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Hotspot and Trend Analysis of Recycled Concrete Research in China Based on CiteSpace

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Abstract: Currently, researchers in the field of construction waste recycling predominantly focus on recycled aggregate reinforcement technology while neglecting the critical factor: mix proportion design. This study employs the CiteSpace visualization analysis tool to systematically investigate the influence mechanism of brick aggregate and old mortar mixing ratios in recycled concrete (RCC) on their mechanical properties. The findings reveal three distinct phases in how brick and old mortar content ratios impact the mechanical performance of RCC. The research adopts experimental and micro structural analysis as primary methodologies to explore alternative approaches, underlying mechanisms, and performance evaluations of different mix ratio. Key research hotspots and frontiers identified include "construction waste", "fundamental properties", "mechanical performance", "bond strength", "constitutive relationships" and "pavement performance". Future advancements in RCC are anticipated to prioritize high-performance, eco-friendly properties, and microstructural mechanisms, thereby driving applications in engineering practices and standardizations within the construction industry.

1. Introduction

With the accelerating pace of urbanization, the continuous accumulation of construction and demolition waste (CDW) has evolved into a critical environmental challenge. Against this backdrop, RCC, recognized for its prominent resource utilization characteristics and circular economy value, has emerged as a pivotal research direction in the field of civil engineering materials. Its application prospects have garnered significant attention from both academic and engineering communities. The primary challenge lies in the inferior mechanical properties of discarded bricks and hardened concrete (including old mortar) when used as coarse/fine aggregate, primarily attributed to inherent defects such as porous structures and weak interfacial bonding. By leveraging CiteSpace to analyze the CNKI database, studies reveal that the content of bricks and old mortar significantly impacts the strength and durability of RCC through mechanisms including water-cement ratio threshold effects, interfacial transition zone (ITZ) weakening, and optimal replacement ratio. This paper systematically examines the evolutionary trajectory of research on the influence of discarded brick aggregate and mortar content on the mechanical properties of RCC, providing a theoretical foundation for optimizing brick and old mortar mix ratio in RCC applications.

2. Data Sources and Research Methodology

2.1 Data Sources

For the visual analysis of the influence of brick and old mortar content on the mechanical properties of RCC, this study utilizes literature and related data from the China National Knowledge Infrastructure (CNKI) database as the foundational dataset. Literature retrieval was conducted using CNKI's advanced search function, with RCC as the primary keyword and a time span from May 2002 to March 2025. To ensure accuracy and relevance, the search was restricted to academic sources, including core journals indexed by Peking University Core Journal List, CSSCI (Chinese Social Sciences Citation Index), CSCD (Chinese Science Citation Database), and WJCI (World Journal Citation Index). Non-academic publications, such as conference proceedings, notifications, and press releases, were excluded. Irrelevant literature was further filtered out through rigorous screening criteria. After systematic evaluation, a total of 8,471 academic journal articles and conference papers were selected as the final dataset.

2.2 Research Methodology

This study employs CiteSpace, a software tool developed by researchers at Drexel University, to generate relational matrices that identify connections among diverse data points in the literature. By visualizing these relationships through scientific knowledge mapping, the tool generates intuitive graphical representations of key trends and patterns. This methodological framework facilitates the systematic identification of research hotspots and evolving trends, enabling precise and evidence-based insights into the influence of brick and old mortar content on RCC performance.

