Effect of early strength agent on the properties of new bridge expansion joint UHPC material

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Abstract—With the increasing development of urban transportation, many roads and bridges will have some cracks and damage. If not handled in time, long-term development will have a great impact on thedurability and safety of the bridge. How to quickly and effectively repair the cracks of the bridge has become a problem that we urgently need to solve. As a high-strength, high-toughness, low-porosity, ultra-high-strength cement-based material, ultra-high performance concrete not only has excellent mechanical properties such as compressive, flexural, and impact resistance, but also has good bonding strength and toughness. This material is very suitable for use in bridge expansion joints. This paper proposes a new bridge expansion joint UHPC material by consulting a large number of documents, and studies the effect of early strength agents on it, laying the foundation for the actual use of the new bridge expansion joint UHPC material.

1. Introduction

With the steady pace of my country’s economic development, the infrastructure has gradually entered a stage of improvement, and the construction of the transportation network is still continuing. At the same time as the construction of highway bridges, with the increase of vehicle tonnage, vehicle flow, and even over-limit and overload conditions, it is necessary to pay more attention to road maintenance and repair for highway bridges. Bridge expansion joints, as the connecting parts of highway bridges, ensure the deformation requirements of the bridge deck, free contraction of the beam body, and smooth driving of vehicles on the bridge, which have an important impact on the service life of the bridge. However, due to the poor use environment of bridge expansion joints and easy to be neglected in all aspects of design, construction, and maintenance management, bridge expansion joints are usually the most vulnerable part of the bridge structure. Moreover, frequent maintenance of expansion joints not only seriously affects traffic, but also significantly increases the maintenance cost of the bridge, but also causes environmental problems such as waste of resources. At present, the main types of bridge expansion joints need to be equipped with transition zone concrete, so that the expansion joints and the bridge form an integrated structure\textsuperscript{[1]}. In the investigation and statistical analysis of the damage of bridge expansion joints, it is found that common road bridge expansion joint diseases are mostly caused by the damage of concrete in the transition zone of expansion joints. The concrete disease in the transition zone of the expansion joint
will destroy the integrity of the anchorage system of the expansion joint of the bridge, thereby destroying the normal use function of the expansion joint device[1]. Li Wei et al.[2] found through simulation that in the actual design, application and maintenance of bridge expansion joints, it can be known that in addition to the relevant mechanical properties, the material design of the transition zone of bridge expansion joints also needs to have good bond strength. The area interface must meet the actual engineering use requirements to ensure the normal use of the bridge expansion device. Therefore, the research and development of new bridge expansion joint transition zone repair materials has great practical application significance, and it is also urgent.

Ultra high performance concrete (UHPC) is a kind of ultra-high-strength cement-based material with high strength, high toughness and low porosity. It not only has excellent mechanical properties such as compression, flexural and impact resistance, but also good bond strength, toughness. The original design theory of UHPC was put forward by Hans Henrik Bache in 1978. Its design theory is "Densified System with Ultra-Fine Particles" theory, referred to as DSP theory. Firstly, the cement particles are accumulated, and then the finer silica fume particles are accumulated in the voids of the cement accumulation system to achieve high density and low porosity[3]. Ultra-high performance concrete is the most innovative and practical cement-based composite material in the world today. It has great prospects in the application of structural materials and has great development potential. Now in various engineering applications, many experts and their teams are tapping the potential and availability of UHPC[4]. SHAHIEIFAR et al.[5] found that the compressive strength of UHPC is three to four times higher than that of ordinary strength concrete, and the modulus of elasticity is twice that of ordinary concrete; LI[6], Yang Juan[7] and others tried to add coarse aggregate to UHPC and obtained UHPC with good working performance and compressive strength of C120~C160; VITOLDAS et al.[8] tried not only cement, silica fume, but also glass powder and other materials in UHPC, and obtained a UHPC with excellent mechanical properties. Its compressive strength can reach 149 MPa, and its flexural strength can reach 36.2 MPa. Pierre Richard et al.[9] studied the effects of different materials, processes and maintenance systems on the performance of RPC, and summarized and proposed methods for improving the strength and toughness of RPC; Soliman et al.[10] studied the UHPC mix ratio based on the CPM model, and then analyzed the influence of the amount of glass frit instead of silica fume on the compressive strength of UHPC; Cao Feng, Qin Weizu, et al.[11] used fly ash as an admixture to prepare UHPC with excellent performance, and at the same time studied the physical and chemical effects of fly ash on UHPC. In summary, Ultra-high performance concrete (UHPC) can be applied to bridge expansion joints and has application value.

