Shear test on binding performance of reactive powder concrete and normal concrete

Xinmin Yu¹, Shichuan Chen¹, Shifeng Hou², Dehong Wang², Yanzhong Ju²*

¹State GRID Fujian Economic Research Institute, Fuzhou, Fujian Province 350000, China
²School of Civil Engineering and Architecture, Northeast Electric Power University, Jilin, Jilin Province, 132012, China
*Corresponding author’s e-mail: juyanzhong@126.com

Abstract. In order to investigate the bonding performance between reactive powder concrete (RPC) and normal concrete (NC), nine groups of RPC-NC composite specimens were designed for double-sided shear based on the orthogonal test. The test parameters include interface roughness, RPC water binder ratio and steel fibre content. The results show that the roughness is the most important factor to affect the bond shear strength, followed by RPC water binder ratio, and steel fibre content has the least influence. In the range of 2.11mm ~ 6.01mm average sand filling depth, the bonding strength of RPC and NC with the same water binder ratio increases with the increase of interface roughness. The average bonding strength of 0.22 water binder ratio group is the highest, and it is 7.6% and 28.3% higher than that of 0.24 and 0.20 groups, respectively. Based on the test results, the prediction formula of the bond shear strength of RPC-NC considering the interface roughness and the water binder ratio of RPC is established.

1. Introduction

Concrete structure is a very widely used structural form, but due to the characteristics of its materials and use environment, the concrete structure has serious durability problems [1]. At the same time, the bearing capacity of the existing buildings can’t meet the current use requirements due to the change of the use function and the extension of the use period of the buildings. Therefore, reconstruction and reinforcement of the existing buildings are necessary measures. Compared with demolition and reconstruction, partial or overall reinforcement of the existing concrete structures can restore or enhance the original design function and extend its use period, and it can save a lot of human resources and capital investment [2]. At present, high-strength concrete and fibre-reinforced concrete materials are still widely used in structures reinforcement. However, due to the defects of these materials, new cracks often occur in a short period of time. Reactive power concrete (RPC) is developed by Bouygues Company in France in 1990s, and it is a new cement-based composite material with high strength and durability [3, 4]. RPC not only has ultra-high compressive strength, but also has ultra-high cracking strain, and its bending cracking strain can reach 0.00075 [5, 6]. RPC has a good application prospect in the reinforcement of concrete structures [7].

At present, researchers at home and abroad have carried out a lot of research on the bonding performance between new and old concrete, but mainly concentrated on the bond between normal concrete, high-strength concrete and old concrete [8-11]. The research on the bonding performance of
RPC and normal concrete is limited. The existing results of the bonding performance of new and old concrete are usually based on the bond test of old concrete and post-poured normal concrete or high-strength concrete, and it is necessary to study whether they are suitable for the bonding performance of ultra-high performance RPC and normal concrete.

2. Experimental survey

2.1. Specimens design
RPC-NC bonding test chooses RPC water binder ratio, steel fibre content and interface roughness as influence factors. The water binder ratio of RPC is 0.2, 0.22 and 0.24 respectively; volume fraction of steel fibre is 1.0%, 1.5% and 2.0% respectively; interface roughness is achieved by different interface treatment methods, characterized by average sand filling depth, and interface treatment methods include manual brushing (the average sand filling depth is 2.11~2.39mm), manual light chiseling (the average sand filling depth is 4.43~4.53mm), and manual groove cutting (the average sand filling depth is 5.67~6.01mm). According to the orthogonal test, 9 groups of tests are designed, and each group makes 3 test specimens. In order to know the test parameters of each group, the test group name is composed of test parameters. The interface treatment methods are represented by the combination of A and number, and A1, A2 and A3 represent manual brushing, manual light chiseling and manual groove cutting respectively; the water binder ratio of RPC is represented by the combination of W and W/B value; the volume fraction of steel fibre in RPC is represented by the combination of F and volume fraction value. For example, a3w0.22f1.0 represents that the interface treatment method of this group is manual groove cutting, the water binder ratio of RPC is 0.22, and the volume fraction of steel fibre is 1.0%. The test parameters of each group are shown in Table 1.