3. Influence of Recycled Concrete Mechanical Properties

3.1 Annual Publication Analysis

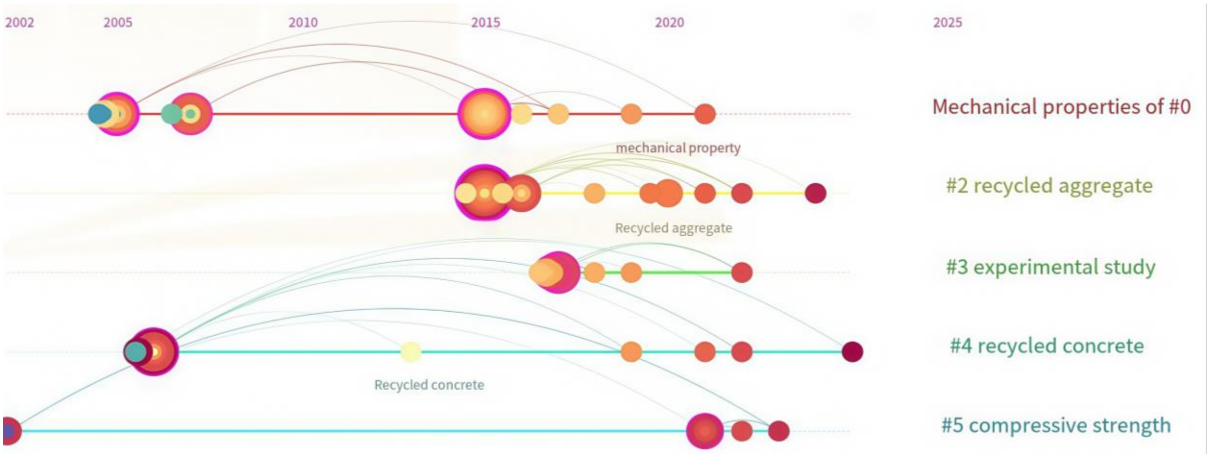

Figure 1: Animated timeline

Prior to 2005, research findings on the analysis of annual publication volume (Figure 1) were relatively scarce, with a total of 125 articles published annually. In recent years, research on the influence of brick and old mortar content on the mechanical properties of RCC has grown steadily. Key research hotspots include modified brick-lime RCC permeable concrete performance comparisons mechanical property evaluations drying shrinkage tests and RCC prepared via equivalent mortar substitution. However, limitations persist, such as a lack of direct studies focusing on brick content and incomplete timeline coverage in existing literature.

With the rapid socioeconomic development in China, research on the influence of brick and old mortar mix ratio on the mechanical properties of RCC has garnered growing attention. Since 2006, the annual publication volume has increased significantly, reflecting deeper investigative efforts. Studies now not only examine multiple mechanical performance indicators (e.g., compressive strength, flexural strength) but also explore performance variations under specific conditions such as freeze-thaw cycles. Some investigations delve into the microstructural characteristics and hydration products of RCC to elucidate the mechanisms underlying its degraded mechanical performance. This shift in research emphasis is driven by synergistic factors, including policy directives, environmental sustainability demands, technological advancements, and expanding market applications. Notably, the publication output has grown at an average rate of 300 articles per year, underscoring the topic's expanding academic and practical relevance.

In 2016, annual publication volume reached 611 articles, marking the second developmental phase in research on the influence of brick and old mortar content on the mechanical properties of RCC. Studies during this period became more diversified and in-depth, encompassing mesostructural analysis, damage mechanisms, environmentally friendly performance evaluations, and application prospects of RCC. Specific research directions included RCC applications in green architecture durability degradation models under environmental coupling effects and fatigue damage patterns under dynamic loads. Concurrently, universities, research institutions, and industry associations began strengthening resource integration and collaborative efforts to systematize research on brick and old mortar content impacts. By 2020, annual publications exceeded 682 articles, underscoring the sustained growth and expanding academic focus in this field.

Strengthened national environmental policies, such as China’s dual carbon targets, have elevated the prominence of RCC as a green building material. Concurrently, advancements in construction technologies have expanded the material’s performance envelope and application scope, particularly research on hybrid fiber-reinforced composites and high-performance RCC. In 2022, publications exceeded 697 articles, marking the third developmental phase in the systematic investigation of RCC’s mechanical properties.

3.2 Author and Structural Analysis

During the analysis of literature data, co-occurrence networks reveal a spectrum of relationships, including collaboration, co-citation, and coupling. The analysis of research collaboration networks indicates that academic associations predominantly manifest as co-occurrence relationships between authors and institutions, whereas interdisciplinary collaborations primarily manifest as institutional synergy networks.

