.

[9] JGJ55-2011 Specification for mix proportion design of ordinary concrete [S].Beijing: China Architecture and Building Press, 2011.