Viser Technology Pte. Ltd.
Research and Application of Materials Science
DOI: 10.33142/rams.v6i1.12890

Research Article Open Access

Research and Application of Recycled Concrete Technology in Prefabricated Buildings

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Abstract

The utilization of waste concrete as a raw material for recycled concrete in the domain of prefabricated components is garnering greater interest. This paper delineates and examines the concept, categorization, methodologies of preparation, applicable sectors, and evaluative metrics of recycled concrete technology, highlighting its prospective benefits. Nonetheless, for the successful integration of recycled concrete technology into prefabricated component applications, it is imperative to systematically enhance its physical, mechanical, and attributes, as well as its environmental efficacy. Moreover, to foster the continued advancement of recycled concrete technology, innovative initiatives, standardization, educational programs, demonstration projects, and collaborative efforts are crucial to promote broader adoption and realize improved outcomes within the realm of prefabricated components. In conclusion, recycled concrete technology is poised to play a pivotal role in prefabricated construction, offering robust support for propelling the construction industry towards a sustainable future.

Keywords: *recycled concrete; prefabricated buildings; Environmental performance assessment*

1 Introduction

The construction industry's heavy reliance on conventional concrete has amplified resource depletion and environmental consequences. This has paved the way for recycled concrete technology, which recycles and reuses waste concrete to mitigate the need for fresh materials, conserve energy, and substantially reduce the construction sector's environmental footprint [1-2]. Prefabricated construction has emerged as a cornerstone and direction of modern construction practices, characterized by efficiency, quality control, and sustainability. With the world's urbanization pace accelerating, the construction industry is confronting challenges like resource scarcity, elevated energy use, and increased carbon emissions. In this context, exploring the integration of recycled concrete technology into prefabricated buildings presents a novel avenue for achieving sustainable prefabricated structures.

Prefabricated buildings capitalize on factory-produced, modular components that can be seamlessly integrated with renewable concrete technology. The controlled factory setting allows for the preparation of recycled concrete, followed by the prefabrication of components, which enhances construction quality and efficiency. The incorporation of recycled concrete into prefabricated facades, floors, and structural systems can bolster building performance and sustainability, while also offering cost savings [3]. Consequently, there is an immediate necessity for comprehensive performance evaluation, optimization strategies, and environmental impact assessments of recycled concrete technology within prefabricated buildings.

2 Overview of Recycled Concrete Technology

Recycled concrete represents a sustainable alternative in the building industry, derived from waste concrete and construction debris. Processed through crushing, cleaning, and sorting, it serves to mitigate resource waste, lessen environmental impact, and advance sustainable construction practices, positioning it as a material with substantial promise [4].

Received on April 17, 2024; Accepted on May 10, 2024

Definition and Classification of Recycled Concrete: Recycled concrete is produced by processing waste concrete from structures or construction debris. It can be categorized into three types based on the source and use of the recycled aggregates: recycled coarse aggregate concrete, recycled fine aggregate concrete, and full recycled concrete. Recycled coarse aggregate concrete is primarily composed of recyclable coarse aggregates, while recycled fine aggregate concrete uses recyclable fine aggregates. Full recycled concrete is made from entirely recyclable aggregates recovered from waste concrete structures or construction waste. This material has gained widespread adoption within the construction industry.

The preparation of recycled concrete involves two main steps: collecting and treating waste concrete to produce recycled aggregate, and mixing concrete and performing quality control adjustments to ensure that its quality and performance meet the requirements.

Performance and Characteristics of Recycled Concrete: In the context of prefabricated buildings, the use of recycled concrete is not only about conserving resources and reducing the carbon footprint but also about enhancing building quality and sustainability while potentially lowering construction costs. Through ongoing optimization of its physical, mechanical, durability, and environmental properties, recycled concrete can rival traditional building materials and even offer superior sustainability attributes.

3 Application of Recycled Concrete in Prefabricated Buildings

The integration of recycled concrete technology into prefabricated buildings offers a versatile solution across various components, including exterior wall systems, floor systems, and structural systems. This technology extends beyond traditional applications, providing a array of benefits for construction projects and considerable potential for growth.

3.1 Application of recycled concrete in prefabricated exterior wall systems

The aesthetic appeal, thermal insulation, and overall energy efficiency of a building are crucial to its performance. Recycled concrete technology can be effectively applied to prefabricated exterior wall systems, offering both practical and aesthetic advantages.

Wall Tiles: Recycled concrete wall tiles not only provide excellent thermal insulation but also meet decorative standards, contributing to energy savings.