A visual analysis of researchers investigating the influence of brick and old mortar content on RCC mechanical properties was conducted using CiteSpace, generating a co-occurrence network map (Figure 2). The data reveals a network comprising 420 nodes (researchers) and 167 edges (collaborative connections), with a network density of 0.0303. In the co-occurrence network, overlapping nodes indicate collaborations between researchers, while the font size of names corresponds to their publication output. The analysis highlights limited intersections (collaborations) among researchers, with Li Taihang and Yuan Chengfang emerged as the core authors due to their high publication volumes. The data further suggests that while the field has a substantial number of researchers and abundant outcomes, interdisciplinary and cross-institutional collaboration remains insufficient, indicating room for improvement in both breadth and depth of research. Future advancements in economic investment, surveying technologies, and collaborative frameworks are anticipated to foster more comprehensive and in-depth studies.

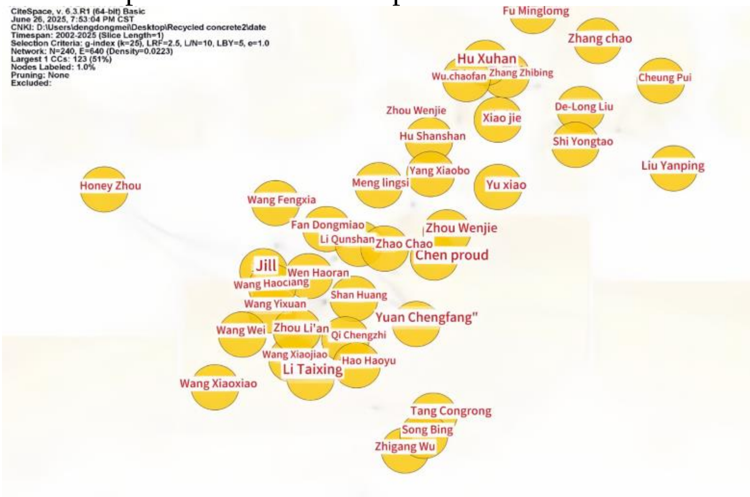

Figure 2: Researcher Co-occurrence Network Map

Similar to author collaboration networks, institutional co-occurrence maps reveal partnerships among research entities. The visualization analysis of institutions using CiteSpace highlights the geographical distribution of institutions focused on the influence of brick and old mortar content on RCC mechanical properties (as shown in Figure 3). To ensure visualization clarity and analytical rigor, only institutions with 10 or more publications were included in the network analysis. The resulting co-occurrence network comprises 364 nodes (institutions) and 150 edges (collaborative connections), with a network density of 0.031. The analysis results indicate moderate institutional collaboration, with overlapping nodes signifying partnerships. Institutions demonstrating high publication outputs include the School of Civil and Architectural Engineering at Anyang Institute of Technology, North University of China, Huaqiao University, Shenzhen University, and Yanbian University While the data confirms active research contributions from these institutions, the limited number of intersections suggests room for enhancing cross-institutional synergy. Future collaborations could broaden the scope and depth of investigations into brick and old mortar effects on RCC performance.

The majority of studies investigating the influence of brick and old mortar mix ratio on RCC mechanical properties are conducted by higher education institutions. Such research requires interdisciplinary expertise, encompassing fundamental mechanical properties, durability, microstructural analysis, and engineering applications. Researchers must possess high levels of professionalism and interdisciplinary competence, as the work involves extensive preliminary tasks including field investigations, data collection, and literature reviews. These demands necessitate substantial human and material resources, which universities, acting as hubs for education and research, can uniquely provide. They attract and convene specialized scholars, offer advanced laboratory facilities, and secure funding to support rigorous investigations. Geographically, leading institutions in this field are concentrated in economically developed regions with rich traditional architectural heritage, such as Henan Province, Wuhan, Guangdong, Jilin, and Shanghai. Notably, research teams in Shanghai have made significant contributions to understanding the deterioration mechanisms of mechanical properties in RCC, proposing control strategies and methodologies, and advancing structural design frameworks. Their findings have elucidated the degradation mechanisms of RCC's mechanical performance, established control protocols, and laid the groundwork for incorporating RCC into structural engineering practices. These advancements have also informed the development of relevant technical standards and specifications.

