Analysis of Interfacial Bonding Properties of Existing Railway Concrete Bridges Reinforced with Ultra-High Performance Concrete

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Abstract. The material deterioration of existing railway concrete bridges in the service process is frequent, and it is urgent to strengthen and repair them. Ultra-high performance concrete, as a repair material, has excellent mechanical properties. In this paper, the interfacial bonding properties of ultra-high-performance concrete reinforced existing railway concrete bridge structures are studied. The changes of the bonded strength of the repaired interfacial bond of the composite specimens under different interface treatments were studied by splitting tensile test, and the changes were evaluated and compared. The results show that the bond effect between UHPC and ordinary existing concrete structures is excellent and can be used in the reinforcement and repair work of existing railroad concrete bridges. Before strengthening and repairing, roughening and moistening the interface of existing concrete structures can substantially improve the bond performance of the interface.

Keywords: UHPC; Existing railway concrete bridges; Reinforcement repairs; Interfacial bonding properties

1 Introduction

With the rapid development of China's transportation industry, railway operation plays an extremely important role in the modern transportation system, becoming the mainstay of the transportation industry. By the end of 2024, the total mileage of China's railways had reached 162,000 km, and in such a large number of railway lines, railway bridges generally occupy more than 70 % of the total length of the line. In recent years, due to early design deficiencies, long-term loading and the influence of the external harsh environment, many existing railway concrete bridges have gradually undergone material deterioration during service, with cracking of girders, concrete breakage and other phenomena, resulting in insufficient durability and reduced load-bearing capacity. In response to the many existing railway diseased bridges, if they are dismantled and

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rebuilt, on the one hand, it will seriously affect the normal operation of the national railway lines, and on the other hand, it may be burdensome to the future economy and pose a hidden danger to public safety [1]. Under the limitations of social and economic factors, effective reinforcement and repair of damaged structures has become a widespread concern [2-4]. According to the current domestic and international engineering cases of old bridge reinforcement and rehabilitation, the reinforcement cost of bridges is generally about 30 % of the cost of new bridge construction. In addition, the process of bridge reinforcement and renovation has a short cycle and convenient construction, which can minimize the impact of construction on railway operation. Therefore, it is of great significance to reinforce existing railway bridges effectively to restore the good bearing capacity and long-term durability of railway bridges, and to improve the economic and social benefits of operating lines.

Traditional normal concrete has a wide range of applications in the construction of existing railway concrete bridges. However, due to its low strength and poor durability, it has significant limitations in the reinforcement and renovation work of existing railway concrete bridges. Ultra-high performance concrete (UHPC) is a new type of cement composite material with excellent mechanical properties, high durability, and low permeability [5, 6], and due to its excellent performance, it has become a promising material for the strengthening and repairing of concrete structures nowadays [5,7]. UHPC provides an innovative solution for the reinforcement and repair of concrete structures, especially for the reinforcement and repair of high-value concrete structures in harsh environments, and is expected to gradually replace traditional reinforcement technology and become the core material in the field of structural repair. Therefore, in the reinforcement and repair of existing railway concrete bridges, UHPC can be considered as a repair material and applied to the damaged and weak parts of the structure to enhance the mechanical properties and impermeability of the existing structure [8] and ensure the safe operation of the railway line.

In this paper, the interfacial bond performance of UHPC to reinforce concrete bridges of existing railways is investigated. The bonding strength of the repair interface of composite specimens under different treatments was tested by splitting tensile test, and the bonding strength was evaluated and compared. The results of this paper are helpful to promote the application and promotion of UHPC in the reinforcement and repair of existing railway concrete bridges, help the preventive reinforcement and post-disaster rapid repair of traditional railway and high-speed railway bridges, and provide key technical support for improving the resilience of China's railway infrastructure.

2 Materials and Test Methods

2.1 Composite Specimen Preparation

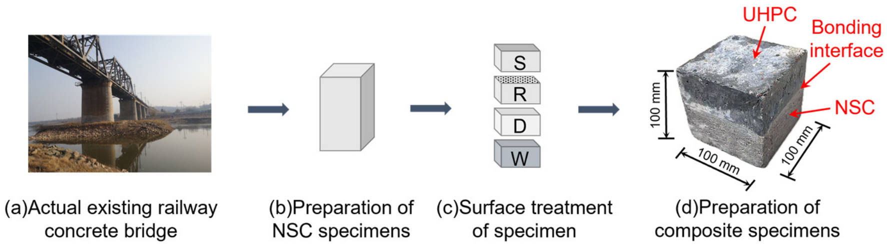

Fig. 1. Composite specimens preparation process.

