Review Study on the interface between ultra-high performance concrete and ordinary concrete

Abstract

Ultra High-Performance Concrete (UHPC) based on RPC configuration technology The research on material properties, structural components, and engineering practice has become one of the research hotspots of cement-based materials today. This paper summarizes the test methods of UHPC-NC interface bonding performance at home and abroad, the calculation formula of interface shear strength, the influencing factors, and the research progress of interface high-temperature resistance introduces the test method of UHPC-NC interface bonding mechanical properties and summarizes. The influence of different factors on the bonding performance of UHPC-NC interface, including fiber, interface roughness, interface moisture content, interface agent, existing concrete strength, cementitious material, and curing system, etc. The results show that: UHPC-NC has excellent interfacial bonding strength, among which, the appropriate curing system and fiber can reduce the shrinkage of UHPC and enhance the compatibility between materials; the increase of interface roughness and existing concrete strength can effectively avoid interface destruction; interface agent, interface water content and gelling material can improve the transition zone; UHPC-NC interface has good anti-permeability and anti-freeze-thaw performance; the incorporation of polypropylene fibers can improve the anti-burst performance of UHPC, and the mixed incorporation of different types of fibers can also reduce the high-temperature burst of UHPC. At present, there are many evaluation criteria for the mechanical properties of UHPC-NC interfaces, but there is a lack of research on the high-temperature resistance of UHPC as a repair material and UHPC-NC interfaces after high temperature.

Key words：UHPC；concrete interface；high temperature；

1.Introduction

As a cement-based material, concrete has become the most widely used building material due to its good material properties, simple construction technology, and relatively low cost［1］. With the development of the social economy and the continuous improvement of scientific and technological levels, people have higher requirements for the performance of materials used in the construction industry, and more and more high-performance concrete materials that are superior to ordinary concrete have been born one after another. UHPC is a cement-based composite material with excellent mechanical properties. Ultra-high performance concrete (UHPC) can be applied to new concrete structures or repair existing concrete structures［2，3］. Bonded materials consisting of ultra-high-performance concrete and normal concrete (NC) have high potential in the repair and reinforcement of new construction and existing structures. With the engineering application of UHPC and the continuous improvement of the performance requirements of engineering structures, it is a problem to be studied systematically and meticulously to study the bonding performance of the UHPC-NC interface.

UHPC is an ultra-high-strength cement-based material with high strength, high toughness, and low porosity. Its basic formulation principle is: by increasing the fineness and activity of the components, without using coarse aggregate, to minimize the internal defects (pores and micro-cracks) of the material, to obtain ultra-high strength and high durability. For the current definition of UHPC, foreign countries generally require that its compressive strength level should not be lower than 150 MPa, and its flexural strength should be above 40 MPa [4]; China’ s technical indicators for UHPC are lower than those of foreign countries. " Powder Concrete" [5] stipulates that the concrete with a standard value of compressive strength higher than 100MPa and a flexural strength of not less than 12MPa is called UHPC.

2.Research Status of Bonding Properties of New and Old Concrete

For the bonding performance of the new-old concrete interface, some scholars at home and abroad have done a lot of research on the macrostructure and microstructure from the perspective of influencing factors [6-8]. The influencing factors of the research mainly focus on the surface treatment method, repair material, interface agent, dry and wet state of the interface, repair material, etc., as well as the research on the bonding mechanism and bonding strength test method. In the reinforcement process of old concrete, the state of the old concrete interface is considered to be the most important factor affecting the bond strength. A good quality bond surface has a non-negligible effect on the bond strength of the interface.