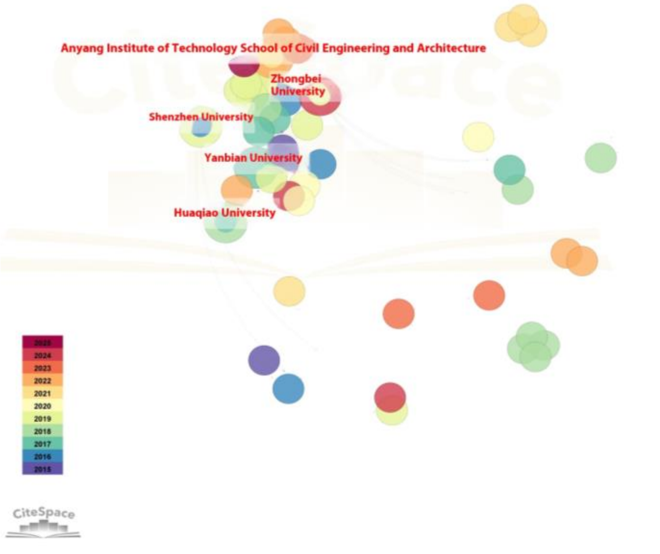

Figure 3: Research Institution Co-occurrence Network

3.3 Analysis of Research Hierarchy

Research on the mechanical properties of RCC is primarily categorized into three hierarchical levels: theoretical research, experimental research, and numerical simulation.

(1) Theoretical Research. This focuses on developing theoretical models and analytical methods to predict the mechanical behavior of RCC. For example, studies investigate how parameters such as mix ratio and replacement rates of recycled aggregates influence mechanical performance. Additionally, they establish theoretical frameworks and computational approaches to model the complex relationships between material composition and mechanical responses.These studies establish the foundational knowledge required to systematically understand the mechanical behavior of RCC.

(2) Experimental Research. Experimental studies investigate the influence of various parameters on the mechanical properties of RCC. For instance, these studies examine changes in mechanical behaviors, such as compressive strength, splitting tensile strength and flexural strength, under different conditions, including variations in water-cement ratio, recycled aggregate replacement rate,and curing period. Experimental research serves as a critical method to validate theoretical models and elucidate the behavioral patterns of RCC’s mechanical properties.

(3) Numerical Simulation. Numerical simulations employ computational software to model and analyze the mechanical behavior of RCC. For example, these simulations investigate stress-strain relationships, failure modes and other mechanical responses under diverse loading conditions. By validating theoretical models and computational methods for RCC’s mechanical performance, numerical simulations offer practical solutions to complex problems. This approach enhances the understanding of RCC’s mechanical behavior, particularly in scenarios where experimental or analytical approaches face limitations.

4. Research Hotspots and Frontier Trends

Keywords encapsulate the essence of research themes. Analyzing keyword co-occurrence patterns in literature data (Figure 4) reveals pivotal hotspots within this research domain. Additionally, thematic clustering of keywords enables focused analysis on targeted subsets, thereby elucidating cutting-edge themes in the field.

Figure 4: Semantic co-occurrence

4.1 Keyword Co-Occurrence Analysis

Table 1: Keyword Frequency and Centrality

Number	Frequency	Centrality	Year	Keywords
1	8	0.28	2015	Recycled aggregate
2	7	0.33	2015	Mechanical properties
3	7	0.19	2006	Recycled concrete
4	5	0.02	2006	Construction waste
5	4	0.21	2005	Highway
6	4	0.16	2017	Axial compression performance
7	4	0.11	2007	Mix ratio
8	4	0.04	2016	Concrete
9	3	0.15	2021	Compressive strength
10	3	0.1	2017	Experimental study
11	2	0.02	2002	Recycled aggregate
12	1	0.03	2016	Eccentric compression
13	1	0.03	2016	Axial compression
14	1	0.03	2016	Profiled steel
15	1	0	2002	Recycling process

A co-occurrence analysis of keywords in RCC literature data from CNKI was conducted using CiteSpace. The results reveal a network comprising 202 nodes (keywords) and 117 edges (connections), with a low network density of 0.0298. The sparse density and limited intersections indicate weak associations among keywords. Additionally, centrality scores for the top 15 high-frequency keywords were calculated (Table 1). Statistical findings highlight that core keywords include "recycled aggregates", "mechanical properties", RCC, "construction waste", "highways", and "axial compression performance". Among these, "recycled aggregates" (centrality=0.28), "mechanical properties" (centrality=0.33), RCC (centrality=0.19), and "construction waste" (centrality=0.02) rank as the top four in centrality.

