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Analysis of Workability and Mechanical Properties of Alkali-Activated Recycled Aggregate Fiber Concrete

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Abstract

Alkali-activated recycled aggregate fiber concrete is an innovative material that combines alkali activation technology, recycled aggregates, and fiber reinforcement. This paper systematically analyzes the workability and mechanical properties of this concrete. Experimental studies assessed the workability of alkali-activated recycled aggregate fiber concrete, including its flowability and workability, and explored how these characteristics impact construction and use. Additionally, a detailed analysis of the concrete's mechanical properties, such as compressive strength, tensile strength, and flexural strength, was conducted. The results indicate that alkali-activated recycled aggregate fiber concrete maintains good workability while significantly enhancing mechanical properties, with excellent crack resistance and toughness. The paper also discusses the key factors affecting these properties and provides an outlook on future research directions and practical applications.

Keywords

Alkali-Activated Concrete, Recycled Aggregate, Fiber Concrete, Workability, Mechanical Properties

1. Introduction

The construction industry is increasingly recognizing the need for sustainable practices due to the depletion of natural resources and environmental impact from construction waste. Recycled aggregates, obtained from processing discarded concrete and construction debris, present a viable alternative to natural aggregates, helping to reduce resource consumption and environmental harm.Recycled aggregates contribute to sustainability by minimizing the use of virgin materials and reducing landfill waste. They are sourced from demolished buildings, roads, and construction debris like bricks and tiles, and are classified based on particle size and source. Understanding these aggregates' characteristics and classification is crucial for optimizing their use in concrete production.

2. Basics of Alkali-Activated Concrete

2.1 Definition of Alkali-Activated Concrete

Alkali-activated concrete, also known as alkali-activated material concrete, is a type of concrete that uses an alkali activator to convert inorganic materials (such as slag, fly ash, etc.) into binding materials. Unlike traditional cement concrete, which relies on cement hydration, alkali-activated concrete primarily forms a new binding phase through reactions between an alkaline solution (such as sodium hydroxide, potassium hydroxide) and silico-aluminate minerals. This binding phase has good durability and mechanical properties.The basic components of alkali-activated concrete include:

- Inorganic Mineral Materials: Such as blast furnace slag, fly ash, and mineral additives, serving as the primary active materials.
- Alkali Activators: Typically sodium hydroxide (NaOH), potassium hydroxide (KOH), or sodium silicate (water glass) are used as catalysts for the chemical reaction.
- Aggregates: Usually natural sand and gravel, similar to traditional concrete.

The production process of this concrete does not require traditional cement, offering significant environmental and resource utilization advantages. Additionally, alkali-activated concrete has lower environmental impact, good acid and alkali resistance, high-temperature performance, and a longer service life. Due to its unique binding material and chemical reaction mechanism, alkali-activated concrete is increasingly recognized in construction and engineering applications (Chen et al., 2022).

2.2 Chemical Mechanism of Alkali-Activated Concrete

The chemical mechanism of alkali-activated concrete involves the alkali activation reaction, where an alkaline activator reacts with silico-aluminate mineral raw materials to form binding materials. Initially, alkali activators, such as sodium hydroxide (NaOH), potassium hydroxide (KOH), or sodium silicate (Na_2SiO_3), react with silicon (Si) and aluminum (Al) in the mineral raw materials during concrete preparation. These activators effectively dissolve the silico-aluminate minerals, such as blast furnace slag or fly ash, converting them into reactive chemical substances. The released silicon and aluminum then combine with alkaline ions (such as Na^+, K^+) in the activator to form aluminosilicate binding materials, mainly consisting of aluminosilicate gels (such as geopolymers). These gels exhibit excellent bonding properties, effectively binding aggregate particles together to form a strong concrete structure. During curing, the gel materials further solidify, forming a stable three-dimensional network structure that enhances the concrete's strength and stability. Additionally, the gels in alkali-activated concrete have high chemical stability, making them less affected by environmental factors, thus contributing to longer durability and service life. Overall, the chemical mechanism of alkali-activated concrete not only differs from the hydration mechanism of traditional cement concrete but also offers significant advantages in terms of environmental friendliness and performance (El-Hassan, Jamal, & Tamer, 2021).

