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Research on High Toughness Concrete based on Green Ultra-low Carbon

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Abstract: Based on the pollution of construction solid waste and the promotion of "double carbon" strategy, this paper aims at designing and researching a kind of low carbon, environmental protection, high toughness concrete. The research in this paper mainly includes the composition of ultra-low carbon green high toughness materials, solid waste reuse, proportion design, performance investigation, component interaction, etc., in-depth elaboration of the characteristics of ultra-low carbon green high toughness concrete, put forward to effectively improve the performance of this kind of concrete, new material composition and proportion design method, for the follow-up of the high-performance concrete optimal proportion design to provide a method. Finally, the development direction of green ultra-low-carbon high-performance concrete is prospected, and the problems existing at this stage are analyzed.

Keywords: Green Ultra-low Carbon; High Toughness; Carbon Emission; Concrete; Alkali-stimulated Cementitious Materials.

1. Introduction

In recent years research has strengthened the development and application of new cementitious materials, low carbon concrete and other sustainable building material products. It is generally believed that low-carbon concrete is a kind of concrete that emits significantly less greenhouse gases compared with traditional concrete from the whole life cycle of concrete production, application and disposal. Therefore it is crucial to adopt green low-carbon concrete and clarify the direction of production, application and development of low-carbon concrete. Green high-performance concrete refers to the process of production and use of concrete to realize the greening of concrete by minimizing carbon emissions while ensuring the performance of concrete such as high strength and high durability [1]. Alkali-excited cementitious materials have the advantages of high early strength, low heat of hydration, and corrosion resistance, etc. Using water glass as the exciter, Ca(OH)2 was mixed into alkali-excited mineral powder concrete, and it was found that Ca(OH)2 accelerated the coagulation of the concrete [2]. Mechanical properties of concrete prepared from quarry waste rock flour and man-made mechanism sand, it was found that the compressive strength of the mechanism sand concrete with 50% replacement of river sand increased by 1.35% and 1.56% at 28d and 56d with the same water-cement ratio, the flexural strength as well as the splitting strength were also improved. The modulus of elasticity of waste rubber fiber concrete gradually decreased with the increase of waste rubber fiber content, indicating that the addition of waste rubber improves the toughness of concrete. Therefore, in this paper, alkali excited materials, mechanism sand, recycled aggregate as basic raw materials, adding waste rubber fiber to improve its toughness, to prepare all solid waste ultra-low carbon green high toughness concrete. Numerous factors can affect the design of all solid waste ultra-low carbon high toughness concrete. One part is the raw materials, the amount and ratio of cement, water, stone and sand, followed by the type and amount of new alternative materials, such as mineral admixture and recycled coarse aggregate. In addition, the environment in which the concrete raw materials are located, structural parts, production and construction processes have an impact on their technical requirements, which affects the design of the concrete ratio. New alternative materials admixture is crucial, they not only reduce the amount of cement in concrete, but also improve the working properties, mechanical properties and durability of concrete [3]. Finally, the properties of concrete mixes in terms of workability, quasi-static and dynamic compressive strength, dynamic elastic modulus, and energy absorption are investigated and analyzed to reveal their working mechanisms, determine their optimum proportions for different applications, and explore their subsequent improvements in response to the problems that arose during the tests.

2. Research Content

2.1. Project Materials

About 90% of the carbon emissions in the cement production process come from the firing of clinker. The use of cement component optimization technology can reduce the amount of clinker in cement, thus reducing carbon emissions from cement production. One is to replace cement clinker with fly ash, slag, volcanic ash and other industrial waste residues as active mineral admixtures, slag is an industrial waste residue produced by iron and steel enterprises in the smelting process, slag has stable gelling activity under certain conditions, and it can be used as a good gelling material instead of cement, and cement is a good slag excitation material, so slag is used as a coagulating concrete gelatinizing material, and at the same time, cement can be used as a slag Cement is also a good slag excitation material. This is not only conducive to improving the performance of concrete, but also reduce CO2 emissions, and the large-scale use of fly ash and other industrial waste is conducive to environmental protection. The second is the use of alkali excitation cementitious materials, alkali excitation cementitious materials (AAM), also known as geopolymer, is a kind of aluminosilicate minerals in the alkali excitation agent under the action of excitation activation of the formation of inorganic cementitious materials, which has the advantages of good durability, excellent performance, green environmental protection and so on. It has the advantages of good durability, green and environmental protection, etc. A large number of studies have shown that alkali-activated cementitious materials have the advantages of significantly improving the mechanical properties and durability in the later stage, and are regarded as an ideal substitute for ordinary silicate cement. AAM, as a main raw material for reuse and recycling of solid wastes, can effectively reduce the environmental pollution, and promote to achieve the goal of "Carbon Peak, Carbon Neutral".

