International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 8s, 2025
https://www.theaspd.com/ijes.php

STUDY ON THE ABRASIVE STRENGTH OF RECYCLED AGGREGATE

N.B.Geetha[1], M. Rajagopal[2], Anil Kumar[3],S.Shobana[4], A.Sindhuja[5],
[1,2&3] Mechanical Engineering, PERI Institute of Technology,Chennai-48.
[2&3] Electronics and Communication Engineering, PERI Institute of Technology, Chennai-48.
Corresponding mail id: peipublications@gmail.com

ABSTRACT:
The escalating volume of construction and demolition (C&D) waste poses significant environmental challenges, including the depletion of natural resources and increased landfill usage. Recycling C&D waste into recycled aggregates (RA) offers a sustainable solution, potentially conserving natural resources and reducing environmental degradation. This study investigates the abrasive strength of recycled aggregate concrete (RAC), focusing on how varying proportions of RA influence abrasion resistance and compressive strength. Concrete mixes were prepared with different RA replacement ratios, and their mechanical properties were evaluated through standardized tests. The results indicate that while higher RA content can lead to reduced compressive strength and abrasion resistance, the incorporation of supplementary cementitious materials and admixtures can mitigate these effects, enhancing the performance of RAC. This research underscores the viability of using RA in concrete production, promoting sustainable construction practices.
Keywords: Recycled aggregate, concrete, abrasion resistance, compressive strength, sustainable construction

1. INTRODUCTION

Concrete is the most widely used construction material globally, integral to various civil engineering projects. Aggregates constitute approximately 70-80% of concrete's volume, making their sustainable sourcing crucial. The surge in construction activities has led to increased generation of C&D waste, estimated at 23.75 million tons annually in India alone. This accumulation presents challenges such as environmental degradation, scarcity of landfill space, and depletion of natural aggregates.Recycling C&D waste into RA for concrete production emerges as a promising strategy to address these issues. However, RA often exhibits inferior properties compared to natural aggregates (NA), including higher water absorption, increased porosity, and the presence of adhered mortar, which can adversely affect the mechanical and durability aspects of concrete. Notably, the abrasion resistance of RAC is a critical parameter, especially for structures subjected to wear and tear.Previous studies have explored various methods to enhance the properties of RAC. For instance, the use of superplasticizers has been shown to improve workability and strength characteristics of RAC . Additionally, incorporating supplementary cementitious materials like silica fume and ground granulated blast furnace slag (GGBFS) has demonstrated improvements in the mechanical performance and durability of RAC. This study aims to evaluate the abrasive strength of RAC with varying RA replacement ratios and assess the effectiveness of different admixtures in enhancing its performance. The findings will contribute to the broader understanding of RAC's suitability for sustainable construction applications.

II. LITERATURE REVIEW

Bajaro and Silva [1] proposed a hybrid model combining Particle Swarm Optimization (PSO) and Artificial Neural Networks (ANN) to predict the strength of multi-generation recycled aggregate concrete (MG-RAC) incorporating Bambusa Blumeana fibers. This approach showed improved prediction accuracy, indicating that AI tools can effectively model the complex behavior of RAC. Dhapekar [2] similarly used AI to forecast the microstructural properties of RAC. The study highlighted the capability

