

Advantages and Performance of Novel Sustainable Green Concretes

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Abstract. The popularity of concrete is accompanied by terrible consumption, resulting in huge carbon emissions in our environment. Accordingly, the concept of sustainable development has been valued in the cement material production industry. Based on high-performance concrete, green high-performance concrete materials have been proposed and become a research hotspot. This study sorts out and provides the recognized characteristics of green concrete and introduces different environmentally friendly green concrete types from three ways of reducing the environmental burden. The fly ash concrete shows the characteristics which contain abundant resources, low cost and wide application scope. And for recycled concrete, it can greatly reduce the environmental impact caused by construction waste and reduce the production of traditional concrete. Nano-development of concrete would improve the properties of conventional concrete, to achieve greater strength with minimal environmental burden. Results show that green concrete saves the amount of cement and concrete, is environmentally friendly, and has high strength, high durability, and crack resistance compared with traditional concrete.

Keywords: Sustainability; Green concrete; Fly ash; Recycled-concrete; Nano-material concrete.

1. Introduction

Under the frequent development of modern technology and social productivity, people's lives have undergone tremendous changes. At the same time, a series of major problems such as excessive consumption of natural climate, resources, change, environmental pollution and ecological destruction threaten human survival and development. As the material base of the construction industry, building materials play an essential role in the national economy. Building materials show a close and broad link with resources, energy, and the environment in all aspects, from the exploitation and selection of raw materials through the preparation, use, waste, and recycling of products. Green building materials that can reduce environmental pollution and save resources and energy can meet sustainable development needs and achieve the unity of development and environmental protection [1-3].

As the largest artificial building material, cement concrete plays an irreplaceable role in many constructions engineering fields. However, with the increasing annual production of cement and the amount of concrete poured in the world, its impact on resources, energy, and the environment is enormous. Developing countries must undertake various projects, while developed countries still have much infrastructure to rebuild. It is estimated that the annual production of concrete in the world exceeds 6 billion. In the concrete production process, cement, as an important component, is not an environment-friendly material. Every ton of cement clinker produced will emit about 1 ton of carbon dioxide into the atmosphere. The cement industry emits about 1.6 billion tons of CO₂ into the global atmosphere, occupying for about 7% of the global greenhouse gas emissions. In addition, many raw materials, such as limestone, clay, and fuel coal, must be mined, resulting in large-scale deforestation and soil loss. The annual consumption of sand, gravel and crushed stone for concrete production worldwide is 10-11 billion tons, which harms the ecology of forest areas and river beds. To mix concrete, about 1trillion litres of water is used every year. Water is also required to clean sand, stone, and curing concrete. In addition, a large number of solid wastes from concrete construction and demolition activities have burdened nature. The release and diffusion of construction noise and toxic

substances may cause some problems. Therefore, the concrete industry is facing challenges to the environment [7,8].

The design based on environmental performance has been put on the agenda. As a major energy consumer and producer of environmental impact, the concrete industry must take adequate measures to adopt and develop environmentally friendly and sustainable materials, design, and construction, such as the use of more auxiliary cementitious materials, for instance: fly ash, blast furnace slag, recycled aggregates, and reclaimed water, as well as chemical admixtures such as high-efficiency water reducers, thus enabling the development of green concrete and green buildings.

This study integrates the available information of several emerging technologies in the cement industry. The types of green concrete are mainly introduced from three perspectives: 1) by using specific sustainable materials as a replacement for conventional cement [11,12], the products have satisfied performance during the whole stages of the construction and maintenance of a building. 2) Concrete made of recycled aggregate obtained by cleaning, crushing, grading, and proportioning waste concrete as part or whole of aggregate. It is called recycled aggregates concrete. 3) The strength and performance of concrete are improved from the micro-scale to reduce traditional concrete demand in construction and reduce carbon dioxide emissions [13,14]. The aim is to provide engineers, cement companies, investors, researchers, other stakeholders, and policymakers with a well-structured database of the information about such technologies.

2. Concept and characteristics of green concrete

Green concrete is commonly regarded as an unavoidable byproduct of the advancement of material science and technology as well as the sustainable growth of society. It is a cutting-edge material for civil engineering with environmental coordination and adaptive properties that can satisfy the needs of concrete's sustainable development, significantly minimize environmental pollution, and support the coordinated development of concrete and natural ecological systems. Green concrete has higher strength, better durability, and rich resources for choice than traditional concrete. It can use many abandoned industrial resources to realize the recycling of renewable resources, reduce the emissions of harmful substances, and achieve low carbon emission reduction targets. The buildings with green concrete are suitable for people to live in and have little harm to the human body.

