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Durability research of high performance concrete and its application in engineering

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Abstract. With the development of modern science and technology, the application of concrete is more and more extensive, and the performance of traditional concrete has been difficult to meet the high requirements of engineering. All countries in the world are committed to seeking concrete with good construction performance, good durability, long service life and other advantages. Durability is the main design index of high performance concrete (HPC), so this paper studies and analyzes the main factors affecting the durability of HPC and the technical ways to improve the durability of concrete. The main internal factors affecting the durability of HPC are high water consumption and unstable hydrate in cement. External factors are various environmental conditions and protective measures of concrete structures. The technical ways to improve the durability of concrete mainly include reasonable structural design, reasonable concrete mix ratio, adding mineral admixtures and admixtures, reliable construction technology and regular maintenance. In the future, high-performance concrete should develop in the direction of economic green, and try to be environmentally friendly and recyclable while meeting the strength needs.

Keywords: high performance concrete, durability, engineering.

1. Introduction

Concrete is one of the most important civil engineering materials in modern times, with more than 4 billion tons of concrete used worldwide every year. However, with the development of modern science and technology, the performance of traditional concrete has been difficult to meet the high requirements of engineering. In May 1950, the United States National Institute of Standards and Technology (NIST) and the American Concrete Institute (ACI) first proposed the concept of high performance concrete (HPC) [1]. However, different countries have put forward completely different requirements and meanings for high-performance concrete. It is considered that high-performance concrete should have high durability, high volume stability, high compressive strength and good constructability [2]. Specific to the specific use in engineering, there will be some special properties. Durability is the main design index of HPC so this paper studies and analyzes the main factors affecting the durability of HPC and the technical ways to improve the durability of concrete. In addition, the application examples of HPC in engineering are introduced, and the development prospect of HPC is forecasted.

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2. Common HPC

With the continuous development of science and technology, the application of concrete is more and more extensive, and the raw materials of concrete production have also been rapidly developed. The main materials of concrete production include cement, coarse aggregate, fine aggregate, water reducing agent, etc. [3]. However, the properties of cement are different according to the mixing ratio of basic materials in cement production. Different building environments have different requirements for the performance of concrete in various aspects. The use of different admixtures improves the performance of concrete, expands the variety of concrete, and reduces the cost of concrete.

2.1. Ultra high performance concrete (UHPC)

UHPC is a special concrete which have ultra-high strength, ultra-low water absorption, super durability and corrosion resistance. The basic raw materials of UHPC are very common: water, sand, cement, silica fume, admixtures. However, UHPC is an order of magnitude different from ordinary concrete [4]. There are no special ingredients in the UHPC, and no resins, cellulose or special polymers are used to achieve super high performance. The secret lies in harnessing the chemical and geometric properties of ultrafine particles. These particles are then properly stirred, poured, and cured to achieve a tight packing of the matrix and a strong molecular bond. A bridge built by using UHPC is shown in Figure 1.



Figure 1. A bridge built by using UHPC [5].

2.2. Grinding slag HPC

Grinding slag (shown as Figure 2) is a kind of fine particles with certain fineness and grain gradation made from the aqueous slag discharged in ironmaking by certain grinding process. When mixed into concrete according to regulations, it has a significant effect on the performance of both newly mixed concrete and hardened concrete. The slag in the ground slag concrete reacts with the $Ca(OH)_2$ in the concrete to form C-S-H gel, while the $Ca(OH)_2$ in the ordinary concrete reacts with the sulfate of seawater to form an expansive hydrate. Therefore, slag concrete can reduce the generation of swelling hydrate [6]. In addition, because the ground slag concrete has good impermeability and can inhibit the infiltration of deteriorated ions in seawater into the concrete, it has better seawater erosion resistance than ordinary concrete.

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Figure 2. Grinding slag [7].

2.3. Polypropylene HPC

In the last decade, synthetic fiber concrete has become an increasingly important role in HPC. In particular, polypropylene fiber has attracted the attention of engineering circles for its low cost and remarkable effect of improving concrete performance. The concrete has some problems, such as high brittleness, easy cracking and poor impact resistance. Polypropylene fiber concrete is to add an appropriate amount of polypropylene microfibers into concrete to improve the performance of concrete [8]. Due to the addition of polyester fiber in the concrete, it can be easily distinguished, and its section after breaking is shown in Figure 3. A small amount of polypropylene fiber added to concrete can improve the crack resistance and impact resistance of concrete has been widely used in pavement engineering, and has achieved good results.