Construction waste is sorted, crushed, screened and processed to be used as road material, reducing land pollution and beautifying the environment. In the process of waste treatment, according to the standard of mixing coarse aggregate in concrete, part of the construction waste is used as waste concrete, and recycled aggregate is prepared at the same time. The weak interface between the original aggregate and the attached old mortar in the recycled aggregate increases the damping energy dissipation capacity of the concrete under external loading, and has a certain potential to improve the damping performance of concrete. Recycled aggregates can be added to replace natural aggregates to form recycled concrete, realizing the reuse of resources, which can also be widely used in road construction.

Due to the large amount of human mining river sand, the ecological environment is seriously damaged, the current mechanism sand is widely used in high-performance concrete, gradually replacing the river sand in the status of concrete engineering. Mechanism sand is through the ore crushing, screening, shaping and other processes, the production of a good gradation of products, compared with river sand, mechanism sand can be better in the actual application of the project to meet the use of standards. At the same time, due to the mechanism of sand is made from the ore in the fine grained stone grinding, its application process will produce a certain amount of stone powder. Mechanism sand is not the more pure the better performance, mixed with the right amount of stone powder to help improve the compactness of concrete, improve the overall performance of concrete; but mixed with stone powder can not be too much, otherwise it will reduce the strength and performance of concrete. High-quality performance of sand and gravel aggregates has become a hot spot for researching the performance of high-performance concrete.

Modern concrete structures are often subjected to dynamic loading effects such as earthquakes, impacts, explosions, etc. However, as a brittle material, concrete has poor impact resistance and energy absorption strength. The improvement of the mechanical properties of concrete is mainly due to the optimization of the internal structure and the application of special materials. For example, if rubber fibers are added to concrete, this material can improve its toughness at the microscopic level and obtain high-performance concrete, which provides a strong material support for modern construction. Rubber fiber is crushed by the rubber, cut from a certain toughness of the fibrous polymer. With the booming development of transportation, the number of scrap tires has increased dramatically. Scrap tire rubber has a lightweight, toughness and other characteristics, and waste rubber is not easy to degrade, landfill disposal not only occupies land, but also on the soil and groundwater pollution. Therefore, the waste tires crushed into particles and mixed into the concrete, so that it has good deformation properties and energy absorption properties, in order to improve the toughness of the concrete at the same time can achieve the green recycling of waste tire rubber.

The relationship between solid waste and low-carbon concrete is inseparable, and the goal of low-carbon concrete cannot be achieved without efficient utilization of solid waste. However, only industrial solid waste that is not harmful to the performance of concrete can be used. Nowadays, green and low-carbon has become the main theme of the development of the construction materials industry. Based on the above discussed background, this this project aims to study a low-carbon, environmentally friendly, high toughness concrete, that is, a high-performance concrete using mineral admixtures, alkali stimulated cementitious materials, recycled coarse aggregate, mechanism sand fine aggregate as the basic raw materials, and adding waste rubber fibers as a way to improve the toughness of concrete. This basis focuses on the working performance, mechanical properties and impact toughness of concrete, and seeks to apply this ultra-low carbon high toughness concrete to engineering practice to achieve the goal of environmentally friendly and green production. Green ultra-low carbon high toughness concrete material components are shown in Fig 1.

