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Low-carbon Application of Renewable Concrete in Green Buildings

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Abstract. In recent years, the rapid development of the construction industry has driven a continuous rise in the consumption of building materials. Meanwhile, the concept of green development has increasingly taken root in people's minds, and the recycling and reuse of building materials have gradually become a focus of attention in industry. This initiative can not only reduce resource waste and alleviate environmental carrying pressure but also effectively control construction costs, thus having both ecological and economic value. As the most widely used basic material in construction projects, the recycling of concrete is of crucial significance to the development of green buildings. This paper first elaborates on the core definition of green buildings, clarifies their core connotations of energy conservation, environmental protection, and sustainable development, and introduces the evaluation criteria for green buildings in terms of resource utilization and environmental impact. It then focuses on analyzing two mainstream types of recycled concrete: one is recycled concrete based on aggregate recycling, and the other is recycled concrete prepared from industrial waste and by-products. At the same time, it objectively examines the advantages and disadvantages of these two types of recycled concrete in terms of performance, cost, and environmental friendliness. Finally, the study concludes that there are still deficiencies in the current technical systems, evaluation criteria, and application research related to recycled concrete, which need to be further improved and optimized, so as to provide directional references for the development of green building materials in the future.

Keywords: Green buildings; recycling material; renewable concrete.

1. Introduction

As the world was impacted by the pandemic and multiple other factors, the economy is gradually showing resilience and moving towards recovery in fluctuations. Against this background, the process of urban renewal is accelerating and many old buildings and facilities are facing demolished. This will make many green cycling problems. Such as the issue of green and environmentally friendly treatment of construction waste. Meanwhile there are more new buildings to build. So the resource utilization problem needs to be solved and requires a series of green solutions and processing technologies to recycle waste resources. From 1990 to 2020, the production of concrete had increased four times. It reached about 260 tons by 2020. In addition, the annual demand for raw concrete aggregate (about 20billion tons/year) exceeded the total extraction of fossil fuels (about 150 tons) . This would exacerbate the shortages of sand, the damage of ecosystem, and social conflicts. Although industry efforts had reduced CO2 emissions per unit of output by around 20% by clinker substitution and improving thermal efficiency, it increased in production had outweighed these gains. Therefore, during 1990-2020, the number related to the concrete of the CO2 emissions had increased two times. As the same time, global emissions also increased from 5% to 9% [1]. At present. The whole world was committed to a green and development path. Meanwhile, the governments had also made many plans, such as net-zero buildings ahead of the United Nations (UN) Climate Change Conference (COP30) and so on. Although some measures had been taken and had some process, the construction industry is still one of the main factors that leading to the environmental degradation. It consumed 32% of the world's energy and contributing ing34% of the world's CO2 emissions. At the same time, the construction industry mainly relied on materials like cement and steel which account for 18% of global emissions and are the main source of construction waste [2]. This requires the construction of a production and construction model with higher technological content and lower resource consumption. Based on the background, the construction industry needs to change from the traditional concept of green sustainability. More and more researchers have begun to pay attention to the research of renewable concrete, the purpose of which is to make construction waste concrete reach the standard of resource recycling through some means. The process involves crushing, cleaning and grading waste concrete, then mixing it with cement to create recycled concrete. Recycling concrete from construction waste not only solves the problem of construction waste disposal but also saves concrete raw materials [3].

Therefore, this article aims to begin by briefly describing the definition and evaluation standards of green buildings. Then it reviews recent research findings on renewable concrete, a green building material and analysis the advantages and disadvantages of different types of materials in terms of performance, environmental benefits and economic feasibility. At the same time, two urban construction cases are cited to prove its feasibility. The main progress and existing problems of current research are summarized and prospects are given.