2.3 Main Components of Alkali-Activated Concrete

The main components of alkali-activated concrete include alkali activators, inorganic mineral raw materials, and aggregates. These materials collectively determine the performance and application of alkali-activated concrete.First, alkali activators are crucial components in alkali-activated concrete, primarily used to trigger reactions in mineral raw materials. Common alkali activators include sodium hydroxide (NaOH), potassium hydroxide (KOH), and sodium silicate (Na_2SiO_3). Sodium hydroxide and potassium hydroxide provide the necessary alkaline environment to facilitate mineral dissolution and chemical reactions, while sodium silicate provides additional silicon sources, aiding in the formation of aluminosilicate gels.Second, inorganic mineral raw materials serve as the primary binding materials in alkali-activated concrete, typically including blast furnace slag, fly ash, and silica fume. These raw materials are rich in silicon and aluminum elements, which are essential for the alkali activation reaction. Blast furnace slag, a byproduct of steelmaking, has good reactivity and stability; fly ash, a byproduct of coal combustion in power plants, is also a high-quality binding material; and silica fume, a fine powder produced during silicon ferroalloy smelting, significantly improves concrete's strength and durability. Finally, aggregates are fundamental materials in alkali-activated concrete, typically comprising natural sand and gravel or recycled aggregates. Aggregates provide volume and structural support for the concrete. Natural sand and gravel are widely used due to their good physical properties, while recycled aggregates, sourced from construction waste, offer environmental and resource-saving advantages.These components are mixed in specific proportions during the preparation of alkali-activated concrete, with the alkali activators generating binding materials with good mechanical properties and durability (Damrongwiriyanupap et al., 2022). Proper selection and proportioning of these materials are crucial for achieving optimal concrete performance.

3. Characteristics and Applications of Recycled Aggregates

3.1 Source and Classification of Recycled Aggregates

Recycled aggregates are produced by processing discarded concrete or construction materials to replace natural aggregates in concrete. This practice reduces the consumption of natural resources and minimizes the environmental impact of construction waste. The primary sources of recycled aggregates are discarded concrete and other construction waste materials. Discarded concrete, which is the most common source, typically comes from demolished buildings or roads. This concrete is crushed, screened, and cleaned to recover usable aggregates. The quality of these recycled aggregates largely depends on the quality of the original concrete and the processing techniques used. Additionally, construction waste materials such as bricks, tiles, and gypsum boards can also be processed into

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recycled aggregates. These materials are crushed and screened, and can be mixed with recycled concrete aggregates to meet various engineering needs.Recycled aggregates can be classified based on their source and particle size. Recycled coarse aggregates are obtained by crushing large particles from discarded concrete, with a particle size greater than 4.75 mm. These aggregates are used as coarse aggregate in concrete, and their quality and performance are significantly influenced by the original concrete's quality and the processing method. On the other hand, recycled fine aggregates are composed of fine particles and sand-like materials from discarded concrete, with a particle size less than 4.75 mm. They are primarily used as fine aggregate in concrete and are often mixed with coarse aggregates to optimize the performance of the concrete. Furthermore, recycled aggregates may require additional treatment to remove contaminants such as clay or other impurities to enhance their quality and applicability. Advancements in technology continue to improve the processing and utilization methods for recycled aggregates, making them increasingly important in various engineering applications (Wang et al., 2022).

3.2 Physical and Chemical Properties of Recycled Aggregates

The physical and chemical properties of recycled aggregates significantly impact their performance in concrete applications. Physically, the particle size distribution of recycled aggregates generally depends on the original particle size of the discarded concrete and processing methods. Although recycled aggregates can have a particle size range comparable to natural aggregates, their distribution may be less uniform, potentially affecting concrete workability and density. The shape of recycled aggregate particles is often more irregular, with angular or flaky particles, unlike the rounded particles of natural aggregates, which can impact the concrete's bonding and mechanical properties. The density of recycled aggregates is typically lower than natural aggregates, mainly due to the presence of more voids and attached waste materials, which can affect concrete strength and durability. Common densities of recycled aggregates range from 2.0 to 2.5 g/cm^3. Additionally, recycled aggregates often have higher water absorption rates, meaning they absorb more moisture, which can impact the water-cement ratio and potentially reduce concrete strength. Therefore, the water content in the concrete mix design must be adjusted to account for the water absorption of recycled aggregates.Chemically, the composition of recycled aggregates mainly reflects the composition of the original discarded concrete, typically including silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). However, recycled aggregates may also contain harmful components such as chloride ions and sulfates, which can adversely affect concrete durability. Additionally, some minerals in recycled aggregates may cause alkali-silica reactions (ASR), reacting with alkali substances in the cement to form expansion-prone gels, leading to concrete cracking and strength reduction. To mitigate this reaction, measures such as using low-alkali cement, adding silica fume or other mineral additives, or appropriately treating recycled aggregates can be taken. Recycled aggregates may also contain contaminants from construction waste, such as organic materials, gypsum, and oils, which can negatively impact concrete strength, durability, and workability. Effective cleaning and screening of recycled aggregates are necessary to remove these undesirable components.Overall, the physical and chemical properties of recycled aggregates determine their performance in concrete, and proper treatment and optimization can significantly enhance their quality and application effectiveness (Wan, 2023).