| Group number | Interface treatment methods | Average sand filling depth (mm) | Water binder ratio of RPC | Volume fraction of steel fiber |
|--------------|----------------------------|--------------------------------|---------------------------|------------------------------|
| A1W0.20F1.0  | Manual brushing            | 2.23                           | 0.20                      | 1.0%                         |
| A2W0.20F1.5  | Manual light chiselling    | 4.46                           | 0.20                      | 1.5%                         |
| A3W0.20F2.0  | Manual groove cutting      | 5.67                           | 0.20                      | 2.0%                         |
| A3W0.22F1.0  | Manual groove cutting      | 5.74                           | 0.22                      | 1.0%                         |
| A1W0.22F1.5  | Manual brushing            | 2.39                           | 0.22                      | 1.5%                         |
| A2W0.22F2.0  | Manual light chiselling    | 4.53                           | 0.22                      | 2.0%                         |
| A2W0.24F1.0  | Manual light chiselling    | 4.43                           | 0.24                      | 1.0%                         |
| A3W0.24F1.5  | Manual groove cutting      | 6.01                           | 0.24                      | 1.5%                         |
| A1W0.24F2.0  | Manual brushing            | 2.11                           | 0.24                      | 2.0%                         |

At present, the tests used for the bond performance of concrete are mainly divided into the tensile and shear performance tests [12, 13]. In this paper, the double-sided shear test is used to study the shear performance of RPC-NC bonding. The double-sided shear test also adopts the 150 mm × 150 mm × 150 mm cube specimen. When the specimen is made, the NC with width of 50 mm on both sides is poured laterally. After standard curing for 28 days, RPC is poured into the remaining space. The specimen form is shown in Figure 1. The design strength class of normal concrete used in the test is C30.
2.2. Test method

The shear test of RPC-NC composite specimens is carried out by a 100 t microcomputer controlled electro-hydraulic servo universal material testing machine. During the loading of the composite specimens, the loading is controlled by load with the constant loading rate of 0.5kN/s at first. When the load reaches 100kN, it shall be changed to be controlled by displacement with the constant loading rate of 0.2mm/min until the specimen is finally damaged. The specific specimen loading is shown in Figure 2.

3. Results and discussion

3.1. The phenomena and analysis of shear test

All the specimens are shear peeling failure on the bonding surface between RPC and NC of one side. When the specimen is loaded, small cracks appear on the bonding surface of one side at first. At this time, the slip of the specimen is small. With the increase of the load, the cracks gradually develop vertically along the interface, the crack width continues to grow, and the interface cracks also appear on the other side. When the load reaches the ultimate load of the shear specimen, the specimen makes a large sound of concrete being sheared. For the specimen with manual brushing interface, RPC and NC are completely separated due to the weakest bonding force of the manual brushing interface when cracking. For the manual light chiselling and manual groove cutting interface, RPC and NC can still bond together after cracking. As the test continues, RPC and NC are gradually separated. It can be observed that the two materials have obvious relative slip at the cracking interface. As the loading continues, the relative displacement of the two materials gradually increases until the failure. By observing the failure surface of the specimen, it can be found that the RPC side is bonded with NC aggregate and the cut stone section, the NC side is bonded with steel fibre and RPC gel, and the protruding stone on the interface is cut during the test. This phenomenon is especially obvious at the interface of manual light chiselling and manual groove cutting. The reason is that the cementitious material in RPC can flow into the gap of NC surface to form a certain bonding force due to the large interface roughness of manual light chiselling and manual groove cutting.

3.2. The shear load-displacement curves

Figure 2 shows the shear load-displacement curves of RPC-NC composite specimens before reaching the maximum shear load. It can be seen from the figure that the interface treatment has a significant effect on the shear capacity and vertical displacement of the specimens under the same W/B. The vertical displacement and shear capacity of the composite specimens increase with the increase of the interface roughness. The vertical displacement and shear capacity of manual brushing interface are the minimum, and those of manual groove cutting interface are the maximum under each W/B. From the view of interfacial bonding, the increase of interface roughness makes the bonding strength increase, thus improving the shear capacity of composite specimens. When the specimen reaches the shear bearing capacity, the interface will be damaged with relatively large slip, and the shear failure of composite specimens is attributed to brittle failure. The results show that the manual brushing
interface is separated directly, while the manual light chiselling interface and manual groove cutting
interface crack with the small crack width and the two materials are still bonding together. This
indicates that the interface roughness has a great effect on the shear strength of RPC-NC composite
specimens.