2. Green Building Overview and Evaluation Standards

2.1. Green Building Definition

Green building (also known as green construction) is a construction process that is more environmentally friendly and resource-efficient than traditional building, and strives to have a positive impact on the natural environment and the global climate. Compared with the low-process pollution of traditional buildings, green buildings are mainly aimed at protecting natural resources, minimizing environmental impacts and improving the quality of life of residents. Its core concepts include energy saving, water saving, material saving, environmental protection and health [4]. Energy saving refers to optimizing the building facade, reasonable layout and improving thermal insulation performance. Effectively reducing energy consumption during the operation of the building is a key link in achieving the goal of saving resources in green buildings. It helps to reduce dependence on traditional energy and thus reduce pressure on the natural environment, which is in line with the pursuit of green buildings to have a positive impact on the natural environment and the global climate. Water-saving measures focus on the recycling and efficient use of water resources. By collecting rainwater and purifying and recycling water through processes such as green plants, the demand for external water supply is effectively reduced and the pollution of water resources is reduced. Material saving aims to emphasize that the use of building materials should be renewable, recyclable and environmentally friendly materials as much as possible to reduce the development and consumption of natural resources, such as the use of prefabricated buildings. Environmental protection measures focus on reducing pollutant emissions and recycling waste during construction. For example, water mist spraying around the construction site can effectively reduce dust pollution to the outside. Health concepts focus on factors such as indoor air quality, lighting, and noise control to protect the physical and mental health of residents [5]. Among them, the use of recycled concrete is a way to save materials.

2.2. Global Evaluation Standards for Green Building Concepts

In recent years, some developed countries have successively introduced their own building environment evaluation standards, including the Building Research Establishment Environmental Assessment Method (BREEAM) in the UK, the Leadership in Energy and Environmental Design (LEED) in the United States, and the Well Building Standard developed by the International WELL Building Institute [6]. Developing countries such as China have also introduced "green building evaluation standards". Among them, the BREEAM standard is based on established benchmarks to evaluate the specifications, design, construction and use of buildings. Its indicators cover a wide range of categories and standards from energy to ecology, such as carbon emission reduction, low-impact design, climate change adaptation, ecological value and biodiversity protection. However, in comparison, the LEED certification standard is a more comprehensive set of evaluation standards, including integrated processes (IP), location and transportation (LT), sustainable sites (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor environmental quality (EQ), innovation (IN) and regional priority (RP). The use of recycled concrete can help to gain extra points in the materials and resources (MR), sustainable sites (SS) and innovation (IN) scoring standards. Table 1 lists the scoring rules for leed (v4.1).

Table 1. Lists the scoring rules for leed (v4.1)

Rating categories(LEED v4.1)	Weight/Score	Main evaluation content
Location and Transportation(LT)	16 Points	Encourage sustainable site selection and reduce transportation carbon emissions.
Sustainable Sites(SS)	10 Points	Ecological protection, rainwater management, and urban heat island effect control
Water efficiency (WE)	11 Points	Reduce indoor and outdoor water consumption and promote the use of recycled water.
Energy and Atmosphere(EA)	33 Points	Energy efficiency improvement, renewable energy utilization, commissioning
Materials and Resources(MR)	13 Points	Materials life cycle and waste management
Environmental Quality(EQ)	16 Points	Improve air quality, thermal comfort, and light and acoustics.
Innovation(IN)	6 Points	Innovative strategies or practices that go beyond standard practices
Regional priority(RP)	4 Points	Region-specific priority issues

Note: The total score is approximately 110 points, with slight adjustments for different project types (new construction, existing buildings, community development). Awards such as Certified, Silver, Gold, and Platinum can be obtained based on the score.

Four certification levels (≥40, ≥50, ≥60, ≥80 points)

3. Recycled Concrete Types

3.1. Recycled Concrete Based on Aggregate Recycling

Recycled aggregate concrete (RA) is made from recycled aggregate from building demolition waste. This material is crushed and graded to form aggregate, which can then be further divided into recycled coarse aggregate (>5mm) and recycled fine aggregate (<5mm) based on particle size. Concrete formulated with a certain proportion of recycled RA replacing natural aggregate can save up to 60%

of limestone resources and reduce greenhouse gas emissions by 15%-20%. For example, brick and mortar waste, generated during the demolition of buildings and infrastructure and consisting of broken bricks and mortar, can be used as a substitute for fine aggregate in concrete. Reusing this material helps reduce landfill use. Recycled coarse aggregates, such as ceramic fertilizer, are a byproduct of the ceramics manufacturing process and include broken bricks, tiles, and ceramics. Because it is rich in silica and alumina, it can replace a certain portion of Concrete's coarse aggregate [7].