Liao of Hunan University [9] mainly studied the effects of age, humidity, curing temperature, and interface form on the bond strength of the UHPC-NC interface through the oblique shear test, splitting test, and direct tensile test; the results showed that: UHPC-NC About 95% of the bond strength of the interface has been completed at the 7d age, the strength development rate before the 3d age is the fastest, and the development rate after 7d is quite slow, almost 0; the interface bond strength of the chiseled rough interface is the largest, smooth The interface is the worst. The Dalian University of Technology Zhao et al. [10] used the sand filling method to quantitatively measure the roughness of the interface and then made the bonded splitting test block of new and old concrete. Through the test, it was found that the old and new concrete was affected by the roughness of the interface and the direction in which the new concrete was poured. The rougher the bonding interface, the better the bonding effect; the bonding strength of horizontal pouring is stronger than that of vertical pouring. He of Hunan University [11] studied the influence of six interface bonding materials on the interface strength of new and old concrete through oblique shear, flexural, tensile, and shear tests. Double steel plate bonding, with the cooperation of the electro-hydraulic servo testing machine, the signal obtained by the closed-loop control feedback is used to simply and effectively obtain the stress-strain full curve of the bonding tensile properties of the new and old concrete interface, which is useful for deeper research on new and old concrete The tensile properties of interfacial bonds have profound implications.

The research on the interface bonding performance of UHPC-NC was carried out earlier in foreign countries, involving many test methods and factors affecting the interface bonding, and the research on the interface bonding performance is relatively comprehensive, and a series of research results have been obtained, which is the foundation for the development of UHPC. Applications provide a theoretical basis. Tayeh et al. [12-15] studied the bonding performance of the UHPC-NC interface through a 30° inclined shear test and splitting test. The test results showed that the failure modes of the inclined shear test can be divided into interface failure, interface failure, and partial matrix. There are four types of concrete failure, interface failure + matrix concrete failure, and matrix concrete failure. The failure modes of the splitting test can be divided into three categories, namely interface failure, interface failure + partial matrix concrete failure, and matrix concrete failure. The bond strength depends on the interface roughness, the greater the interface roughness, the higher the interface bonding strength, and the sandblasting interface reached the highest bonding strength; and the roughness of the matrix concrete was quantified, and the interface roughness and interface bonding strength were given regression relationship. Cleland et al. [16] showed that natural drying and wet-saturated non-luminous water interfaces can obtain higher bond strengths, while furnace-dried state and wet-saturated non-luminous water interfaces have lower bond strengths.

3.Study on Adhesive Properties of UHPC-NC Interface

Semendary et al. [17-19] studied the bonding performance of the UHPC-NC interface through direct tension, oblique shear, and direct shear tests. The test variables included matrix concrete strength, UHPC age, matrix concrete roughness, and matrix concrete interface. Humidity, matrix concrete aggregate type, interfacial shear reinforcement, etc. The test results show that with the increase of age and interface roughness, the NC aggregate at the interface can be observed to break at the interface where the NC aggregate is debonded, and the fractured aggregate indicates that the adhesion between UHPC and NC is greater than the tensile strength of the aggregate. The mean texture depth (MTD) was used to quantify the interface roughness in the oblique shear test, and the interface bond strength reached the maximum when the MTD was 4.28; the interface reinforcement could improve the interface ductility in the direct shear test.

Farzad et al. [20] studied a numerical simulation method on the uhpc-nc interface to predict the bearing capacity of the interface structure. The results showed that the failure of the specimen in the three-point bending test was interface debonding. After uhpc was changed to nc, the interface bond strength 40% reduction; in the direct shear test, the interfacial bond strength decreased with uhpc to nc, and the bond strength of the surface wetting was enhanced; compared to the dry specimens, the specimens with wetted surfaces performed better bonding behavior; numerical models can provide better predictions of load-carrying capacity.

Haber et al. [21] investigated the relationship between bond strength and consolidation, mechanical interlocking, chemical bonding, substrate surface conditions, and preparation through laboratory tests, field tests, and microstructural analysis using scanning electron microscopy (SEM). , the results show that if good overburden consolidation can be achieved when the interface porosity is less than 10%, the interface will have sufficient bond strength, and if there is not enough consolidation, surface roughening treatment is required; surface water Chemical treatment can reduce microcracks in the substrate, thereby improving the tensile strength of the interface. Hydration results in a higher degree of roughness at the interface, enhancing the mechanical interlocking of the interface.

