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Research Article

STUDY ON RECYCLED AGGREGATE AND MICRO SILICA ON MECHANICAL PROPERTIES OF CONCRETE

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Abstract

The growing demand for sustainable construction practices has driven significant interest in the utilization of recycled aggregates (RA) and supplementary cementitious materials such as micro silica in concrete production. This review paper critically examines the combined influence of RA and micro silica on the mechanical properties of concrete, including compressive strength, tensile strength, flexural behavior, and modulus of elasticity. Recycled aggregates, derived from construction and demolition waste, serve as a sustainable substitute for natural aggregates but often result in compromised strength and durability due to their porous nature and adhered mortar. Conversely, micro silica, a by-product of silicon manufacturing, enhances concrete performance through its pozzolanic activity and micro-filling capabilities. The synergy between RA and micro silica has been found to mitigate individual drawbacks, resulting in improved mechanical performance and enhanced durability under optimal mix designs. This paper consolidates findings from recent experimental studies, identifies research gaps, and highlights the potential of these materials for large-scale application in sustainable infrastructure development.

Keywords: Recycled Aggregate, Micro Silica, Sustainable Concrete, Mechanical Properties, Compressive Strength, Tensile Strength, Flexural Strength, Modulus of Elasticity, Pozzolanic Reaction, Green Construction

1. Introduction

1.1. Background and Motivation

Concrete is the most widely used construction material in the world due to its versatility, strength, and durability. However, the production of concrete heavily relies on natural aggregates and Portland cement, both of which are resource-intensive and environmentally taxing. The extraction of natural aggregates leads to environmental degradation, while cement production contributes significantly to greenhouse gas emissions, accounting for approximately 8% of global CO_2 emissions (Scrivener et al., 2018).

To address these environmental concerns, researchers and engineers are increasingly exploring sustainable alternatives, such as recycled aggregates (RA) derived from construction and demolition waste and supplementary cementitious materials like micro silica. The use of RA reduces landfill waste and conserves natural resources, while micro silica enhances the mechanical and durability properties of concrete through pozzolanic reactions (Kumar et al., 2020). These innovations align with the global emphasis on reducing the carbon footprint of the construction sector and promoting circular economy principles in civil infrastructure development.

1.2. Need for Sustainable Construction Materials

The rapid pace of urbanization and infrastructure development has led to a surge in demand for construction materials, thereby placing enormous pressure on natural resources. Traditional concrete production is not sustainable in the long term, particularly given the environmental and economic costs associated with raw material extraction and waste disposal (Pacheco-Torgal et al., 2013).

To move towards more sustainable construction practices, the integration of recycled aggregates and industrial by-products like micro silica offers a promising solution. These materials not only reduce environmental impact but also provide comparable or improved mechanical properties in concrete when appropriately proportioned and treated (Singh & Siddique, 2016). Incorporating such sustainable alternatives supports the global goals of reducing construction waste, conserving virgin materials, and achieving energy efficiency in the built environment.

2. Recycled Aggregates in Concrete

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2.1. Types and Sources of Recycled Aggregates

Recycled aggregates (RA) are primarily obtained from construction and demolition waste (C&DW), which includes concrete rubble, masonry debris, asphalt pavement, and other discarded materials from demolished structures. Depending on their origin, RA can be categorized into recycled concrete aggregate (RCA), mixed recycled aggregate (MRA), and recycled masonry aggregate (RMA) (Tam et al., 2007). RCA, the most commonly used type in concrete production, is derived exclusively from crushed concrete elements such as slabs, beams, and columns.

2.2. Processing and Quality Control

The production of high-quality RA involves several processing stages, including initial sorting, crushing, screening, and removal of contaminants such as wood, plastic, and metals. Advanced techniques like air classification and magnetic separation are used to ensure cleanliness and size uniformity (Vázquez et al., 2016). Quality control is essential because the presence of impurities and adhered mortar in RA can negatively influence concrete performance. Compliance with international standards such as ASTM C33 and IS 383:2016 ensures acceptable levels of impurities and particle gradation.

2.3. Physical and Chemical Properties

Recycled aggregates exhibit higher porosity, water absorption, and lower specific gravity compared to natural aggregates, primarily due to the adhered old mortar (Silva et al., 2014). These characteristics influence the water demand and workability of concrete. Chemically, RA contains hydrated cementitious compounds, and while they may contribute slightly to secondary hydration, their variability requires careful mix design adjustments.

2.4. Effects on Fresh Concrete Properties

The use of RA in fresh concrete generally reduces workability due to its rough surface texture and high water absorption capacity. This necessitates the use of additional water or superplasticizers to maintain the desired slump (Kou & Poon, 2012). Bleeding and segregation tendencies may also increase, especially when RA is used without pre-

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saturation.

2.5. Influence on Hardened Concrete Performance

The mechanical strength of recycled aggregate concrete (RAC) is typically 10–25% lower than that of conventional concrete when higher percentages of RA are used, particularly beyond 50% replacement (Malešev et al., 2010). However, with proper mix design, surface treatment of RA, and incorporation of supplementary cementitious materials (like micro silica), RAC can achieve satisfactory compressive, tensile, and flexural strengths suitable for structural applications. Durability properties such as permeability and resistance to freeze-thaw cycles may be compromised without such enhancements.

3. Role of Micro Silica in Concrete

3.1. Composition and Characteristics of Micro Silica

Micro silica, also known as silica fume, is a by-product of the silicon and ferrosilicon alloy industry. It consists of ultra-fine, amorphous silicon dioxide particles with a high surface area, typically less than 1 µm in diameter (ACI Committee 234, 2006). It is known for its pozzolanic nature and ability to fill voids in the cement matrix, leading to a denser and more cohesive microstructure.