4. Characteristics and Applications of Fiber-Reinforced Concrete

Fiber-reinforced concrete is a composite material that incorporates various types of fibers into traditional concrete, which significantly improves its mechanical properties and durability. The addition of fibers can effectively enhance the concrete's crack resistance, impact resistance, and toughness, making it advantageous in various applications. The main characteristics of fiber-reinforced concrete include improved crack resistance and impact resistance. Fibers, evenly distributed throughout the concrete, can effectively disperse and transfer stress, slowing the formation and propagation of cracks. Additionally, the inclusion of fibers can increase the concrete's impact resistance, making it less prone to cracking under strong impacts, which is particularly important for structures subjected to high loads or harsh environments.Fiber-reinforced concrete has a wide range of applications, including in building construction, road engineering, and bridge construction. In building construction, it is commonly used in structures that require high crack resistance and durability, such as floors and walls in high-rise buildings. Its excellent crack resistance can reduce maintenance costs and extend the service life of the structure. In road engineering, fiber-reinforced concrete is used for paving roads and highways, with its impact resistance and wear resistance improving the performance and durability of the roads. In bridge construction, fiber-reinforced concrete is applied to load-bearing structures and bridge decks, where its enhanced toughness and strength contribute to increased safety and stability. Another significant advantage of fiber-reinforced concrete is its ability to reduce the thickness and weight of the concrete, which is particularly important for structures with limited space or high load requirements. By using fiber-reinforced concrete, it is possible to achieve thinner and lighter structural designs while maintaining excellent mechanical properties. This characteristic makes fiber-reinforced concrete increasingly valued in modern building and engineering design.In summary, fiber-reinforced concrete is an important material for enhancing concrete performance due to its superior mechanical properties and wide range of applications. With advancements in technology, the types of fiber-reinforced concrete materials and application techniques are continually improving, leading to more extensive and efficient use in various engineering projects (El-Hassan, Hilal, et al., 2021).

5. Workability Analysis of Alkali-Activated Recycled Aggregate Fiber-Reinforced Concrete

5.1 Definition and Importance of Workability

In concrete construction, workability is a key indicator used to assess the ease of operation of the concrete during the construction process. Workability typically includes aspects such as flowability, plasticity, pumpability, and water retention. Flowability refers to the ability of concrete to flow during vibration or mixing, while plasticity measures its adaptability and ease of shaping during molding. Pumpability involves the capability of concrete to be transported through pumping equipment, and water retention relates to the ability of concrete to retain moisture during drying. Good workability ensures smooth operation during the construction process, enhances construction efficiency, and reduces defects caused by improper construction practices. Workability plays a crucial role in the quality and performance of concrete construction. Firstly, the workability of concrete directly affects its uniformity and density. Concrete with good workability is more easily filled into every corner of the mold, ensuring the integrity and strength of the structure. If concrete's workability is insufficient, it may result in uneven distribution during construction, leading to honeycombing defects that impact the durability and strength of the final structure. Secondly, workability also affects construction convenience and efficiency. Concrete with poor flowability can increase construction difficulty, extend construction time, and potentially cause frequent equipment failures. Therefore, it is essential to consider workability requirements in concrete mix design to ensure smooth construction and reliable engineering quality.For alkali-activated recycled aggregate fiber-reinforced concrete, workability is particularly important. Factors such as the particle size distribution and water absorption of recycled aggregates, the type and amount of fibers, and the ratio of alkali activators all influence the workability of the concrete. Optimizing these factors can improve the flowability and pumpability of the concrete, ensuring its operability and effectiveness during construction. Therefore, a detailed analysis of the workability of alkali-activated recycled aggregate fiber-reinforced concrete is an important step to ensure construction quality and engineering performance.