Shuo. et al. [22] studied the effects of different repair materials on the bonding performance and microstructure between the concrete matrix and the repair materials. The test results showed that compared with NC repair materials, UHPC has good interfacial bonding performance when combined with concrete substrates. Compared with NC, the interfacial transition zone between UHPC and the substrate is denser, stronger, and more uniform, resulting in good bonding performance. Zanotti et al. [23] studied the effect of fibers on the mechanical properties of the interface. The results showed that adding polymer fibers such as polypropylene fibers, polypropylene fibers, and nylon fibers to repair materials can significantly enhance interfacial adhesion.

The high temperature will trigger the bursting and mechanical strength change of UHPC. The measure to effectively suppress bursting is to add polymer fibers such as polypropylene (PP) fibers to improve the high-temperature bursting resistance of UHPC; the latest research has found that combined curing is a new method to effectively improve the high-temperature performance of UHPC fires, which can avoid bursting［24］. There are different opinions on the effect of fiber content on the bond strength of UHPC-NC. Some studies suggest that the bonding strength of UHPC-NC is positively correlated with the fiber content. Shen［25］conducted splitting and bending tests on UHPC-NC bonded specimens with steel fiber volume content of 0%, 0.5%, 1.0%, 1.5%, and 2.0%, and the results showed that: When the content increased from 0.5% to 2.0%, the increase rate of interfacial bond strength increased from 36.9% to 78.1%. However, some studies suggest that the fiber content is not the reason that affects the bond strength of UHPC-NC. HUSSEIN et al.［26］conducted splitting tests on UHPC-NC bonded specimens with steel fiber volume content of 1.0%, 1.5%, and 2.0%. The difference in the test results is very small. Although the bond strength has increased, the increase rate is not greatly affected by the fiber content.

Guan et al.［27］showed that by cleaning the dust, impurities and loose structure on the concrete surface, increasing the surface roughness can increase the adhesion, but the rougher the concrete surface is not the better, when the roughness exceeds a certain value, the original structure will be damaged, but reduce the bonding performance. Shen［25］researched that the maximum roughness interface that UHPC will appear in actual engineering is the split surface (obtained by splitting the formed concrete test block with a testing machine), when the roughness of the artificially processed interface exceeds the When the roughness of the cracked surface is increased, the performance of the bonded surface will be reduced instead.

Tayeh et al.［13］used sandblasting, wire brushing, drilling, and grooving methods to treat the NC surface of UHPC-NC bonded specimens. The results showed that the bonding strength of the treated group was better than that of the untreated group, the bond strength of the sandblasting group was the highest, and the interfacial bond splitting tensile and oblique shear strengths were more than 100% higher than that of the untreated group.

Zheng et al.［28］studied the effect of sand blasting treatment on the bonding performance of UHPC-NC, quantified the surface roughness of concrete using sand-laying test and laser profile analysis, and pointed out that the NC mortar part is more likely to become rough than the coarse aggregate part, and the results show that In the test, the bonded surface of the specimen treated by sandblasting was not damaged.

There are few relevant studies on the shear performance of the UHPC-NC rebar interface in China, and most of them focus on the description of the failure process of the rebar interface. The shear-bearing capacity of the UHPC-NC rebar interface needs further analysis. For example, Song［29］used a single-sided direct shear test to study the effect of the interfacial reinforcement rate on the shear strength of the bonded interface between new and old concrete. The test shows that the best roughness of the new and old concrete joint surface measured by the sand filling method is 2.5mm-3.0mm, and it is found that under this condition, the new and old concrete components increase with the increase of the planting bar ratio. Finally, it is suggested that the planting bar rate in the project should be greater than 0.36%.

Zhang et al.［30］used double-sided direct shear tests to study the effect of planting bars on the shear strength of the UHPC-C50 interface and proposed the shear capacity of the new-old concrete interface based on the More theory. The test shows that the strength of the matrix concrete plays a decisive role in the shear strength of the specimen, and the maximum slippage of the specimen can reach 45mm with the combination of planting reinforcement and chiseling.

Wang [31] used a double-sided direct shear test to explore the influence of different interface treatments on the bond strength of the UHPC-NC interface and through a comparison of specifications, proposed a formula for the shear strength of the UHPC-NC rivet bond interface.