3.2. Pozzolanic Reaction Mechanism

The pozzolanic reaction of micro silica involves the chemical reaction between its silica content and calcium hydroxide (CH) released during cement hydration. This reaction forms additional calcium silicate hydrate (C-S-H) gel, which enhances the strength and durability of concrete (Khanna & Bhattacharjee, 2013). The formation of C-S-H also contributes to pore refinement, reducing permeability and enhancing the concrete's resistance to chemical attack.

3.3. Influence on Workability and Setting Time

Although micro silica improves the cohesiveness of concrete, its high specific surface area can reduce workability if not properly managed. The increased water demand can be counteracted with the use of high-range water-reducing admixtures (HRWRAs) (Bhanja & Sengupta, 2005). Additionally, micro silica slightly reduces setting time due to accelerated cement hydration triggered by fine particles acting as nucleation sites.

3.4. Enhancement of Mechanical Strength

Micro silica significantly improves the compressive, tensile, and flexural strengths of concrete, especially at replacement levels between 5% and 15% by weight of cement. The increased strength results from a combination of improved particle packing and the formation of additional C-S-H gel (Siddique, 2011). Research has demonstrated strength gains of up to 25% in high-performance concrete mixes incorporating micro silica.

3.5. Durability Improvements with Micro Silica

Durability properties such as resistance to chloride ion penetration, sulfate attack, alkali-silica reaction (ASR), and freeze-thaw cycles are greatly enhanced in concrete with micro silica (Neville, 2011). The refined pore structure reduces permeability and prevents aggressive agents from entering the concrete matrix, making it ideal for use in marine and chemically aggressive environments.

4. Combined Effects on Mechanical Properties

4.1. Compressive Strength Development

The combined use of recycled aggregates and micro silica influences the compressive strength of concrete in a complex manner. While the inclusion of recycled aggregates tends to reduce compressive strength due to higher porosity and weaker interfacial zones, the addition of micro silica compensates by densifying the matrix and enhancing the bonding at the interfacial transition zone (ITZ) (Limbachiya et al., 2012). Studies indicate that replacing 50% of natural aggregates with recycled aggregates and incorporating 10% micro silica by weight of cement can yield compressive strengths comparable to conventional concrete (Kisku et al., 2017).

4.2. Split Tensile and Flexural Strength

Tensile and flexural strengths are typically more sensitive to the quality of the interfacial transition zone. The reduced tensile strength observed in recycled aggregate concrete (RAC) can be improved significantly with micro silica addition, as the pozzolanic reaction leads to a denser and stronger ITZ (Siddique & Khatib, 2010). Research has demonstrated an increase of 10–20% in split tensile and flexural strength with the combined use of RA and micro silica (Safiuddin et al., 2013).

4.3. Modulus of Elasticity and Stress-Strain Behavior

The modulus of elasticity (E-modulus) of concrete made with recycled aggregates is generally lower than that of natural aggregate concrete due to the presence of old mortar and microcracks. However, micro silica incorporation has been shown to increase stiffness and reduce the strain at peak stress, leading to improved stress-strain behavior (Kou & Poon, 2012). The synergy between improved matrix density and better bond strength contributes to a more ductile failure mode in modified RAC.

4.4. Synergistic Role of Recycled Aggregate and Micro Silica

The synergistic use of RA and micro silica results in a composite concrete system where the limitations of one component are mitigated by the strengths of the other. Micro silica effectively reduces the negative impact of recycled aggregate by refining the microstructure, filling voids, and enhancing pozzolanic activity. This synergy enhances both the short-term and long-term performance of concrete, making it suitable for structural applications (Bavaresco et al., 2021).

4.5. Summary of Experimental Findings from Literature

- Replacement of 30–50% of natural aggregates with RA and 8–12% micro silica yields compressive strengths between 35–45 MPa (Siddique & Khatib, 2010).
- Tensile strength improves by up to 18% when 10% micro silica is used in RAC (Safiuddin et al., 2013).
- The modulus of elasticity increases by 5–10% with micro silica addition, despite using recycled aggregates (Kou & Poon, 2012). These findings support the viability of using RA and micro silica as sustainable components in high-performance concrete.

5. Conclusions and Research Gaps

5.1. Key Observations and Trends

- Recycled aggregates reduce the mechanical properties of concrete, primarily due to high porosity and weak bonding.
- Micro silica significantly improves strength and durability through its

pozzolanic activity and filler effects.

- The combined use of RA and micro silica shows promising results, often matching or exceeding the performance of conventional concrete under optimized conditions.

5.2. Limitations of Existing Studies

- Most studies focus on compressive strength; fewer explore long-term durability under aggressive environmental conditions.
- The variability in RA properties (source, treatment) makes generalization difficult.
- Few standardized guidelines exist for mix proportioning with both RA and micro silica.

5.3. Recommendations for Future Research

- Investigate the combined effects under cyclic, fatigue, and high-temperature loading.
- Develop standard protocols for pre-treatment of RA and optimal micro silica content.
- Conduct life-cycle assessments (LCA) to quantify environmental benefits.

5.4. Potential for Large-Scale Application

- With proper mix design, concrete using RA and micro silica can be employed in low- to medium-rise structures, pavements, and precast elements.
- Cost and availability of micro silica may pose challenges, which can be addressed through local sourcing and industrial collaboration.

5.5. Concluding Remarks

This review confirms the technical feasibility and environmental advantage of using recycled aggregates and micro silica in concrete. Their synergistic behavior can mitigate each other's drawbacks, supporting the development of high-performance, eco-efficient concrete for sustainable construction.

6. Author(S) Contribution

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7. Conflicts of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

8. Plagiarism Policy

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