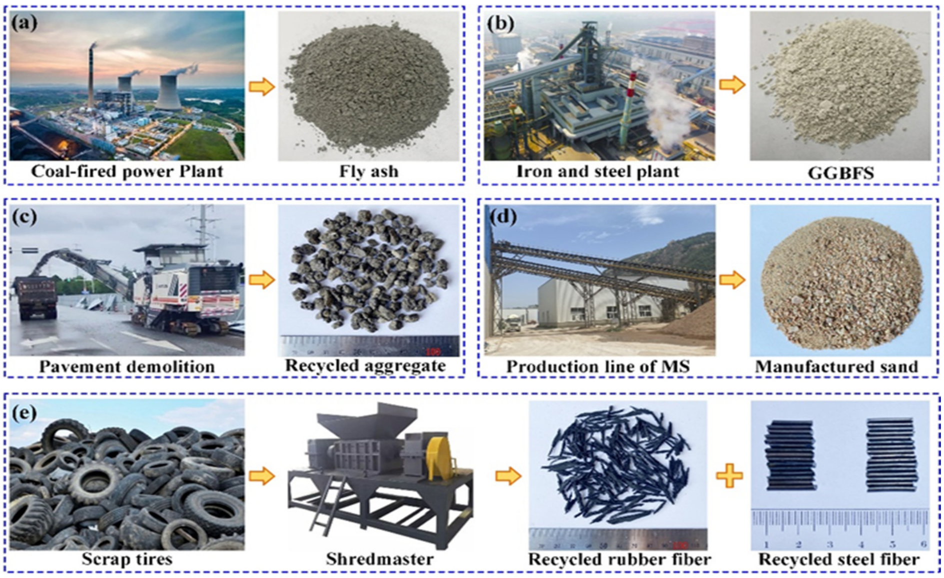

Fig 1. Material components

2.2. Green Ultra-low Carbon High Toughness Concrete Working Performance, Mechanical Properties Research and Proportion Optimization

In this paper, alkali-inspired admixtures, mineral admixtures as cementitious materials mixed with recycled aggregates, mechanized sand, and mixed with waste tire rubber fibers to prepare a kind of green ultra-low carbon high toughness concrete. Before the relevant designers participate in the proportioning, focusing on the performance of the relevant raw materials to do a good job in the research work, and at the same time should focus on the analysis of the water cement ratio, the number of cementitious materials, mineral admixtures, sand content, fiber content, and other parameters on the performance of the concrete materials have an impact on the performance of the concrete. In the case of the rest of the conditions are the same, the configuration of different proportions of mortar, when the mechanism of sand content is appropriate, the concrete material mobility increases. This is because the mechanism of sand is a fine aggregate, there is a certain lubrication effect, will increase the fluidity of concrete materials. However, the sand content can not be too high, will reduce the lubrication effect; sand content can not be too low, it is difficult to play its lubricating effect, the concrete working performance will also be reduced. In the case of a certain water-cement ratio, the appropriate amount of mineral admixture can improve the compactness of the concrete structure, thus improving the strength of concrete materials, but the mineral admixture can not be too much, otherwise it will reduce the strength of concrete materials; mineral admixture cannot be too little, otherwise the concrete structure is not enough to be filled, the material strength and compactness of the material is too low. Since the water-cement ratio is the core part of the concrete material proportioning, the cement material as well as the added alkali excitation and mineral admixture directly affect the overall mechanical properties of concrete.

Therefore, this experiment is based on the influence of raw materials on the performance of concrete, with solubility ratio, fiber admixture, recycled coarse aggregate admixture and mechanism sand content and lithology as independent variables, and collapse, compressive strength, flexural strength, cracking resistance as the test indexes, in testing its mechanical properties, in the case of all other conditions remain unchanged, the carbonation of the recycled aggregate concrete and the non-carbonation of the recycled aggregate concrete to do a comparison of the recycled concrete. The concrete is tested for flexural strength, compressive strength and static elastic modulus, and the apparent density and water absorption, flexural compressive strength and static elastic modulus of the two types of concrete are compared. When the mechanism of sand is certain, the fiber content is analyzed, and the load-deflection curve is drawn through the bending toughness experiment to analyze its lateral shift resistance, and the fiber and mechanism of sand content is optimized on the basis of the experiment. The basic working performance of the material is studied by testing each test index separately, observing its test indexes and drawing the stress-strain curve of the material; on the basis of the experiment, the working performance, mechanical performance and economic feasibility of the material are considered comprehensively to optimize the ratio of the green, low-carbon and high toughness concrete. The compressive strength test is shown in Fig 2 below, and the concrete fluidity is shown in Fig 3.