The preparation process of the composite specimen is shown in Fig. 1. First, according to the design strength of actual existing railway concrete bridges, normal strength concrete (NSC) specimens were prepared with the size of 100 mm×100 mm×50 mm, and placed in the natural environment to simulate the actual service environment after curing. Then, the NSC specimens were subjected to different treatments (smooth surface, rough surface, dry surface, wet surface). Finally, UHPC was prepared as a reinforcing repair material and poured onto the treated interface of the NSC specimen to form the composite specimen shown in Fig. 1(d). The formed composite specimens were used to carry out subsequent tests after the curing was completed.

Before using UHPC for repair, the different treatments of NSC specimens are described as follows:

(1) Smooth surface (S). The specimen is not subjected to any treatment, and the repaired interface of the specimen is basically maintained in a smooth state.

(2) Rough surface (R). The repair interface of the specimen is flushed with a high-pressure water gun to remove the surface floating layer, so that it presents a rough state.

(3) Surface drying (D). Dry the specimen with an oven for 48 h, and then take it out to be used after cooling.

(4) Surface wetting (W). The specimen was pre-wetted with a water tank for 15 min, and then removed to wipe off the surface water droplets with a rag.

2.2 Splitting Tensile Test

The splitting tensile test has become the preferred method for UHPC-NSC interfacial bonding performance research due to its ease of operation and clarity of data analysis, which can accurately characterize the interfacial bonding strength and the key influencing factors, and provide a reliable basis for the interface optimization design. In this study, a SANS electro-hydraulic servo universal testing machine with a range of 2000 kN was used to carry out splitting tensile test on the composite specimens, as shown in Fig. 2. A semi-cylindrical spacer is placed between the upper and lower pressing plates, and the spacer is connected with the specimen by a wooden spacer of standard specifications. The loading rate of 0.04 Mpa/s was used to uniformly apply stress to the repair interface of the composite specimen, and the maximum load value was recorded. The interfacial splitting tensile strength was calculated by the following formula, which was used as the evaluation standard for the adhesion performance between the NSC specimen and the UHPC reinforcement repair material.

$$f_t = \frac{2P}{\pi A} \tag{1}$$

Where: f_t is the splitting tensile strength, MPa; P is the destructive load, N; A is the area of split section, mm^2.

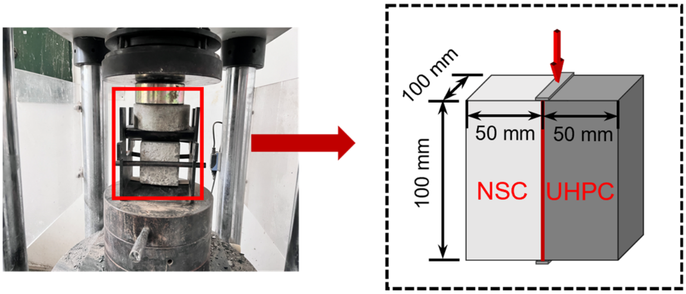

Fig. 2. Splitting tensile test.

3 Results and Discussion

3.1 Splitting Tensile Strength

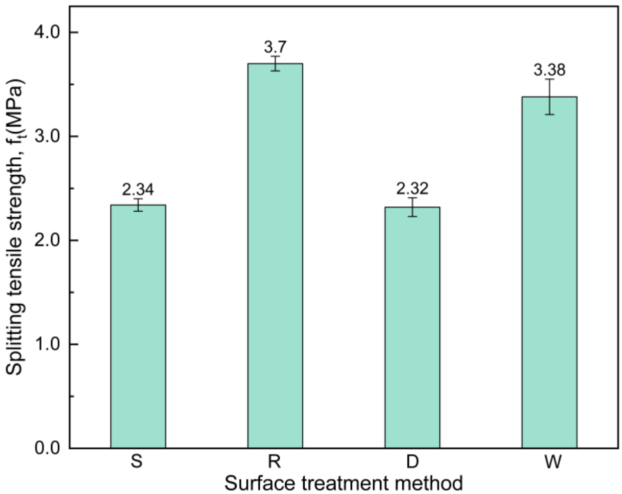

Fig. 3. Splitting tensile test results.