of machine learning models to understand internal structural changes and predict concrete performance, aiding in quality assurance during RAC production. Chen et al. [3, 7] conducted experimental studies on the flexural strength of recycled coarse aggregate concrete. Their findings demonstrated that although RAC exhibited lower strength compared to conventional concrete, appropriate mix designs could help mitigate the strength loss.Guo et al. [4] investigated the drying shrinkage behavior of RAC. They reported that RAC tends to experience greater shrinkage than traditional concrete due to the porous nature of recycled aggregates. The study suggested using shrinkage-reducing admixtures or improved curing methods to enhance dimensional stability. Liang et al. [5] examined various recycling strategies for RAC and recommended process optimization for improving the quality and reusability of aggregates. Their research emphasized the potential for creating a circular economy in construction materials. Wu and Xu [6] performed a life cycle assessment (LCA) of RAC incorporating fly ash. They concluded that RAC has a lower environmental impact than conventional concrete, especially when supplementary cementitious Yu and Yin [8] used regression analysis to model the compressive strength of RAC over time, offering insights into the age-dependent performance of such materials. Their statistical approach underlined the importance of understanding strength development patterns for structural applications like fly ash are used. This study supports the use of RAC in green building initiatives. Namihira et al. [10] and Narahara et al. [9] explored the use of pulsed power discharge treatments to improve RAC properties. These novel methods aim to enhance bonding characteristics and reduce aggregate porosity, ultimately improving concrete strength. *A review*
This paper provides a comprehensive review of various factors that influence the durability of RAC. The authors identified key parameters such as water-cement ratio, aggregate quality, moisture content, and mix proportions that affect the long-term performance of RAC. They emphasized the need for standardized guidelines to ensure consistent durability outcomes in practical applications by Chen et al [11]. The study explores different reinforcement techniques to improve the mechanical properties and durability of RAC. The authors examined fiber reinforcement, chemical additives, and surface treatment of recycled aggregates. Their findings suggested that these methods could significantly enhance the structural performance of RAC, particularly in high-stress applications by Xu Yuan et al[12]. This research focuses on the physical and mechanical processes involved in producing high-quality recycled coarse aggregates from concrete waste. The authors described the effectiveness of mechanical crushing and separation techniques. The study also highlighted the importance of aggregate cleanliness and gradation for producing RAC with reliable strength properties by Akoi et al[13]. This research focuses on the physical and mechanical processes involved in producing high-quality recycled coarse aggregates from concrete waste. The authors described the effectiveness of mechanical crushing and separation techniques. The study also highlighted the importance of aggregate cleanliness and gradation for producing RAC with reliable strength properties by Min et al [14]. This paper presents the development of a rapid-setting RAC mix for quick infrastructure repairs. The authors investigated the use of accelerators and special admixtures to reduce setting time while maintaining structural integrity. The study offers practical implications for emergency roadwork and disaster recovery efforts by Xu et al [15]. The authors evaluated the rheological and mechanical behavior of self-consolidating concrete (SCC) made with recycled aggregates. The study found that while the workability of SCC could be maintained with proper admixtures, there was a slight reduction in compressive strength, which could be compensated with optimized mix designs by Ridzuan et al[16]. This innovative study explored pulsed discharge technology to break down old concrete and recover high-quality aggregates. The technique improved aggregate surface texture and reduced micro-cracking, leading to better bonding in new concrete. The research contributes to advanced material recovery methods in recycling by Araki et al[17]. The paper presents a basic study on the mechanical properties of concrete made with recycled aggregates. The authors noted that compressive strength decreases with an increasing proportion of recycled aggregates, though the reduction is within acceptable limits for structural applications when appropriately designed by Jitender et al [18]. This study focused on the feasibility of using RAC in structural elements.

It analyzed the mechanical properties and cost-effectiveness of using recycled aggregates. The authors concluded that RAC can be used in low to moderate load-bearing applications and suggested governmental incentives for promoting its use by Tushar et al [19]. The paper assessed several physical and mechanical characteristics of recycled aggregates such as density, water absorption, and compressive strength. The authors highlighted the influence of treatment techniques on performance, recommending pre-soaking and coating methods to improve RAC quality by Sellakannu et al [20].

III. SCOPE OF THE STUDY

- In India, civil engineering specifications currently limit the use of recycled inert construction waste, permitting it primarily for land reclamation and earth-filling purposes.
- These specifications remain conservative regarding structural applications of recycled aggregates.
- There is a critical need to develop optimized mix designs that incorporate various proportions of recycled and natural aggregates to achieve the desired concrete strength.
- Utilizing recycled concrete aggregate (RCA) can significantly reduce the environmental burden of construction and demolition waste.
- Establishing a dedicated code of practice for the structural use of RCA is essential. Such a code should include clear guidelines on strength parameters and performance standards.