Green high-performance concrete may have the following characteristics.

a. The cement used should be environmental friendly, and the exploitation of sand and stone materials should be orderly without excessive environmental damage. 'Green cement' here refers to the 'green' cement industry, which maximizes resource utilization and secondary energy recovery from other sectors to improve the environment.

b. Minimize cement consumption, reduce 'by-products' in cement production - carbon dioxide, sulfur dioxide, helium oxides and other gases to protect the environment.

c. More processed industrial waste residues, such as ground high-quality fly ash, coal slag, fume of silica, and ash of rice husk, are added as active admixtures to save cement, protect the environment and improve the durability of concrete [10,17].

d. Many water-reducing agents made from industrial waste liquid, especially black pulp waste liquid, and other composite admixtures developed on this basis are used to help other industries digest and treat difficult liquid emissions.

e. Concentrate on mixing concrete and vigorously develop ready mixed commercial concrete, eliminate the waste, powder layer, and wastewater generated by on-site mixing concrete, and strengthen waste and wastewater recycling.

f. Give full play to the advantages of high-performance concrete (HPC), improve the constructability by improving the strength and durability, save cement, reduce maintenance costs, and the uncontrolled use of natural resources [10,13].

g. Recycle a large number of demolished and discarded concrete to develop recycled concrete [17,28].

3. Development status and prospect of green concrete

3.1 Status Quo

Industry of conventional cement and concrete will release redundant CO₂ and other greenhouse gases which bring up the impact on environment. It is estimated that by 2030, the cement production will reach 4 billion tons per year. In addition, more than 5 per cent of anthropogenic emissions of greenhouse gas root in cement production. To reduce the emission of CO₂, sustainability is proposed in Civil Engineering field. Under the long-term development and sustainability conditions, by integrating the available finance and resource from society, it is a preferable path to seek balance between environment and industry. Cement, as one of the most important building materials, has great room for adjustment and upgrading to meet the sustainable development needs of the world today.

3.2 Advantages of Concrete with Mixture

The development and production of green concrete can significantly improve the performance of traditional concrete. In addition, the mineral admixtures required for the production of green concrete are not only widely collected, but also relatively low in price, relatively small in water consumption, high in activity, strong in hardness and bright in application prospect. These mineral admixtures have wide collection channels and low price, relatively small water consumption, high activity and strong hardness. The development and production of green concrete can significantly improve the performance of traditional concrete. In addition, the mineral admixtures required for the production of green concrete are not only widely collected, but also relatively low in price, relatively small in water consumption, high in activity, strong in hardness, and bright in application prospect. In addition, these mineral admixtures have wide collection channels and low price, relatively small water consumption, high activity, and strong hardness.

3.3 Advantages of Recycled Aggregates Concrete

The natural resources of the earth are limited, and most of them are non-renewable resources. Nature cannot withstand the perennial and uncontrolled demand for resource. Otherwise, it could bring immeasurable harm to the environment. Most of the houses in China are brick-concrete structures and reinforced concrete structures. The recycling of construction waste mainly solves the recycling of brick-concrete construction waste. China is dominated by brick-concrete construction waste, which is also true in the future. Waste recycling can effectively reduce the damage to the natural environment and the consumption of natural resources, promote a friendlier relationship between man and the environment, and promote the harmonious coexistence of man and nature.

4. Specific new concrete

Numerous suggestions have been offered to diminish the environmental impact of building without decreasing the amount of concrete produced.

- a. Optimization of the usage of pozzolanic materials such as: blast furnace slag and fly ash, which could be substitutions for cement.
- b. During the whole service cycle of some civil construction, by updating the technology to diminish the consumption of the energy or nature resource.
- c. Introducing of higher performance environmental protection concrete with better durability and strength to improve the strength of corresponding structural components and thereby reduce the amount of concrete used.

This part mainly introduces three specific new concretes: fly ash (FA), recycled, and nanoscale concrete.