The splitting tensile test results of composite specimens with different surface treatments are shown in Fig. 3. The interface splitting tensile strength of the composite specimen is 2.34 MPa when the surface of the NSC specimen is smooth, and the interface splitting tensile strength of the composite specimen reaches a maximum of 3.70 MPa after the surface of the NSC specimen is roughened, which increases by 58.1% compared with that of the surface-smoothed specimen, mainly due to the fact that the roughening treatment makes the effective bonding area between the UHPC and the NSC increase, and the mechanical occlusion at the interface is obviously strengthened, thus improving the interfacial bonding performance. After drying the NSC specimens, the interface splitting tensile strength of the composite specimens was the smallest, which was only 2.32 MPa. This is because the NSC itself has strong hydrophilicity, which attracts the water in UHPC to flow to the NSC, resulting in insufficient Hydration reaction in UHPC, and it is difficult to form effective mechanical interlocking and chemical bonding between UHPC and NSC. Compared with the smooth surface specimens, wetting the NSC specimens also enhanced the interfacial splitting tensile strength of the composite specimens by 44.4 %, which was attributed to the fact that the moisture in the NSC promoted the generation of hydration products in the UHPC, and the interfacial bonding performance was enhanced. It can be seen that both roughing and wetting of the bonding interface of the NSC specimens can significantly enhance the bonding strength of the repaired interface of the composite specimens, while drying decreases the bonding strength.

3.2 Bonding Strength Evaluation

Reinforcement and repair of concrete structures is an ongoing challenge. In the last decade, UHPC has begun to be attempted for structural repair and component repair of concrete bridges. Therefore, in order to ensure the wide application of UHPC in the reinforcement and repair of concrete bridges of existing railroads, it is crucial to study the performance of UHPC as a repair material in the laboratory, with special consideration of the various surface treatments of NSC in actual projects. Table 1 lists the experimental literature bonding strength results between NSC under different surface treatments and UHPC as a repair material. As shown in Table 1, NSC surface roughness treatment can significantly improve the bonding strength of the UHPC-NSC interface, and pre-wetting of the NSC surface before UHPC overlay can also help to obtain better bonding strength at the UHPC-NSC interface.

Table 1. Experimental literature results of bond strength between UHPC and NSC under different surface treatments.

Reference	Surface treatment method	Splitting tensile strength (MPa)
This paper	Smooth	2.34
	Rough	3.7
	Dry	2.32
	Wet	3.38
Zhang et al. [9]	Air surface dry (ASD)	2.20
	air surface wet (ASW)	2.74

Tayeh et al. [8]	as cast	1.85
	sand blasted	3.79
	wire brushed	2.96
	drilled holes	2.6
	grooved	3.24

The test results in this paper were ranked in comparison with the evaluation criteria of bonding strength in reference [10] and summarized as shown in Table 2. In this test, the interfacial bonding strengths of composite specimens under different surface treatments were all greater than 2.1 MPa, and all of them were categorized as excellent, and the improvement of interfacial bonding performance by different surface treatments was in the order of R>W>S>D. In addition, the UHPC showed excellent bonding performance to ordinary existing concrete structures when used as a reinforcement and repair material.

Table 2. Bonding strength evaluation [10] and results of this paper.

Bond quality	Bond strength (MPa)	This paper
Excellent	≥2.1	R>W>S>D
Very good	1.7-2.1	/
Good	1.4-1.7	/
Fair	0.7-1.4	/
Poor	0-0.7	/

4 Conclusion

In this study, we prepared the corresponding normal-strength concrete specimens according to the design strength standards of actual existing railroad concrete bridges, reinforced and repaired them using UHPC, and investigated the interfacial bond properties of composite specimens under different interfacial treatments by splitting tensile test. The following conclusions were obtained:

(1) UHPC has excellent bond performance with normal strength concrete and is a promising concrete reinforcement and repair material that can be used for the reinforcement, repair and renovation of existing railroad concrete bridges.

(2) The improvement effects of different surface treatments on the interfacial bonding properties of composite specimens were shown in the order of R>W>S>D.

(3) Appropriate roughing and wetting of the repaired interface of existing railway concrete bridges prior to reinforcement and repair can significantly enhance the bonding strength of the interface; however, drying treatment does not benefit the enhancement of the bonding strength of the interface.

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