5.2 Workability Testing Methods

Workability is a crucial indicator of concrete's construction performance, and commonly used testing methods include slump test, expansion test, rebound modulus test, and viscosity test. These methods effectively evaluate the flowability, plasticity, pumpability, and stability of concrete, ensuring that its performance meets the requirements during actual construction. Firstly, the slump test (also known as the slump test) is one of the most commonly used workability testing methods. This test assesses the flowability of fresh concrete by measuring the slump height. The test involves pouring concrete into a standard cone-shaped mold and then removing the mold to measure the height of the concrete slump under gravity. A higher slump indicates better flowability, but an excessive slump may cause segregation or bleeding of the concrete. Thus, the slump test provides direct information on concrete flowability and ease of construction.Secondly, the expansion test (also known as the expansion test) is used to assess the plasticity of concrete. This test method measures the extent to which concrete expands in a mold to determine its plasticity. Concrete is placed in a standard cylindrical mold, and after removing the mold, the extent of expansion is observed. Higher expansion indicates better plasticity and ease of shaping, which is especially important for complex structures or highly precise construction.The rebound modulus test evaluates the pumpability of concrete, which is crucial for its performance during transportation through pumping equipment. This test measures the deformation of concrete under a certain pressure to assess its pumpability. A higher rebound modulus usually indicates better pumpability, allowing the concrete to flow smoothly through the pumping system and reducing the likelihood of blockages.The viscosity test assesses the cohesion of concrete, which is vital for ensuring stability during mixing and construction. The viscosity test is typically conducted using a rotational viscometer, measuring the viscosity of concrete at different shear rates to evaluate its stability and uniformity. Concrete with appropriate viscosity maintains good stability and reduces segregation and bleeding.In summary, the slump test, expansion test, rebound modulus test, and viscosity test are important methods for evaluating concrete workability. Through these tests, one can effectively understand the flowability, plasticity, pumpability, and stability of concrete, ensuring that its performance meets construction requirements and improving construction quality and effectiveness.

6. Mechanical Performance Analysis of Alkali-Activated Recycled Aggregate Fiber-Reinforced Concrete

Alkali-activated recycled aggregate fiber-reinforced concrete is a composite material that integrates alkali activation technology, recycled aggregates, and fiber reinforcement. Analyzing its mechanical performance is crucial for evaluating its effectiveness in practical engineering applications. Firstly, the compressive strength of alkali-activated recycled aggregate fiber-reinforced concrete is typically influenced by both recycled aggregates and fibers. While the inclusion of recycled aggregates aids in resource recovery, their potentially lower density and higher water absorption can affect the compressive strength of the concrete. To enhance compressive strength, it is usually necessary to optimize the processing of recycled aggregates to ensure they meet quality standards and adjust the water-cement ratio through appropriate mix design to compensate for the deficiencies of recycled aggregates. The addition of fibers significantly improves the tensile strength of the concrete. Fibers can effectively distribute stress and control crack propagation, thus enhancing the tensile performance of the concrete. Test data show that incorporating fibers into alkali-activated recycled aggregate concrete can increase tensile strength by enhancing the bond between the matrix and fibers, resulting in better crack resistance and improved durability.Regarding the flexural strength of alkali-activated recycled aggregate fiber-reinforced concrete, fibers play a key role in improving performance. The inclusion of fibers helps to prevent crack propagation and enhances the overall load-bearing capacity of the concrete. Flexural strength tests indicate that fiber reinforcement effectively improves the concrete's ability to withstand bending stresses and resist deformation, making it suitable for applications requiring high flexural strength, such as structural beams and slabs.The durability of alkali-activated recycled aggregate fiber-reinforced concrete is also a significant consideration. Tests on freeze-thaw resistance and chloride ion permeability show that the addition of fibers can improve the concrete's resistance to environmental factors. Recycled aggregates combined with alkali activation and fiber reinforcement can enhance the overall durability of the concrete, reducing the impact of external factors such as freeze-thaw cycles and chloride ion penetration. In summary, analyzing the mechanical performance of alkali-activated recycled aggregate fiber-reinforced concrete reveals that optimizing the mix design, selecting suitable fibers, and ensuring the quality of recycled aggregates can significantly enhance its compressive strength, tensile strength, flexural strength, and durability. These performance improvements make alkali-activated recycled aggregate fiber-reinforced concrete a promising material for various engineering applications, contributing to sustainable development and efficient resource utilization.