Yu et al. [32] studied the interface debonding failure performance between NC and UHPC through the pull-out test of 72 drilled core samples and the double shear test of 36 specimens. The results showed that With the increase of roughness increase, the tensile traction values of the C40 and C50 interfaces increased by 100% and 64%, respectively; the shear traction values increased by 202% and 121%, respectively; when the surface roughness increased, the interfacial bond strength between NC and UHPC was enhanced ; With the increase of interface concrete strength, between 2-7MPa, the tensile traction value increases by 204%, and the shear traction value increases by 114%.

Semendary et al. [19] studied the mechanical properties of the HSC-UHPC rebar interface under shear. The test results showed that the maximum slip of the specimen was 0.4mm, and the relationship between the load and the displacement was close to a linear relationship before the specimen was destroyed. It is proposed to estimate the shear strength of the UHPC-HSC rebar interface:

$$V = 0.618\sqrt{\mathrm{f}_{\mathrm{c}}'}$$

The author believes that the concrete strength contributes the most to the shear strength of the UHPC-NC rebar interface, and ignores the contribution of the reinforcement to the interface shear capacity in the formula.

Al-Madani et al. [33] analyzed the effects of matrix concrete treatment methods and curing conditions on the interface bond performance by using oblique shear, split tension, flexural, and direct shear tests. The results showed that the curing conditions did not affect the interface bond strength. Largely, the interface sandblasting treatment provides the greatest interface bonding strength, and the interface direct shear strength of water bath curing is 20% higher than that of thermal curing.

To measure the effect of interfacial reinforcement rate and interface roughness on interface shear performance, Valikhani et al. [34, 35] used direct shear tests to analyze the influence of interfacial reinforcement ratio and interface roughness on interface shear performance. The digital image technique (DIPM) quantitatively describes the interface roughness. The test results show that the greater the interface roughness and the planting bar rate, the higher the interface bonding strength. The planting bar interface not only improves the interface shear strength, but also improves the interface ductility, the failure mode of the specimen changed from brittle failure to ductile failure; for the rough interface, when the interfacial reinforcement ratio exceeds 0.9%, the interface bond shear strength no longer increases. Based on the test data, the formula of interface roughness and interface shear strength is given, and it is correlated with the formula of shear strength under the interfacial reinforcement to predict the interface bond strength, and the accuracy can reach 85%.Valikhani et al. [36] proposed an experimental and numerical procedure to characterize the interface properties of the concrete substrate and the bond strength of the interface. The results showed that the interface bond strength of the smooth surface treatment was 2.9MPa, and that of the rough surface treatment was 3.89MPa.

increased by 134%; the plastic fracture model can predict UHPC tension and compression within acceptable accuracy; the results of double-sided shear tests can be directly used as interface cohesion parameters, and the normal stiffness K_{nn} and tangential stiffness K_{tt} can be used for calibration.

Based on the French UHPC code-AFGC 2013 design criteria, Jiang et al. [37] proposed the shear strength formula under planted reinforcement:

$$V = k\lambda\left[cf_{ctk,el} + \rho f_y + (0.35\mu + 0.3) f_{ctfk}\right]$$

In the formula, $f_{cuk,el}$, f_{ctfk}—concrete tensile elastic limit stress and ultimate stress after cracking.

4.Research on high-temperature mechanical properties of ultra-high performance concrete (UHPC)

The study found that the damage and degradation of reinforced concrete structures in high-temperature (fire) environments until the final failure is a common problem of cement-based materials. Studies have found that compared with ordinary concrete, the internal structure of HPC is denser and its strength is higher, but these characteristics usually have an adverse effect on the mechanical properties at high temperatures [38].

Liu et al. [39] studied the fire resistance of reactive powder concrete (RPC) through high-temperature tests, and the results showed that the residual compressive strength of RPC decreased with the increase of fire duration. Compared with high-performance concrete and ordinary concrete, the studied RPC not only has a higher fire resistance temperature, but also has a larger residual compressive strength after fire; under the same fire temperature and duration, RPC, HPC and OC test The results of thermogravimetric analysis of the sample show that the total weight loss of RPC is lower than that of other samples; RPC is better than ordinary concrete, but high temperature cracking still occurs, and its high temperature cracking mode is unique, which is rare in the past, showing a top-to-bottom pattern. The lower ones burst and peel off layer by layer.