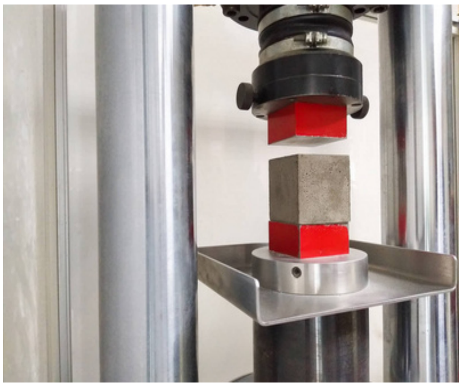

Fig 2. Compressive strength test

Fig 3. Concrete fluidity

2.3. Research on Dynamic Properties of Green Ultra-low Carbon High Toughness Concrete

In this paper, with reference to the dynamic performance test method of ordinary concrete, for the green ultra-low carbon high toughness concrete with optimized mix ratio, dynamic performance test is carried out to evaluate its dynamic modulus of elasticity, damping ratio, wave speed and other dynamic properties. The team carries out Hopkinson's compression rod test. The basic principle of Hopkinson's compression rod test (SHPB) is that a high-pressure air gun gives a certain initial velocity to the impact rod, which impacts the incident rod in the axial direction, generating a compressive stress wave in the incident rod. The compressive stress wave is transmitted to the part of the incident rod that is in contact with the specimen, and since the wave impedance of the specimen is smaller than that of the compression rod, part of the stress wave is reflected and the other part is transmitted; the reflected wave is reflected into the input rod, and the transmitted wave is transmitted into the output rod [4]. The strain signals in the middle of the incident and output rods are collected, and the curves of the three waves can be obtained.

The intensity indexes of the incident wave, reflected wave and transmitted wave derived from the test facilitate the subsequent calculation of its stress, strain and strain rate indexes, so as to plot its stress-strain curve and evaluate its dynamic compressive strength, impact toughness and energy absorption performance.

2.4. Green Ultra-low Carbon High Toughness Concrete Microstructure Characterization Analysis

The use of X-ray diffraction, X-ray energy spectrum analysis and scanning electron microscopy and other modern testing methods for microstructural characterization of the material and damage mechanism analysis, X-ray analysis in the comparison of different strength grades of ultra-low carbon high toughness concrete at the same age of the map, observation of its hydration through the hydration, carbonation reaction of the products of the analysis. Scanning electron microscope meticulously observes the microstructural maps of C30 and C40 low carbon high toughness concrete at different ages to study the interfacial bonding of the materials and compare them with traditional concrete materials.

3. Innovative Points

3.1. Innovative Materials - Target High Toughness Environmentally Friendly Materials

This project is a concentrated expression of the latest research results of ultra-low carbon green concrete. With the continuous development of the economy and society, the development concept of "low consumption, high efficiency, environmental protection, energy saving, waste utilization" is becoming more and more popular. Green high-performance concrete materials of various types of raw materials itself does not have a high concentration of pollution problems, some of the previous choice of materials ignored the impact on the environment, it seems to improve the quality of construction, in fact, the release of pollutants is very much, which not only affects the development of the project, but also on the production of neighboring residents of the production and life of the larger damage. Through the effective application of green high-performance concrete materials, the release rate of pollutants is further reduced, and can strengthen the comprehensive protection of ecology, the building complex to create a better integration with the natural environment, to achieve the goal of sustainable development. Green high-performance concrete materials in the construction industry have been widely welcomed, and is conducive to the construction project from the inside to the outside of the innovation. Studies have been conducted to propose improvements in equipment in terms of green and low carbon, one-time large mass pouring volume enhancement, high-precision metering, automation, and safety [5].

