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Review

Application of Ultra-High Performance Concrete in bridge engineering

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HIGHLIGHTS

- Forty-two typical and practical applications of UHPC in bridges are introduced.
- The shortcomings which constrain the application of UHPC are summarized.
- Potential usages of UHPC for seismic resistance and anti-explosion are predicted.
- Further researches of UHPC in bridge engineering are proposed.

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ABSTRACT

Ultra high performance concrete (UHPC) is a type of cement-based composite, which is the most innovative product in concrete technology during the last 30 years. The advantages of UHPC compared with the common concrete, such as superior mechanical performance, excellent anti-seismic property and resistance against environmental degradation are introduced in the paper. The paper begins by briefly introducing its history of development and technical performance. Then, the research and application situation of UHPC in bridge engineering are discussed and many practical applications in bridge bearing component, bridge deck pavement and bridge joints are summarized. Moreover, the paper analyzes advantages and shortcomings of UHPC and the constraints for the application of UHPC in bridge engineering. In addition, the performance of UHPC in seismic resistance and anti-explosion is briefly summarized. Based on these works, prediction of UHPC further research in the future is prospected.

Contents

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1. Introduction

Ultra-High Performance Concrete (UHPC) is one of the most innovative cement-based structural engineering materials developed in the last 30 years from the perspective of mechanical properties and durability of concrete construction.

As early as 1930, Andresen and Andressen established the mathematical model of the maximum packing density theory. However, the first generation of UHPC designed by the model, called CRC (Compact Reinforced Composite), was born in Aalborg, Denmark until the development of superplasticizer became mature. CRC used sintered bauxite as aggregate, and steel fiber was mixed to improve the material's toughness. Influenced by the performance of superplasticizer at that time, CRC or early UHPC was difficult to achieve satisfactory uniformity by vibration for its viscosity.

At the beginning of this century, "UHPC" was defined for the first time in Europe. With the improvement of design principles and the introduction of ultra-efficient superplasticizer (Polycarboxylic acid), UHPC has a common concrete construction performance in self-compacting compared with the earlier CRC or RPC.

1.1. Development of UHPC

Concrete is a cement-based composite material and a hydraulic binder which is formed by combining cement with various aggregates. The structures developed in a higher, larger, deeper direction since the 20th century; therefore, stricter requirements on materials have been placed. In this case, the High Strength Concrete (HSC) with strength exceeding 60 MPa appeared in the late 1970s then and was widely used at that time [1].

Reactive Powder Concrete (RPC) is one of the most typical UHPC, which was first developed in 1993 at the Bouygues Laboratory in France. Its compressive strength is more than 150 MPa. and RPC is divided into two grades, RPC200 (strength below 200 MPa) and RPC800 (strength from 200 MPa to 800 MPa) [2,3].On the basis of the principle of preparation of RPC, experts from various countries have carried out new UHPC research, but the challenge to improve tensile properties of UHPC still remains. In this case, a fiber-reinforced approach was introduced to achieve a higher tensile strength.

In 2009, at the "Ultra-High Performance Fiber Reinforced Concrete International Conference" held in Marseille, France, it was noted that UHPC would have a new application in environmental protection and super durable performance [4].

1.2. Preparation of UHPC

The material components of UHPC consist of: (1) cement (2) well-graded fine sand (3) quartz sand (4) silica fume and other mineral admixtures (5) steel fiber (6) superplasticizer. The removal of coarse aggregate can improve the homogeneity and the internal structure of UHPC. The high density of UHPC is improved using well-graded fine sand, quartz sand and silica fume, which can reduce the porosity of the UHPC. In addition, the steel fiber has a different tensile stress, which effectively slows down the occurrence of concrete cracks. In order to reduce the amount of water and increase the strength, a large amount of effective superplasticizer is added, but the dosage should be taken care to avoid the retardation of the concrete.

Many scholars have done a lot of research on material components of UHPC. Nancy A [5] studied the possibility of producing and using glass sand (GS) for partial or total replacement of quartz sand in UHPC. Collepardi et al. [6] reported the effect of nano-Si02 on the properties of self-compacting concrete. It was found that nano-Si02 not only improved the cohesion of fresh cement paste, but also improved the mechanical properties and durability of hardened cement paste.

Mixture ratio of UHPC has been one of important research topics. Different regions in the world have their own unique features in water quality, cement, silicon ash and other mixtures, steel fibers may vary due to the high and low level of preparation technology. Furthermore, the environment in different areas may also influence the optimal mixture ratio of UHPC. Therefore, in order to obtain the ideal UHPC material performance, it is necessary to determine the best mixture ratio through experiments in different regions and to avoid directly using the existing proportioning data. This issue may be one of the most important factors that restrict wide applications of UHPC in bridge engineering. Table 1 gives the common mix of UHPC.

Curing temperature also has an impact on the performance of UHPC materials. There are three kinds of commonly used curing methods: room temperature curing, around 90 °C high temperature curing and steam curing at 200 °C. In general, strength of UHPC under the room temperature curing is 10%–30% lower than that of 90 °C high temperature curing. The steam curing above