External Wall Insulation Boards: These boards, made from recycled concrete, enhance thermal insulation properties, reducing building energy consumption and the burden on HVAC systems.

3.2 Application of recycled concrete in prefabricated floor systems

The floor system is a pivotal component of prefabricated buildings, serving both load-bearing and acoustic insulation functions. The adoption of recycled concrete technology in floor systems can enhance their performance, including noise reduction capabilities.

Prefabricated Flooring: Compact and durable recycled concrete floor panels are utilized to bear floor loads, satisfying the mechanical properties and durability requirements of flooring.

Soundproofing Materials: Recycled concrete can be utilized to create soundproofing materials that minimize sound transmission between floors, offering a material-efficient solution that improves the acoustic comfort of residential and commercial buildings.

3.3 Application of recycled concrete in prefabricated components

Prefabricated components are typically produced in a factory setting and then transported to the construction site for assembly into the building's various components. The use of recycled concrete in prefabricated buildings is gaining traction, offering several advantages.

Recycled Concrete Wall Panels: Wall panels made from recycled concrete can reduce the consumption of raw materials while providing comparable strength and stability to traditional concrete panels.

Recycled Concrete Columns and Beams: Recycled concrete is also suitable for manufacturing columns and beams for prefabricated buildings, supporting structural loads and offering cost savings through the use of recycled materials.

Energy-Efficient Wall Systems: Walls constructed with recycled concrete can incorporate heat and sound insulation, contributing to the overall energy efficiency of the building.

The integration of recycled concrete technology into prefabricated buildings represents a promising new direction for the construction industry. It aligns with goals of resource conservation and carbon reduction while enhancing the competitiveness and sustainability of construction projects. However, despite advancements in the mechanical properties, durability, and environmental performance of recycled concrete, further research and practical application are necessary to encourage broader use in prefabricated buildings.

For cast-in-place multi-storey and high-rise recycled concrete houses that use only Class I recycled coarse aggregate, the structural types and maximum heights should adhere to the same standards as those for cast-in-place multi-storey and high-rise ordinary concrete houses [5]. For buildings using Class II and Class III recycled coarse aggregate, compliance with the structural types and maximum heights specified in Table 1 [6] is required. When the substitution rate of recycled coarse aggregate falls between 30% and 50%, the maximum height applicable can be determined through linear interpolation.

Table 1 Structural types and maximum heights for cast-in-place multi-storey and high-rise recycled concrete houses (m)

Structure type	Regenerated coarse aggregate substitution rate	Intensity of fortification				
		6	7	8(0.2g)	8(0.3g)	9
Frame structure	30%	45	40	35	30	21
	50%	40	35	30	25	15
Frame-shear structure	30%	90	85	70	60	35
	50%	70	65	55	45	25
Shear wall structure	30%	100	85	70	60	45
	50%	80	70	60	50	35
Frame-core tube structure	30%	110	90	75	65	50
	50%	90	75	65	55	40

Note: (1) House height refers to the height of the outdoor ground floor to the top of the main roof slab, excluding the local protruding roof Part; (2) The frame in the table includes the special-shaped column frame with no more than six layers and no more than 18m height, excluding other special-shaped column frames; (3) For buildings exceeding the height in the table, special research and demonstration should be carried out to take effective strengthening measures.

4 Performance Evaluation and Optimization of Recycled Concrete Technology

The performance evaluation and optimization of recycled concrete technology are essential to ensure its successful application in prefabricated buildings. This process involves a comprehensive assessment of the physical, mechanical, durability, and environmental properties of the fabricated components it produces.

4.1 Evaluation of physical properties of recycled concrete prefabricated components

The physical properties of recycled concrete, such as density, porosity, and water absorption, are crucial indicators that directly impact its engineering application and performance. Density and Porosity: The density and porosity of recycled concrete are indicative of its quality and compactness. To optimize these characteristics, it is essential to control the concrete preparation process, ensuring thorough vibration and complete filling.

Water Absorption: Water absorption is a critical factor affecting the durability of recycled concrete. The use of appropriate impermeable agents and sealing materials can minimize pores and microcracks, consequently reducing water absorption.

4.2 Evaluation of mechanical properties of recycled concrete

To assess the mechanical properties of recycled concrete, it is essential to determine its compressive strength, tensile strength, and flexural strength, as these indicators are crucial for ensuring the safety and reliability of the structure. The standard deviation of strength must adhere to the specifications outlined in Table 2[7].

Compressive strength: The compressive strength of recycled concrete can be effectively enhanced through stringent control measures. Additionally, the utilization of high-performance gel materials can further bolster compressive strength.