In recent years, researchers have used mineral admixtures and alkali-inspired materials to replace cement as cementitious materials, which not only reduces the huge amount of carbon emissions caused by cement production, but also helps to improve the strength of concrete [6]; recycled aggregates instead of stones as coarse aggregates can be used for road construction [7]; machine-made sands instead of river sands as fine aggregates can reduce the ecological damage caused by human mining activities [8]; and the use of waste tire rubber products mixed into the Concrete to improve its toughness [9] and reduce the waste rubber accumulation, incineration caused by soil and air pollution. This project also used construction waste ceramics to prepare ceramic particle materials, forming a high toughness green low-carbon concrete containing rubber fibers and mixed with ceramic particles, and mechanical test equipment to carry out compressive strength test, flexural strength test, SEM scanning electron microscope test, have achieved good performance results.

3.2. Innovative Research Mechanism - Considering the Interaction between Components

This study of the compatibility between the different components of green concrete to make up for the relevant gaps. Recycled coarse aggregate, mechanism sand, alkali-stimulated cementitious materials, rubber fiber and other components are non-traditional components of concrete, previous research is mostly focused on the effect of a single component on the performance of concrete, such as the study of polycarboxylic acid water reducing agent in the mechanical properties of green concrete, the addition of different dosages of fly ash to test its compressive strength [10], etc. However, the study of the effects on the working, mechanical and dynamic properties of concrete caused by the interactions between the above components is still insufficient. The research of this team intends to carry out the compatibility and interaction mechanism of the above components in the concrete system, which will provide a theoretical basis for the preferred green concrete proportion and performance optimization.

3.3. Innovative Concepts--Achieving the "Double Carbon" Strategy, Green Economization Design

Research shows that the concrete industry is a high-consumption industry, from cement production to concrete production, each link needs to invest a lot of resources and energy, and green high-performance concrete has become the future development direction of concrete. Therefore, this project actively responds to the "double carbon" strategic goal, and strives to adopt the green low-carbon concrete with little environmental pollution in the selection of topics and research direction, and conducts all-round and multi-angle design of concrete in the aspects of cementitious materials, coarse and fine aggregates, and toughness components, etc., and focuses on the concept of "carbon emission ratio", and comprehensively selects the most suitable concrete materials. The research direction is to design concrete from all angles in terms of cementitious materials, coarse and fine aggregates, toughness components, etc., and focusing on the concept of "carbon emission price ratio", to comprehensively select concrete materials with low green cost and low construction and maintenance cost. It is a useful exploration of the green design and production of concrete materials, aiming to contribute to the national protection of the environment and the realization of sustainable economic development.

3.4. Innovative Research Model - Modeling of Concrete Mechanical Properties and Pore Structure Parameters

In this paper, alkali-excited tannery sludge and fly ash (20%) is used to replace cement to prepare alkali-excited composite cementitious cementitious material (ATFC), to study the influence of different sludge dosage and alkali equivalent on the working performance and hydration history of cementitious material, and to establish the relationship model between compressive strength and hydration index; secondly, alkali-excited recycled aggregate concrete (GAC) is prepared by recycled coarse aggregate, to study the influence of alkali-excited composite cementitious material system on the mechanical properties and pore structure parameter of recycled concrete. cementitious material system on the mechanical properties and microstructure time-varying law of recycled concrete, establish the relationship model between mechanical properties and pore structure parameters, and further analyze the connection between its microstructure and macro performance.

3.5. Problems to be Solved

3.5.1. Detailed Design Method of Green Ultra-Low Carbon High Toughness Concrete Ratio

The ratio design method of traditional concrete has been relatively mature, but there is no uniform and universally applicable ratio design method for special components, especially for concrete mixed with multiple special components, which will restrict the large-scale application of concrete materials such as this type of concrete materials in actual projects. Therefore, to propose a reasonable and scientific design method of green ultra-low carbon high toughness concrete proportion is the premise of this project, and also the first problem to be solved in this project.

3.5.2. Interaction of Different Components on Concrete Influence Mechanism

The hydration products of cementitious materials are quite different from ordinary silicate cement, and a large number of studies have been carried out on the influence performance of fly ash and slag under various influencing factors, but it is still necessary to further explore the interaction effects of alkali stimulated cementitious materials, slag and fly ash mixtures. The original aggregate of recycled coarse aggregate, the original old mortar attachment affects the strength of recycled coarse aggregate, water absorption properties, surface characteristics significantly different from natural stone aggregate. The particle gradation and powder content of mechanism sand are also significantly different from natural river sand. In addition, the low modulus of elasticity and water-repellent properties of waste rubber fibers make their influence on the mechanical properties of concrete cannot be ignored. The interaction of the above components when mixed will have a significant effect on the working performance, mechanical properties and dynamic properties of concrete.