![Graphs](image_url)

(a) W/B of 0.2  (b) W/B of 0.22  (c) W/B of 0.24

Figure 2. The shear load-displacement curves.

3.3. Shear strength

The shear strength test results of the binding between reactive powder concrete and old concrete are
shown in Table 2. The bonding shear strength of reactive powder concrete and old concrete is between
1.75 and 4.96, and the bonding shear strength of manual groove cutting group is the highest due to its
highest roughness. It can be seen from the test results that the shear strength of RPC-NC composite
specimens increases with the increase of interface roughness. The reason is that the increase of
interface roughness makes the surface of NC more uneven with coarse aggregate protruding, and the
mechanical occlusion between NC and post-poured RPC is significantly enhanced. In addition, the NC
bonding area with post-poured RPC is also increased, and the bonding strength of interface is
improved, especially for the manual groove cutting interface. The average bonding strength of the
three groups with W/B of 0.22 is the highest, 3.32MPa, and those of the groups with W/B of 0.20 and
0.24 are 3.09MPa and 2.59MPa, which are 7% and 22% lower than that of the group with W/B of 0.22
respectively. The reason is that the slump of RPC with W/B of 0.22 is 180 ± 10 mm, and it has a
suitable workability and better bonding performance with NC. The influence of volume fraction of
steel fibre on the bonding performance of RPC and NC is not obvious. The reason is that the change of
steel fibre content will affect the strength of RPC, but the bonding effect of RPC-NC mainly comes
from the mechanical and chemical bonding forces. The failure of mechanical bonding effect is caused
by the shear failure of RPC-NC interface and has nothing to do with the strength of RPC.

| Group number | A1W0.20F1.0 | A2W0.20F1.5 | A3W0.20F2.0 | A3W0.22F1.0 | A1W0.22F1.5 |
|--------------|-------------|-------------|-------------|-------------|-------------|
| Shear strength (MPa) | 2.07         | 2.23         | 4.96         | 3.64         | 3.24         |

| Group number | A2W0.22F2.0 | A2W0.24F1.0 | A3W0.24F1.5 | A1W0.24F2.0 |
|--------------|-------------|-------------|-------------|-------------|
| Shear strength (MPa) | 3.08         | 2.58         | 3.43         | 1.75         |

The above analysis shows that the bonding shear strength of RPC and NC is mainly affected by the
interface roughness and RPC water binder ratio. Based on the test results, taking the interface
roughness and RPC water binder ratio as independent variables, the test results are fitted with multivariate function. The formula of bonding shear strength of RPC and NC is as follows:

\[
\tau = 4.11 - 13.22\frac{W}{B} + 0.43V_S, \quad 0.2 \leq \frac{W}{B} \leq 0.24, \quad 1.75 \leq V_S \leq 4.96
\] (1)

In the formula, \(\tau\) is bonding shear strength; \(W/B\) is water binder ratio of RPC; \(V_S\) is volume fraction of steel fibre.

4. Conclusion

(1) The shear failure mode of RPC-NC composite specimens is the interface peeling failure of one side, and it is a typical kind of brittle failure. Interface treatment method has a great influence on the shear capacity and relative displacement of composite specimens, and the shear capacity and relative displacement of RPC-NC composite specimens in the manual groove cutting groups are the largest.

(2) The interface roughness has the greatest influence on the bonding strength of RPC-NC. The average bonding strength of the specimens in the manual groove cutting groups is 52.5% and 70.4% higher than that in the manual light chiselling groups and the manual brushing groups, respectively. In the process of repair and reinforcement, it is suggested that the interface treatment method should adopt manual groove cutting.

(3) The average bonding strength of specimens with RPC water binder ratio of 0.22 is 3.32 MPa, and it is 7.6% and 28.3% higher than that of 0.20 and 0.24 respectively. The influence of volume fraction of steel fibre on the interface bonding strength is not obvious. It is suggested that the water binder ratio of RPC for concrete reinforcement is 0.22-0.24, and the volume fraction of steel fibre is 1.0%.

(4) Based on the test results, the prediction formula of RPC-NC bonding shear strength is established by taking the interface roughness and RPC water binder ratio as variables, and it can provide a basis for the initial application of RPC-NC composite members.

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