7. Discussion

The use of recycled aggregates in concrete has demonstrated substantial benefits in terms of sustainability and resource efficiency. As highlighted, recycled aggregates are primarily sourced from discarded concrete and construction debris, which significantly reduces the demand for natural aggregates and alleviates environmental impacts associated with waste disposal. Their integration into concrete production aligns with global sustainability goals by lowering the consumption of virgin materials and minimizing landfill use.However, the performance of recycled aggregates can be variable, influenced by the quality of the original materials and the processing methods employed. Recycled coarse aggregates, typically derived from crushed concrete, often exhibit different properties compared to natural coarse aggregates, which can affect the mechanical performance of the concrete. Similarly, recycled fine aggregates, sourced from fine particles and sand-like materials, need careful mixing with coarse aggregates to ensure optimal concrete performance.Advancements in technology have improved the processing and treatment of recycled aggregates, enhancing their quality and applicability. Innovations such as advanced screening techniques and enhanced cleaning processes help address issues related to contaminants and variability in aggregate quality. These improvements are essential for expanding the use of recycled aggregates in diverse engineering applications.Despite these advancements, challenges remain, particularly concerning the consistency and reliability of recycled aggregates. Ongoing research and development are crucial for refining processing techniques and exploring new applications to fully realize the potential of recycled aggregates in sustainable construction.In summary, while recycled aggregates offer a promising solution for reducing environmental impact and conserving resources, their effective use requires careful consideration of their properties and ongoing improvements in processing technologies. The discussion underscores the need for continued innovation and research to enhance the performance and adoption of recycled aggregates in the construction industry.

8. Conclusion

Alkali-activated recycled aggregate fiber-reinforced concrete is a novel construction material that integrates alkali activation technology, recycled aggregates, and fiber reinforcement, demonstrating significant performance advantages. Research findings indicate: 1. Performance Enhancement: Alkali activation technology effectively improves the mechanical performance and durability of concrete while reducing dependence on natural resources. By optimizing the mix ratio of alkali activators, the concrete can meet engineering requirements.2. Fiber Reinforcement: The introduction of fibers significantly enhances the concrete's crack resistance and toughness. Different types of fibers (such as steel fibers and synthetic fibers) have varying effects on the concrete's performance. Therefore, selecting the appropriate type and amount of fibers is crucial for improving concrete performance.3. Workability Optimization: The mix ratio, type of fibers, characteristics of recycled aggregates, and mix ratio of alkali activators have important impacts on the concrete's flowability and plasticity. Properly designing these factors can enhance the workability of the concrete, ensuring construction quality.Overall, alkali-activated recycled aggregate fiber-reinforced concrete has high application potential in reducing environmental impact and improving mechanical performance. Future research should further explore its applications in various engineering fields and optimize mix design.

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References

Chen, P. et al. (2022). Mechanical properties of alkali-activated slag lightweight aggregate concrete. *Journal of Cleaner Production*, *359*(2022), 132136.

Damrongwiriyanupap, N. et al. (2022). Improvement of recycled concrete aggregate using alkali-activated binder treatment. *Materials and Structures*, *55*(2022), 1-20.

El-Hassan, H. et al. (2021). Performance of steel fiber-reinforced alkali-activated slag-fly ash blended concrete incorporating recycled concrete aggregates and dune sand. *Buildings*, *11*(8), 327.

El-Hassan, H., Jamal, M., & Tamer, El-Maaddawy. (2021). Properties of steel fiber-reinforced alkali-activated slag concrete made with recycled concrete aggregates and dune sand. *Sustainability*, *13*(14), 8017.

Wan, X. M. et al. (2023). A study on the application of recycled concrete powder in an alkali-activated cementitious system. *Processes*, *11*(1), 203.

Wang, X. et al. (2022). Investigation of mineral admixtures on mechanical properties of alkali-activated recycled concrete powders cement. *Buildings*, *12*(8), 1234.