The frequency and centrality metrics collectively indicate that current research hotspots in RCC focus on mechanical performance, recycled aggregates, construction waste utilization, and applications in highway engineering.

4.2 Modal analysis

Building on the keyword co-occurrence analysis, this study conducts further thematic clustering to effectively identify and analyze research hotspots and frontier themes in RCC (Figure 5). Leveraging the clusters function in CiteSpace, the analysis employs the log-likelihood rate (LLR algorithm) to extract thematic clusters. The results indicate that the clustering analysis was performed on time-sliced data with a keyword proportionality factor of k=25, and the selection criterion was based on theg-index (k=25). Key metrics validate the robustness of the clustering structure: Modularity index (Q-value): 0.831, indicating a significant community structure (Q>0.3 signifies significance, with 0.4-0.8 considered ideal for clustering). Weighted average silhouette coefficient: 0.8701, approaching 1, confirming high homogeneity and a rational clustering structure. Comprehensive analysis confirms that the keyword-based thematic clustering method effectively captures research hotspots and critical issues in the field.

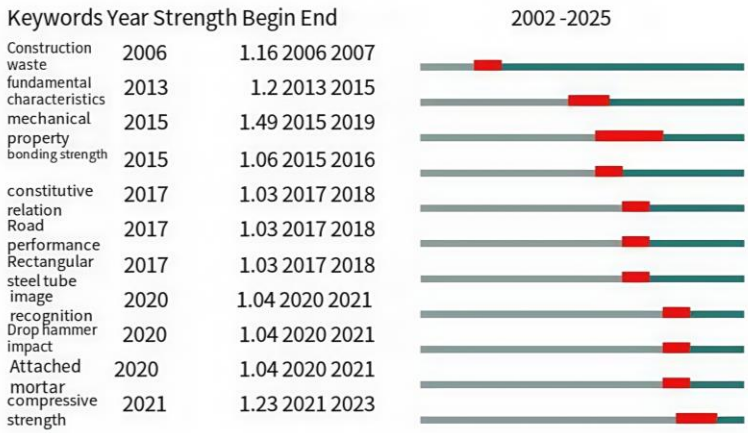

Figure 5: Top 11 Keywords with the Strongest Citation Bursts

Through data cleaning and integration analysis of LLR algorithm clustering results (including category merging and outlier removal), the findings demonstrate that the academic focus in RCC research over the past two decades has centered on six core themes:Material mechanical properties Compressive strength performance Fundamental physical parameters Construction waste utilization Interface-adhered mortar Bond strength characteristics of interfacial layers.

(1) "Mechanical Properties". RCC generally exhibits inferior mechanical properties compared to conventional concrete; however, these properties can be significantly enhanced through optimization techniques. The compressive strength of RCC demonstrates a notable dependency on recycled aggregate replacement rates: a 10% increase in replacement rate corresponds to a 5%-15% reduction in compressive strength. Notably, under strictly controlled water-cement ratios (≤0.38), RCC achieves excellent mechanical performance. For instance, at a 30% replacement rate, the compressive strength gap between RCC and conventional concrete narrows to within 7.5%, with certain mix ratio even demonstrating performance parity or superiority.

Tensile/Flexural Strength. The tensile strength of RCC shows a 45% reduction, while the flexural strength decreases by 8.6%-12%. However, these properties can be improved through the incorporation of fly ash (≤30%) or aggregate quality optimization (e.g., acid washing). The variation in elastic modulus exhibits distinct time-replacement rate dual-factor characteristics: although increasing recycled aggregate replacement rates leads to significant elastic modulus reductions (up to 24.6%), RCC specimens subjected to long-term curing (2-year period) demonstrate excellent modulus recovery, achieving 97% of the reference concrete’s elastic modulus. Key Research Contributions: Xiao Jianzhuang et al.[1] developed a compressive strength-replacement rate relationship model and found that fatigue performance exhibits minimal differences compared to conventional concrete. Chen Zongping et al.[2] established a flexural-compressive strength relationship equation.