2. Test
In the bridge expansion joint repair project, there are often some small space cracks. In order to facilitate construction and construction quality, there are higher requirements for the fluidity of repair materials. In this paper, a large amount of literature and related research results are combined. The fixed water-to-binder ratio is 0.18, the sand-to-cement ratio is 1.1, sulfoaluminate cement accounts for 10% of the total cement, and 1% polycarboxylic acid superplasticizer is added to the UHPC matrix with better fluidity is prepared. In order to achieve the purpose of rapid open traffic, UHPC should have a higher early strength. Lithium carbonate is often used as an early strength agent because it can accelerate cement hydration and significantly increase the early strength of cement-based materials. On the basis of the benchmark mix ratio, the early mechanical properties of UHPC were improved by mixing with early strength agents, and new bridge expansion joint UHPC material with better early flow properties and better mechanical properties was prepared.

2.1. Materials
The cement adopts PO 52.5 grade ordinary Portland cement, the measured 28d compressive strength is 57.5MPa, the flexural strength is 9.92MPa; the content of lithium carbonate is 99.5%, the density is 2.11g/cm³, and the melting point is 618°C; fly ash is selected I Grade fly ash; average particle size of silica fume is 89nm, specific surface area is 1.85×104m²/kg; water-reducing agent adopts
polycarboxylate high-performance water-reducing agent, water reduction rate is greater than 30%; fine aggregate is selected using 20-40 Quartz sand of 40-80 mesh, 80-120 mesh; the steel fiber is a fine copper-plated steel fiber with a length of 13mm and a diameter of 0.3mm. The chemical composition of the cementitious material is shown in Table 1.

| Composition | Fe$_2$O$_3$ | Al$_2$O$_3$ | SO$_3$ | CaO | SiO$_2$ | MgO |
|-------------|-------------|-------------|--------|-----|--------|-----|
| Cement      | 4.51        | 5.76        | /      | 64.5| 23.1   | 1.4 |
| Fly ash     | 9.35        | 31.62       | 1.21   | 4.57| 52.52  | 0.73|
| Silica Fume | 0.14        | 0.25        | 0.58   | 0.36| 95.4   | 0.47|

2.2. Test ratio design
The experimental design mix ratio group is the experimental group A1–A4, and the lithium carbonate content is 0%, 0.05%, 0.1%, 0.15%, respectively. By changing the lithium carbonate content, the effect of the lithium carbonate content change on the new bridge expansion UHPC material is studied. Table 2 shows the test mix ratio.

| Test group | Portland cement | Sulphoaluminat | Silica Fume | Fly ash | Steel fiber | Quartz sand | Water reducing agent | Lithium Carbonate |
|------------|------------------|----------------|-------------|---------|-------------|-------------|----------------------|------------------|
| A1         | 0.614            | 0.068          | 0.154       | 0.164   | 0.110       | 0.900       | 0.032                | 0                |
| A2         | 0.614            | 0.068          | 0.154       | 0.164   | 0.110       | 0.900       | 0.032                | 0.05             |
| A3         | 0.614            | 0.068          | 0.154       | 0.164   | 0.110       | 0.900       | 0.032                | 0.1              |
| A4         | 0.614            | 0.068          | 0.154       | 0.164   | 0.110       | 0.900       | 0.032                | 0.15             |