4.1 Fly Ash Concrete

Nowadays, there is a general trend is to substitute a high amount of PC with fly ash [19,20]. As a green and environmentally friendly active mineral admixture, fly ash can be used as cement-based composite material instead of part of cement for concrete preparation, and fly ash has a filling effect and pozzolanic effect. Usually, concrete with high-volume fly ash (HVFAC, Figure 1) refers to the concrete with FA that content is more than 30% in the total cementitious mass of materials. Due to the pozzolanic activity of used fly ash, a low water-cement ratio, and a superplasticizer, the fly ash concrete performs a similar mechanical property to Portland cement concrete. Fly ash can improve the early strength of concrete, which helps to compensate for the lack of early strength of concrete after adding other mixtures.

With the gradual development and in-depth study of technical personnel in the field of materials, now, alkali-activated concrete is located at the summit of the technology of cement replacement, which means alkali-activated materials would replace the traditional cement binder completely. At present, two kinds of Fly Ash-based materials with low calcium are hot research topics: (1) alkali-activated fly ash concrete (AAFAC) (2) slag/FA-based geopolymers concrete (Figure 2). For both types, in the construction stage, it is possible to obtain sufficient mechanical properties. The internal interface structure of concrete can be improved by adding fly ash to reduce the porosity and increase the compactness of concrete. Moreover, replacing part of cement with fly ash in hydraulic concrete can save the amount of cement and effectively utilize local industrial waste [2,3,10]. At the same time, it can reduce environmental pollution and engineering cost and has the dual role of saving energy and protecting the environment.



Figure 1. Common fly ash concrete

According to statistics, in practical applications, compared with cement, the hydrothermalization generated by adding fly ash into concrete can reduce the hydrothermalization by more than 10 %. If fly ash is added to mass concrete, the maximum value of hydrothermalization can be effectively delayed to three days, thereby reducing the occurrence of cracks in concrete due to high temperature. As the application of fly ash gradually develops towards diversification and complexity, relevant staff should conduct reasonable screening before using fly ash to maximize the performance and quality safety of concrete.

Water bleeding is a common problem in construction projects. If the concrete mix proportion is unreasonable, there would be three phenomena within several hours from pouring concrete to the initial setting: water bleeding, plastic settlement and plastic shrinkage. The mitigation measures of water bleeding is when the volume of fly ash is equal to or less than 15 % of fine aggregate, the addition of fly ash has little effect on the bleeding of fresh concrete, but with the increase of fly ash content, the bleeding tends to decrease. Especially when the content reaches 35 % and 40 % , the addition of fly ash has a certain regulatory effect on the workability of concrete.

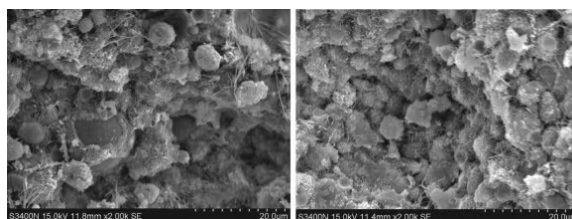


Figure 2. Microstructure of fly ash concrete

4.2 Recycled Concrete

Fly ash concrete material aims to improve the environment: protect natural resources, reduce carbon dioxide emissions, reduce the amount of waste generated. Simultaneously, recycled cement aggregate (RCA) can potentially reduce the transport burden compared with natural aggregate (NA), as concrete is usually recycled at demolition sites or near cities (Figure 3).

Concrete with replacement of traditional cement and natural aggregate often has the greatest potential to reduce environmental impact if it meets the engineering requirements of the structure. Based on this concept, there are four kinds of “green” concrete mixtures, which are verified by experiments to have the same compressive strength. The environmental assessment is carried out and by comparing with the corresponding traditional concrete mixture (NAC). The concrete is recycled aggregate concrete containing cement binder (RAC), mass fly ash concrete containing natural aggregate (NAC_FA) and recycled aggregate (RAC_FA), and alkali-activated fly ash concrete containing natural aggregate. (NAC_AAFA, Figure 4).

In terms of strength, the compressive strength of recycled concrete is greatly affected by the strength of the original waste concrete. Usually, it is positively correlated with the compressive strength of the original waste concrete. The compressive strength of 28 d is 15 % lower than that of the original waste concrete under the same water cement ratio. The tensile strength difference between the two will gradually decrease with the increase of concrete age.

The tensile strength of recycled concrete is also closely related to the original waste concrete, which is generally about 18 % lower than that of natural aggregate concrete [4,17]. The tensile strength of recycled aggregate concrete also increases with age, but remains unchanged after 28 d. To further improve recycled concrete's tensile strength, an appropriate water reducer and fine silica fume can be added to the mixing process, and the improvement effect is the most obvious after 28 days.