Figure 3. Polypropylene HPC [9].

3. Main factors affecting durability of HPC

In process of using concrete, it will be used to resist various destructive factors, so the durability of concrete is very important. His durability will determine the life of the construction made of concrete we use, and it is also an important part of the use of buildings. Durability is a very important performance of concrete.

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3.1. Internal factor

It is very complicated to find the factors that affect the durability of concrete, which mainly depends on the characteristics of concrete materials and the design and construction quality of concrete structures. Cement is composed of cement, water, coarse and fine aggregate and some admixtures. If the quality of aggregate and the grade of cement cannot meet the requirements of concrete, then in the later use process, the structural compressive resistance of concrete will be seriously affected, thus causing the concrete structure to be damaged. The steel bar is the skeleton of the whole reinforced concrete structure. If there are problems in its quality, it will have a serious impact on the compressive performance of the whole concrete structure in the later stage, resulting in an impact on the resistance of the whole concrete to the outside world. Raw materials are formed by artificial composite concrete materials such as mixing, shallow injection, vibration, curing and hardening, such as water-cement ratio, cement type, aggregate type and grade, which directly affect the durability of concrete structures [10]. Defects in concrete (such as cracks, bubbles, holes, etc.) will cause moisture and corrosive substances to penetrate into concrete, and the physico-chemical interaction with concrete will affect the durability of concrete structures.

3.2. External factor

The production process and environment are the external factors. A series of links in the process can lead to changes in the internal structure of concrete, resulting in a reduction in the overall performance of concrete. For example, if the concrete mixing process is not uniform, it will lead to the uneven distribution of aggregate inside the concrete, resulting in the reduction of local carrying capacity, affecting the durability of the concrete. If there are problems in the binding and welding of steel bars inside the concrete, it will cause structural instability during the use of concrete, reduce the bearing capacity, and lead to the overall destruction.

To a large extent, the impact of environmental factors on the durability of concrete is the most direct, and the prevention of environmental factors is also the most difficult in concrete protection. Common external environmental factors mainly include: (1) freeze-thaw cycle failure; (2) chloride ion erosion; (3) carbonization failure; (4) alkali aggregation reaction; (5) wear failure; (6) corrosion of rebar [11].

4. Technical approach to improve durability of HPC

4.1. Reasonable and perfect design

The design of concrete mix ratio should meet the strength and workability of concrete. In addition, it should reduce the amount of cement and water consumption as much as possible, reduce the heat of hydration, reduce shrinkage cracks, and improve the density. Moreover, it is necessary to consider the use of reasonable water reducing agents and air entraining agents to improve the internal structure of concrete. In addition, adding a sufficient amount of mixture can improve the durability of concrete [12]. Under the premise of satisfying the use function, the structural design is as regular and simple as possible. Because the corrosive medium in the environment is easy to invade the concrete at the edges or protrusions of the members, the shape, drainage and joints of the structure should be fully considered in the design. The strength and specific properties of cement materials are actually determined by the setting and hardening of cement mortar. If the cement is destroyed, the durability of the concrete will be reduced. Therefore, the choice of cement varieties should be selected according to the specific situation. It is necessary to choose cement with small alkali content and low hydration heat. In addition, Cement with good heat resistance, water resistance, corrosion resistance and frost resistance should be chosen.

4.2. Production technology

Mineral admixtures need to be used scientifically. Increasing the amount of mineral admixtures is conducive to reducing the heat discharge of concrete and reducing the water consumption of concrete. If the amount of cementing material is kept unchanged or slightly increased. The decrease of concrete tensile properties caused by mineral admixtures is compensated by the decrease of concrete water-binder

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ratio [13]. This can effectively improve the temperature control and crack prevention ability of mass concrete.

The higher the concrete pouring temperature, the greater the uniform temperature difference, and the greater the temperature stress generated, so it is very important to control the mold temperature of concrete in the construction process. The temperature of concrete can be reduced by controlling the temperature of raw materials and mixing with ice.

In terms of construction, the mixing of condensate should adopt the secondary mixing method, sand packing method and other technologies to improve the workability of concrete mix, water retention, concrete strength and water consumption; In order to reduce concrete cracks, temperature cracks, shrinkage cracks, construction cracks should be controlled, concrete pouring vibration system should be established, concrete compaction and permeability should be improved, the surface process after concrete vibration should be paid attention to, and maintenance should be strengthened to reduce concrete cracks.