(2) "Compressive Strength". Compressive strength is significantly influenced by factors such as replacement rate, water-cement ratio, and aggregate quality. Xiao Jianzhuang et al.[1] found that at a 100% replacement rate, the compressive strength of RCC is only 61% of conventional concrete. To address this, they proposed enhancement strategies: Acid-washed recycled aggregates can increase compressive strength by 23-40 percentage points. Incorporating 30% fly ash improves long-term strength. Additionally, Purushothaman et al.[3] demonstrated that acid-treated RCC achieves compressive strength values approaching those of conventional concrete.

(3) "Fundamental Properties". RCC exhibits distinct differences from conventional concrete in fundamental properties such as slump, dry shrinkage, and strain behavior: Slump: A 10% increase in replacement rate results in a 10-15 percentage point decrease in slump, though this can be mitigated by incorporating high-efficiency water-reducing agents Dry Shrinkage: RCC exhibits 30%-50% higher dry shrinkage rates than conventional concrete, necessitating strict control of aggregate water content.

Peak Strain: The peak strain of RCC is 20% higher than that of conventional concrete, while its Poisson’s ratio remains comparable (approximately 0.2). Key research findings: Hu Minping et al.[4] observed that the elastic modulus of early-age RCC develops more slowly compared to conventional concrete.

(4) "Construction Waste". The resource utilization of construction waste is expected to drive the advancement of RCC. Production and Application: China’s annual construction waste output reached 3.012 billion tons in 2023, with a utilization rate of 8.9%. RCC is primarily applied in pavements, small-scale structures, and similar infrastructure. Industrial Chain and Market Growth: The industrial chain encompasses sorting, crushing, screening, and other critical processes. The market scale expanded from 1.27 billion CNY (2018) to 12.414 billion CNY (2023), reflecting significant industrial development.

(5) "Attached Mortar". The degradation of RCC performance is significantly correlated with residual mortar content. Particularly under sulfate attack environments, higher attached mortar content accelerates performance deterioration. This is primarily attributed to two mechanisms: Residual mortar increases permeation pathways for harmful ions. Secondary reactions between mortar and aggressive ions exacerbate microstructural damage. For every 10% increase in mortar coverage, the compressive strength erosion coefficient decreases by 8-12 percentage points.

(6) "Bond Strength". The interfacial bond performance between RCC and steel reinforcement exhibits characteristics similar to conventional concrete. Specifically: Under static loading, bond strength remains comparable, but RCC exhibits 20-30 percentage points higher characteristic slip displacement. Wang Bingsheng et al.[5] demonstrated that RCC bond strength can exceed that of conventional concrete. However, some studies report minor reductions (5-10 percentage points), primarily due to interfacial effects from mortar-attached recycled aggregates.

5. Conclusion

Based on literature data from CNKI (2002-2025), this study employs visual analysis methods to conduct a systematic investigation of the RCC research field. Key research focuses include: annual publication trends, author-institution collaboration networks, hierarchical distribution of research topics, keyword co-occurrence relationships, and thematic clustering patterns. By integrating quantitative statistical analysis with knowledge mapping, the following critical findings are derived.

(1) Publication trends exhibit three distinct developmental phases. Initial Emergence (2006-2015): Research on RCC entered an emerging stage, characterized by foundational explorations and limited publication output. Steady Growth (2016-2020): The field transitioned into its second developmental phase, achieving unprecedented publication volumes and maintaining a steady upward trajectory. Technological Advancement (2021-Present): Driven by advancements in digital technologies and information systems, research methodologies and tools have undergone continuous upgrades, ushering in a third developmental phase marked by innovation and refined analytical frameworks.

(2) Author and institutional analysis collaborative exchanges among researchers and institutions are relatively frequent, leading to research that is comprehensive and in-depth.

(3) Research hierarchy analysis current studies on RCC are predominantly theoretical and numerical simulation-based. However, there remains a need to strengthen experimental research and innovative approaches to address practical challenges.

(4) Keyword co-occurrence and thematic clustering insights thematic clustering analysis of traditional Chinese residential architecture research highlights six core focal areas: mechanical properties, compressive strength, fundamental performance, construction waste, utilization attached mortar, characteristics bond strength mechanisms.

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