However, this type of recycled concrete also has certain drawbacks. Water absorption is a commonly used durability indicator because it measures porosity, which is closely related to durability. Micro structural assessment using scanning electron microscopy (SEM) analysis revealed that the texture and Micro structure of recycled aggregate generally influences the porosity and water absorption capacity of concrete, due to the higher water absorption of residual mortar adhering to the recycled aggregate. Regarding work ability, which measures the ease of preparation, application, compaction, and finishing of concrete, the use of recycled aggregate can negatively impact the work ability of recycled concrete compared to concrete using natural aggregate, making it difficult to achieve the desired work ability. Regarding compressive and tensile strength, the compressive strength of concrete mixes decreases with increasing replacement of natural aggregate with recycled aggregate, due to the type and quality of the recycled aggregate and its water absorption capacity. Durability also depends on the porosity and distribution of the concrete containing recycled aggregate, the presence of contamination, and the condition of residual mortar adhering to the aggregate. Some studies have found that as the replacement of natural aggregate with recycled aggregate increases, the durability of concrete decreases, including resistance to chloride ion penetration, acid attack and absorption, shrinkage, and carbonation [8,9].

3.2. Recycled Concrete Based on Industrial Waste and By-products

In recent years, the utilization of industrial byproducts such as fly ash, slag, and lime, as well as other discarded materials, has been widely researched. For example, iron ore slag, a byproduct of steel production, can cause some environmental pollution when handled. However, this slag can partially replace cement minerals and, under certain conditions, improve concrete work ability and strength. There is also waste incineration bottom ash, which primarily consists of metals and minerals. These minerals can be used to produce building materials such as cement clinker, aggregates, and binders, which can be used as aggregates in road and dam construction. This has led to the emergence of alternative cementitious materials and novel binders, such as geopolymer concrete and alkali-activated materials. These materials often utilize industrial byproducts, reducing waste and lowering carbon emissions. Compared to traditional concrete, geopolymer concrete can reduce CO_2 emissions by up to 80% [10,11].

Recycled concrete made from these industrial waste and byproducts, such as using waste glass powder to partially replace cement, increases in unreacted residues when the replacement rate exceeds 20%, and this problem becomes more severe with larger particle size, resulting in insufficient strength gains at 28 days to offset the loss of cement. At the same time, the construction industry's readiness to adopt zero-carbon concrete technology varies globally and is affected by factors such as local regulations, market demand and technical means. There are still obstacles to renewable concrete, such as lack of technical knowledge, perceived risks associated with new materials, lack of long-term performance data and insufficient policy framework [12].

4. Conclusion

Outlook and summary, this article first discusses current global concrete production and emissions to illustrate some of the challenges facing the global construction industry, including material consumption, environmental pollution, and the global contribution of carbon dioxide emissions. It then analyzes the low-carbon application value of recycled concrete in green buildings. It begins by explaining the concept of green building and its international evaluation standards, with the LEED standard being the most widely used. It then explores the impact of recycled concrete based on aggregate recycling, industrial waste and byproducts, and functional properties on its mechanical properties and environmental benefits. Ultimately, it concludes that recycled concrete offers significant advantages in reducing construction waste, lowering building material consumption, and achieving carbon reduction, making it a key material approach to promoting green building. However, there remains an imbalance between mechanical performance and environmental benefits, and some material improvement technologies are lacking. Two case studies are then presented to demonstrate the feasibility of this project.

Overall, renewable concrete plays a vital role in green building. With advancing technology, growing awareness of sustainability, and continuous improvements in construction techniques and policy frameworks, it holds promise to become a key material supporting carbon neutrality in construction, contributing to the global goal of sustainable development. It is recommended to integrate BIM technology with construction techniques, conducting simulated experiments at prefabrication sites. By analyzing data such as hardness and tensile strength, suitable materials can be optimized before scaling up production to meet building requirements. Simultaneously, developing prefabricated construction combined with renewable concrete can minimize transportation and installation costs while reducing environmental pollution. Establishing stringent regulations for renewable concrete is essential to ensure production quality and compliance. This requires systematic research into renewable concrete and addressing existing challenges—a collective societal effort with profound practical significance that yields economic and environmental benefits. In the near future, as the overall properties of green concrete are optimized, diverse low-carbon recycled materials can be applied across municipal roads, bridges, commercial buildings, residential apartments, and other structures based on specific architectural needs. This paves the way toward near-zero carbon and even negative carbon emissions.

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