Tensile strength: While the tensile strength of typical recycled concrete tends to be lower, it can be enhanced by incorporating fiber materials or employing specialized strengthening techniques.

Flexural strength: Flexural strength, an important parameter for evaluating concrete performance under bending loads, plays a significant role in structural integrity. Achieving favorable flexural resistance necessitates the selection of appropriate concrete mix proportions and strengthening strategies. The onset of quality issues like cracks can substantially compromise the concrete's bending strength.

Table 2 Standard deviation of recycled concrete strength σ (Mpa)

Strength class	⩽C20	C25～C45	C50～C55
σ	4.0	5.0	6.0

4.3 Durability evaluation of recycled concrete

The assessment of the durability of recycled concrete includes evaluating freeze-thaw resistance, sulfate resistance, and chloride ion permeability through testing. These performance indicators are directly linked to the service life and maintenance expenses of concrete structures. It is recommended to incorporate an air-entraining agent in freeze-resistant recycled concrete of grade F100. Additionally, antifreeze solutions containing chlorine salts should not be utilized in reinforced recycled concrete. Table 3[7] details the specifications for water-to-binder ratio and minimum cementitious material dosage for recycled concrete with varying frost resistance grades.

Table 3 Maximum water-binder ratio and minimum amount of cementing material

Design frost resistance grade	Maximum water-binder ratio		Minimum amount of cementing material (kg/m^3)
	No entrainment agent	Air entrainment agent	
F50	0.5	0.55	300
F100	0.45	0.50	320

Freeze-thaw Resistance: The freeze-thaw durability of recycled concrete can be enhanced by incorporating antifreeze agents and optimizing the particle size distribution.

Sulphate Resistance: For concrete subjected to sulphate attack, it is crucial to employ a well-designed recycled concrete mix, particularly by utilizing cementing materials that exhibit high sulphate resistance.

Chloride Ion Permeability Resistance: To improve the resistance of recycled concrete against chloride ion penetration, the use of chloride ion inhibitors and appropriate sealing treatments can be beneficial. The fundamental durability requirements for recycled concrete intended for structural applications are outlined in Tables 4 and 5[7].

Table 4 Basic requirements for durability of recycled concrete used in structures

Environmental grade		Maximum water-binder ratio	Minimum strength class	Maximum chloride content (%)	Maximum alkali content (kg/m³)
1		0.6	C25	0.3	No limit
2	a	0.55	C30	0.2	3.0
	b	0.5(0.55)	C35(C30)	0.15	
3	a	0.45(0.50)	C40(C35)	0.15	
	b	0.4	C45	0.10	

Table 5 Maximum water-binder ratio of impermeable recycled concrete

Design impermeability grade	Strength grade of concrete	
	C20～C30	C35、C40
P6	0.55	0.50
P8～P12	0.50	0.45
＞P12	0.45	0.40

4.4 Environmental performance assessment of recycled concrete

The environmental assessment of recycled concrete technology encompasses evaluations of carbon footprint, energy efficiency, and life cycle analysis. These assessments are critical in determining the environmental impact of recycled concrete and in providing data that supports sustainable construction practices.

Carbon Footprint: Assessing the carbon emissions of recycled concrete relative to conventional concrete allows for conclusions regarding its environmental impact. The goal is to reduce carbon emissions by incorporating energy-efficient technologies into the production process and by utilizing low-carbon concrete formulations.

Energy Efficiency: Energy efficiency is a key component of sustainable development, affecting both the preparation of concrete and the construction process. The use of energy-saving technologies, such as those that harness renewable energy, can enhance overall energy efficiency.

Life Cycle Analysis: Life cycle analysis considers the environmental impact of concrete across all stages, including production, preparation, transportation, construction, and maintenance. By optimizing these stages, it is possible to improve the overall environmental performance of concrete.

5 Conclusion

Recycled concrete is a kind of sustainable building material that has attracted widespread interest in the field of prefabricated construction and has been applied to some extent. Recycled concrete technology offers a potential solution for sustainable construction by recycling and reusing discarded concrete. This paper deeply studies and discusses the definition, classification, preparation method, performance evaluation, application and optimization strategy of recycled concrete technology.

Although there is great potential for recycled concrete technology in prefabricated buildings, there are still challenges to be overcome in terms of standardization, innovation, education and training, demonstration projects and cooperation. In the future, we believe that recycled concrete technology will continue to play an even greater role in prefabricated construction, leading the construction industry towards a more sustainable future while contributing to environmental protection and resource conservation.

Acknowledgements: Supported by the Science and Technology Research Program of Chongqing Municipal Education Commission (Grant No.KJQN202204305, and No.KJQN202305501).

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