2.3. Test procedure
(1) Weigh the raw materials required for the test according to the design mix ratio.
(2) Moisten the mixing pot first, then pour the weighed ingredients into the mixing pot, mix dry for 2 minutes, then add the weighed water, and stir slowly for 5 minutes. Finally, evenly distribute the steel fibers and stir for 5 minutes. The stirring is over.
(3) The mixed UHPC is tested for fluidity first. Finally, it was formed into a steel mold with a size of 40 mm×40 mm×160 mm, placed at room temperature, and covered with plastic film for curing. The compressive and flexural strength were tested at the ages of 1d, 3d, 7d and 28d.

3. Test Results and Discussions
3.1. Effect of Lithium Carbonate on the Early Performance of New Bridge Expansion Joint UHPC Materials
It can be seen from Fig.1 that the change of the lithium carbonate content has a significant impact on the early performance of the new bridge expansion joint UHPC material. The fluidity, compressive strength (1d) and flexural strength (1d) of the new bridge expansion joint UHPC material all vary with the content of lithium carbonate shows a trend of first increasing and then decreasing; it can be seen that when the content of lithium carbonate is 0.1%, the early performance of the new bridge expansion joint UHPC material is the best, its fluidity is 166mm, the strength (1d) is 33.5MPa, and the flexural strength (1d) is 8.0MPa.
3.2. Effect of Lithium Carbonate on the Compressive Strength of New Bridge Expansion Joint UHPC Material

It can be seen from Fig.2 that when the content of lithium carbonate increases, the compressive strength of new bridge expansion Joint UHPC material at the ages of 1d, 3d and 7d all show a tendency to increase first and then stabilize. When the content of lithium carbonate reaches 0.1%, its compressive strength reached the maximum value, respectively 33.5MPa, 84.62MPa, 100.58MPa. However, the incorporation of lithium carbonate has an adverse effect on the 28d compressive strength of new bridge expansion Joint UHPC material, and as the amount of lithium carbonate increases, the 28d compressive strength of new bridge expansion Joint UHPC material decreases.
3.3. Effect of Lithium Carbonate on the Flexural Strength of New Type Bridge Expansion Joint UHPC Material

Fig. 3 shows that when the content of lithium carbonate increases, the flexural strength of new bridge expansion joint UHPC material at the ages of 1d, 3d and 7d, all show a trend of first increasing and then decreasing. When the lithium carbonate content reaches 0.1%, the flexural strength reaches the maximum value, which are 8.0MPa, 15.2MPa, 16.63MPa and 18.08MPa respectively. However, the incorporation of lithium carbonate has an adverse effect on the 28d flexural strength of new bridge expansion joint UHPC material, and as the amount of lithium carbonate increases, the 28d flexural strength of new bridge expansion joint UHPC material decreases.

![Fig.3 Effects of different lithium carbonate content on the flexural strength of new bridge expansion joint UHPC materials](image)

4. Conclusion

Based on the results and discussions presented above, the conclusions are obtained as below:

(1) Commonly used bridge surface defects and joint reinforcement repair materials have problems such as low strength and poor durability, which make repairing efficiency low. Because UHPC has excellent mechanical properties and durability, at the same time, it has low porosity, high density and good impermeability. If UHPC is applied to the repair of bridge expansion joints, it is expected to become a repair and reinforcement material with excellent performance and significantly improve repair efficiency.

(2) The change of lithium carbonate content has a significant impact on the fluidity of fresh UHPC slurry. The fluidity of fresh UHPC slurry shows a trend of first increasing and then decreasing with the content of lithium carbonate. When the blending amount is 0.1%, the fluidity of fresh UHPC slurry is the most stable.

(3) When lithium carbonate is incorporated, the strength of new bridge expansion joint UHPC will be enhanced, and the recommended dosage is between 0.05 and 0.1%. However, with the increase of lithium carbonate content, it will adversely affect the later mechanical strength of new bridge expansion joint UHPC.

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