Nazri et al. [40] exposed the specimens to high temperature, especially at 200, 400 and 600 °C for 2 hours, and the fire resistance of the specimens were classified according to their compressive strength, peeling and weight loss; the residual strength after heating was tested , the results showed that the compressive strength of UHPFRC at 200°C was not affected, and the test piece had no cracks or spalling; some mass loss at 200°C was attributed to the loss of water; block explosive spalling; the presence of steel fibers does not help prevent explosive spalling.

Bei et al. [41] studied the effect of fiber type, amount and length on the explosive spalling of ultra-high strength concrete under rapid heating and rapid cooling conditions. The results showed that the addition of steel fibers prolongs the bursting time, but does not affect spalling. The addition of polypropylene (PP) fibers or polypropylene and steel fibers improves the anti-stripping performance; 0.2% (volume) polypropylene fiber ultra-high-strength concrete has excellent anti-stripping performance, and 12 or 19mm polypropylene fibers enhance the anti-stripping performance. Resistance to explosive peeling. Polypropylene fiber mainly improves the anti-stripping performance by forming tubular channels; when the amount is less than 0.20%, the anti-stripping property is poor. At the same time, when the amount of PP fiber is 0.20% or more, the peeling resistance is the best. In this case, the compressive strength residual rate exceeds 70%, and the mass loss rate is within 8%; PP fiber lengths of 6 and 9mm the samples will undergo obvious explosive spalling, while the samples with PP fiber lengths of 12 and 19mm have obvious spalling resistance at high temperature. The compressive strength residual rate exceeds 70%, and the mass loss rate is within 8%.

Chen et al. [42] studied the shear strength of the concrete-concrete interface of Z-shaped specimens after high temperature at different temperatures of 20, 200, 400, and 600 ◦C was experimentally studied using the Z-shaped push test. The effects of recycled aggregate concrete, high-strength concrete, interface roughness, and cement mortar surface binder on recycled aggregate concrete were mainly analyzed. The results showed that the interface shear strength decreased significantly at high temperature; the shear strength of smooth interface was lower than that of rough interface. The decline of the interface is faster; under the condition of similar compressive strength, the interface shear strength of RAC specimens is not lower than that of natural aggregate concrete specimens, and even shows better fire performance; the use of high-strength concrete helps Improve the interfacial shear strength, but after exposure to high temperature, the deterioration of the interfacial shear strength is obvious; the shear strength of the smooth interface decreases rapidly after exposure to 200 ° C, and the residual strength is only 23-35% at room temperature, the residual strength of the rough interface remained at 65–87%; when RAC and NAC were designed with similar compressive strengths, the interfacial shear strength of RAC was not lower than that of NAC. The degradation tendency of RAC is relatively mild. The use of HSC as post-cast concrete or on both sides of the interface can improve the shear strength to a certain extent; cement mortar as a surface binder can improve the shear strength of concrete and reduce the degradation of concrete-concrete interface after high temperature.

Wu et al. [43] found that with the increase in fire temperature, the strength and elastic modulus of high-strength concrete gradually decreased, and the peak strain gradually increased. Through regression analysis, the corresponding regression formula is given. Then, compared with ordinary concrete, it was found that in the temperature range from room temperature to 500 °Ç high-strength concrete has obvious characteristics different from ordinary concrete. The critical temperature of sudden change in the mechanical properties of high-strength concrete is 400°C, while that of ordinary concrete is 200°C. Before the critical temperature, the decreasing rate of the strength and elastic modulus of high-strength concrete with the increase of temperature is lower than that of ordinary concrete, but after the critical temperature, the decreasing rate is greater than that of ordinary concrete.

Xiao et al [44] concluded that after experiencing a temperature of 20-900 °C, the mass loss rate and residual compressive strength of high-performance concrete mixed with polypropylene fiber after high temperature, and the conclusion that no high-temperature burst was found. Polypropylene fiber melts at high temperatures and produces a large number of capillary pores inside the dense high-performance concrete, which reduces the steam pressure caused by water vapor migration, thereby slowing down the occurrence of high-temperature bursting. The loss of compressive strength of high-performance concrete mixed with polypropylene fiber is close to or even smaller than that of ordinary concrete after experiencing the same high temperature.