4.3. Overhaul and maintenance

The durability of the structure requires proper use and normal inspection and maintenance, especially for infrastructure projects in open air and harsh environments. For important projects, structural life economic analysis and evaluation should be carried out in the design, including one-time investment at the time of construction and maintenance costs over the entire service life. Experience has proved that only by appropriately increasing the initial investment cost, strengthening the corrosion resistance of the structure is the most economical and effective way [14]. In terms of investment allocation, the project maintenance cost is decoupled from the primary construction cost, and the maintenance cost is insufficient for a long time, and the project cannot be maintained in time, resulting in greater losses.

Due to the uncertainty of environmental effects and the complexity of structural durability problems, it is difficult to accurately predict durability or service life in the design stage of many structural projects in harsh environments. This requires actual testing of structural material properties after the completion of the project, and the durability of the structure is designed through regular testing during the use of the structure. Regular inspection of important structural works is also necessary to ensure structural safety, especially for densely populated public buildings and lifeline works.

5. Examples of different types of HPC in engineering

In the development of modern society, HPC has been developed by leaps and leaps in various civil engineering projects. In order to adapt to different environmental conditions, each project has a different aspect of higher demand for concrete. The following will be analyzed in a specific case.

5.1. Zhanjiang Port iron ore wharf project

The iron ore terminal project of Zhanjiang Port is located in the coastal area of South China and belongs to the seaport project. The general situation of the whole project is shown in Figure 4. The concrete structures have been in the seawater environment for a long time. The infiltration of chloride ions in seawater into concrete leads to the corrosion of steel bars, which is the main reason for the reduction of durability of concrete [15]. In order to improve the compactness and permeability resistance of concrete and prolong the reasonable service life of the structure, it is necessary to improve the ability of concrete to resist external erosion. In order to achieve the purpose of improving the durability of concrete, and using HPC is an effective way to solve this problem. In order to strengthen the corrosion resistance of concrete, HPC with grinding slag is selected as the material. HPC with pulverized slag is made by grinding blast furnace slag to a certain fineness, adding activators such as high efficiency water reducing agent, and replacing cement with a large amount of the same amount. Concrete costs do not increase much, and can reach or exceed ordinary concrete. The most important characteristic of HPC with grinding slag is its strong resistance to chloride ion penetration. Therefore, the application of fine slag HPC in Marine reinforced concrete buildings can effectively prevent the corrosion of steel bars in

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concrete caused by chloride ion invasion, thus greatly improving the durability of Marine reinforced concrete buildings.



Figure 4. Zhanjiang Port iron ore wharf project [16].

5.2. Guangzhou east ring highway

In Guangzhou East Ring Expressway, polypropylene fiber concrete has successfully solved the requirements of crack resistance, impact resistance and wear resistance of magnetic pavement in toll station. This section of road cannot lay steel mesh or use steel fiber due to the buried magnetic induction coil for automatic testing. Meanwhile, the thickness of the road surface is limited. Therefore, 0.9kg Dura fiber is added into each cubic meter of C50 concrete, and the pavement thickness is 33cm, which not only solves the engineering problem, but also reduces the material and construction costs by eliminating a layer of steel wire mesh [17]. Since the toll station was built and put into use, the busy traffic flow of Guangzhou expressway has not caused obvious damage to the road surface, and the use effect is good. The overall overview is shown in Figure 5.



Figure 5. Guangzhou east ring highway [18].

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6. Conclusion

HPC is considered to be the most comprehensive concrete in the world due to its high durability, high workability and many other excellent characteristics, and it gives full play to its high durability and excellent long service life in many important bridges, seaports and high-rise building projects. The HPC can reduce the cost effectively by improving the blending ratio and blending material. The maintenance cost of defective concrete works is huge, so it is particularly important to increase the durability of concrete, which can reduce a lot of maintenance costs. Therefore, the paper also analyzes the factors that affect the durability of concrete and how to improve the durability of concrete.

The popularization of HPC is an inevitable trend in the development of concrete technology. In the future, it is necessary to meet the needs of the project as the goal, to maximize the realization of green environmental protection and cost savings, that is, vigorously develop green high-performance concrete. The so-called green HPC must first have the characteristics of high performance [18]. As a foundation building material, concrete's quality indexes such as compressive resistance and durability are the basic foothold of concrete. Its green color should be reflected in the entire process of production and use. In the selection of raw materials such as rubber, aggregate and admixtures, the occupation of natural resources and energy consumption should be minimized, and the recycling of materials should be emphasized. HPC should be controlled in the use process, reduce the load on the environment in the whole process, and form a green production and use system.

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