3.5.3. Continuous Optimization of Green Ultra-Low Carbon High Toughness Concrete Performance and Construction Management

How to optimize and redesign the green concrete mix ratio based on the purpose of use according to the unused application occasions, combined with the experimental data and related mechanisms obtained from this project, is the key to whether the green concrete of this project can be applied on the ground.

Improve the unified and complete management method of green high-performance concrete materials. The construction of green ultra-low carbon high toughness concrete still needs to establish a professional team guidance and management mechanism. The professionalism and practices of technical personnel should be continuously improved, and every aspect of the use of green high-performance concrete materials should be improved. Otherwise, continue to follow the old ideas and methods, cannot achieve the green application of construction.

4. Conclusion

In this study, a green ultra-low carbon high toughness concrete is designed by using mineral admixtures such as slag fly ash, alkali stimulated cementitious materials, recycled coarse aggregates, mechanism sand, adding waste rubber fibers and other new materials with raw materials. Through the compressive strength tester and slump test, Hopkinson compression rod test to test its compressive strength, work performance, impact resistance; X-ray diffraction, X-ray spectroscopy and scanning electron microscopy, and other modern testing methods to characterize the interface microstructure of the material and damage mechanism analysis. Innovative material composition, interaction research mechanism, innovative concepts such as “double carbon” and “carbon emission ratio”, as well as the model of the relationship between the mechanical properties of cementitious materials and pores, which have not been studied before. This experiment designs a kind of concrete with small pollution, good mechanical properties and strong toughness, which provides a theoretical basis for the subsequent selection of green, low-carbon and high-toughness concrete ratios. However, this experiment also exists in the detailed method of designing the ratio, the constraints of the applicable conditions of different material ratios; the final impact of different component influencing factors on the performance of green concrete, the subsequent construction management specification of green concrete, and the question of whether this material can be actually landed, and this paper provides a reference for the research on the frontier direction of green high toughness concrete.

References

[1] Li X. Research on the synergistic preparation of green and low-carbon composite cementitious materials from multiple sources of solid waste [D]. Hebei University of Engineering, 2023.

[2] Gui Baoxing, Wu Chi, Luo Yu. Low-carbon green research and application of high-performance concrete[J]. Residence, 2023, (06):148-150.

[3] ZHANG Ping, CHEN Xu, LI Shaochun,et al. Preparation of green low-carbon high-performance concrete and its performance [J]. New Building Materials,2020,47(09):155-158.

[4] Yang Q. Research on dynamic mechanical properties of recycled concrete in Hopkinson compression bar experiment [D]. Xi'an University of Science and Technology, 2018.

[5] Ziyun Chen, Ruwei Zhang, Yuchen Liu, et al. Research on the technology of new offshore concrete mixing equipment based on green and low carbon [J]. Construction Machinery, 2024, (02): 26-29.

[6] ZHANG Lipeng, MIAO Baodong, PENG Wenbo, et al. Study on the performance of geopolymer cementitious materials based on orthogonal test [J]. Construction Technology (in Chinese and English),2024,53(03):146-155.

[7] ZHANG Lingtong, ZHANG Dong, LI Baoyuan,et al. Application of construction waste concrete recycled aggregate in road subgrade [J]. Heilongjiang Science,2023,14(20):18-21.

[8] LIU Pingyun, ZHANG Han, LI Kun,et al. Experimental study on the effect of water-cement ratio on the performance of mechanism sand concrete[J]. Concrete and Cement Products, 2024, (05):1-6.

[9] Lai DD. Research on impact resistance of fiber-rubber concrete for structural protection [D]. Zhejiang University, 2023.

[10] Li Shun, Yu Qijun, Wei Jiangxiong. Influence of molecular structure of polycarboxylic acid water reducing agent on the hydration process of cement [J]. Journal of Silicates, 2012, 40 (04): 613-619.