Zhao et al. [45] showed that the compressive strength, tensile strength, and flexural strength of steel fiber high-strength concrete decreased with the increase in temperature, and the decrease range was small within 400 °C, and decreased significantly after 400 °C. At the same temperature, steel fibers increase the strength value of high-strength concrete after high temperatures. After adding steel fibers, the bridging and crack resistance functions of steel fibers limit the volume change of concrete under rapid temperature changes and high-temperature environments, and reduce the initiation and expansion of micro-defects inside concrete, so that steel fiber concrete can withstand high-temperature conditions. It shows good mechanical properties, and to a certain extent, plays a role in alleviating the deterioration of the high-temperature performance of high-strength concrete. Moreover, the bonding effect of steel fiber and cement gel makes steel fiber concrete have better tensile and flexural properties at high temperatures, and the ability to resist bursting is improved. In addition, steel fibers have good thermal conductivity, are distributed in three-dimensional random directions in concrete, and overlap each other, which can make concrete reach uniform internal temperature faster at high temperatures, thereby reducing internal stress caused by temperature gradients. Reduce internal damage, and inhibit the volume change of concrete due to rapid temperature changes, thereby reducing the generation and development of micro-defects inside the material, slowing down the deterioration of the material, thereby preventing the bursting of the concrete and improving the strength of the concrete after high temperature. But when the temperature reaches a certain level, the cement gel gradually disintegrates, and the cohesive force with the steel fiber gradually loses, so that the reinforcing effect of the steel fiber decreases sharply, which is manifested as a significant decrease in the strength of the steel fiber reinforced concrete at high temperature. Some scholars［46， 47］found that high-performance concrete prepared by mixing polypropylene fibers with low melting points and steel fibers with high melting points can also improve its high-temperature mechanical properties.

5.Conclusion

This paper reviews the research progress of UHPC-NC interface bonding performance test and high-temperature resistance at home and abroad, and draws the following main conclusions:

· The UHPC-NC interfacial adhesion test method is introduced. Among them, the tensile test can be divided into direct method and indirect method; the shear test is mainly divided into single-sided and double-sided shear test; the oblique shear test measures the shear stress and compressive stress of the interface.

· Different test methods have a great influence on the measurement results of the interface bond strength of composite structures. However, the difficulty of each method and the discreteness and reliability of the test results are different. Therefore, the appropriate measurement method should be selected according to the research purpose. Different test methods have different sensitivities to interface treatment, and the appropriate test method should be selected according to the research purpose. Splitting tests, shear tests and inclined shear tests can better evaluate the effect of interface treatment.

· Factors affecting the interface bond strength include fiber, interface roughness, interface agent, interface water content, existing concrete strength, cementitious material, and curing conditions, etc. The fiber reduces the material shrinkage and improves the interface load transmission mode; increasing the interface roughness can increase the contact area between UHPC and NC, thereby enhancing the interface bonding characteristics; the interface bonding strength of UHPC-NC increases with the existing concrete strength. Interface agents, interfacial water content, and gelling materials can improve the microstructure of the UHPC-NC transition zone; selecting appropriate curing conditions can reduce the adverse effects of shrinkage.

· At present, the experimental research of UHPC-NC is mainly aimed at the short-term interface bonding strength, lacking the long-term performance of interface bonding, especially the long-term retention in harsh environments; in addition, the interface dynamic properties of UHPC-NC, such as impact resistance, blast resistance, and fatigue properties, need to be further studied.

In order to better explore the bonding performance of UHPC-NC interface and promote the application of UHPC in repair and reinforcement engineering practice, the following suggestions are put forward:

· For experiments that are difficult to implement and have large data dispersion, the experimental data should be compared with the simulation results to verify the accuracy of the test results.

· At present, there are relatively few studies on the interfacial adhesion of UHPC composite structures for hybrid fibers and fiber size and shape, and research in this area should be strengthened.

· The research on UHPC in harsh environments should be strengthened to provide more help for the application of UHPC in structural engineering.

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