Figure 3. Recycled aggregates



Figure 4. Principle of recycled aggregates concrete

Previous research and test have shown that the behaviors of structural elements made by analyzed concrete types under short-period loading are very similar to the corresponding NAC. Shear capacity of the beams made of NAC_FA, NAC_AAFA, RAC and RAC_FA are quite similar to the corresponding NAC beams [7,8]. In terms of seismic behaviors, the conclusion is equally valid.

In addition to recycled aggregate concrete, other waste materials can be used as raw materials for preparing recycled concrete [21-23]. In recent years, scholars have focused on related waste generated in different industrial fields, such as construction waste, waste glass, waste tires, and waste stone powder. Because the chemical components of these wastes are similar to those of river sand and cement in the composition of high-performance concrete (HPC), if they can be partially or entirely replaced as components of HPC, under the premise of maintaining the design strength, they can not only realize the recycling of resources, reduce the production cost of HPC, but also bring significant environmental benefits. Therefore, replacing HPC components with industrial waste based on

chemical component similarity is one of the main directions for developing HPC environment-friendly in the future [4,17].

4.3 Development Of Cement Concrete on a Nanoscale

Besides the replacement and reuse from a macro perspective, such as fly ash concrete and recycled aggregate concrete mentioned above, in academia, it is widely believed that concrete should be developed at nanometer scale to improve its chemical and physical mechanical properties. Because of its high activity, nanoparticles can accelerate cement hydration, improve properties from different perspectives. By introducing engineering nano-materials, for instance nano-SiO₂, nano-Fe₂O₃, nano-CuO, and nano-TiO₂, mechanical strength and durability of materials could be developed in a considerable trend [24,25].

Nano-TiO₂ was selected as filler to prepare nano-TiO₂ modified cement-based concrete composites with different doping contents, and the effect of nano-TiO₂ doping content on the mechanical properties and durability of concrete composites was studied [21-23]. The mechanical properties analysis showed that with the increase of nano-TiO₂ doping content, the compressive strength and flexural strength of nano-TiO₂ modified cement-based concrete composites at 7 and 28 d showed a trend of first increase and then decreased. When the doping content of nano-TiO₂ was 4 % (mass fraction), the compressive strength and flexural strength at 7 and 28 d reached the maximum value.

Investigation results of the effect of Nano-metakaolin (NMK) on the physical characteristics and micro-structure of mortar of cement show that 1) The compressive strength and tensile strength of NMK cement mortar are higher than those of ordinary cement mortar with the same water cement ratio. 2) The increase of tensile strength is 49 % higher than that of the control mortar, and the increase of compressive strength is 7 % when 8 % NMK is replaced. 3) Due to its morphology, NMK in cement mortar plays the role of nanofibers. 4) The observations confirmed that the NMK acted as a filler and an activator to promote hydration. In addition, it is assumed that the number of particles per unit volume can improve the strength of concrete, rather than increase the mass concentration of several layers of graphene. While maintaining the strength, it has opened up a new road.

Nano-materials, especially nano-colloid SiO₂, have significantly modified cement-based materials [18-20]. The material has a small particle size and large specific surface area, which fills the crystal nucleus and micro-aggregate in cement-based materials. It promotes the hydration of cement by secondary hydration with calcium hydroxide, improves the compactness of cement-based materials, and improves the mechanical properties, deformation properties and frost resistance of cement-based materials. Many tests show that the strength of concrete at various ages is enhanced by adding nano-colloid SiO₂. Compared with ordinary concrete, the strength of concrete mixed with this material increases greatly.

In the future, if nano-materials modification concrete is put into the market, the use and dependence on traditional concrete can be relatively decreased without reducing the strength of architectural materials to achieve the purpose of environmentally friendly and sustainable development.

5. Conclusion

Manufacture of cement concrete result in 8 to 10 percent of world's total emissions of CO₂. Green concrete, which response the demands of sustainability, its production process does not lead to a destructure of the environment, and its high performance would satisfy the strength required. This paper introduces the green concrete from three mainstream direction, respectively are fly ash, recycled and nano-development concrete. High energy consumption and environmental impact of cement manufacturing processes could be relatively reduced by altinatives metioned above. Hopefully this paper would be useful for personnel in order to promote the conservation of the environment in a global level, through the popularization of the green concrete.

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