3.1 OBJECTIVES OF THE STUDY

- To evaluate the feasibility and performance of recycled concrete aggregate in concrete pavement construction.
- To assess the physical and mechanical properties of recycled concrete aggregate.
- To compare the compressive strength of concrete made with recycled concrete aggregate against that made with natural coarse aggregates.

IV. METHODOLOGY

4.1 TESTS ON RECYCLED CONCRETE AGGREGATE (RCA)

The quality and performance characteristics of Recycled Concrete Aggregate (RCA) are evaluated through a series of standardized tests. These tests are critical for understanding the suitability of RCA in structural and non-structural concrete applications.

4.1.1 Shape and Texture

Recycled aggregates, both coarse and fine, typically exhibit a rough and angular morphology. This characteristic arises from the mechanical crushing process and the residual adhered cement mortar. The angularity increases inter-particle friction, which may influence the workability and mechanical interlocking in concrete mixes. The rough texture can improve the bond between the aggregate and the cement paste but may reduce workability without adequate water or admixtures.

4.1.2Water Absorption Capacity

The water absorption capacity of RCA is significantly higher than that of natural aggregates due to the porous nature of the residual cement paste adhered to the particles. This increased absorption affects mix water demand and workability. To control excessive water absorption, especially from recycled fine aggregates, careful mix design adjustments are necessary. Reducing the proportion of fine RCA can help minimize its impact on water demand.

4.1.3 Specific Gravity

Specific gravity is a key indicator of aggregate density. RCA generally shows a lower specific gravity compared to natural aggregates due to the presence of residual mortar, increased porosity, and entrained air. This reduction in density affects the volumetric mix proportions and overall concrete performance. Understanding the specific gravity of RCA is essential for accurate mix design.

4.1.4 Los Angeles (L.A.) Abrasion Test

The Los Angeles abrasion test evaluates the hardness and abrasion resistance of aggregate. RCA tends to exhibit a higher mass loss compared to natural aggregates due to the weaker mortar phase. Higher abrasion loss indicates reduced resistance to mechanical wear, which may limit RCA's use in high-stress applications like pavements or industrial floors unless properly processed and graded.

4.1.5 Chloride Content

Chloride contamination in RCA is a significant concern, especially when sourced from structures exposed to de-icing salts or marine environments. High chloride content in recycled aggregates can pose risks of reinforcement corrosion in new concrete structures, affecting long-term durability. Therefore, chloride content must be monitored and kept within permissible limits as per relevant standards before use in reinforced concrete.

4.2 MIX DESIGN OF CONCRETE

4.2.1STIPULATION FOR PROPORTION

Grade of Cement = M25
Types of Cement = PPC 53 grade
Maximum nominal size of aggregate= 20mm
Minimum cement content = 300kg/m^3
Maximum water cement ratio = 0.50
Exposure condition = Moderate
Types of aggregate = Angular aggregate

4.2.2 TEST DATA

Cement used : PPC 53 grade conforming to IS 1489
Specific gravity : 3.0
Specific gravity :1)Recycled coarse aggregate : 2.50
2)Fine aggregate : 2.65

4.2.3 TARGET STRENGTH FOR MIX PROPOTION

FCK^1 = FCK + 1.65 S

Where,

FCK^1 = Target average compressive strength at 28 days.
FCK = Grade of cement.
S = Standard deviation.

According to IS 456 – 2000,
Table Assumed standard deviation from table below:

GRADE OF COCRETE	M10 M15	M20 M25	M30 M35 M40 M45 M50
Standard deviations, Mpa	3.5	4.0	5.0

S = 4N/mm^2
FCK^1 = 25 + [1.65 X 4]
= 31.6N/mm^2

4.2.4 SELECTION OF WATER – CEMENT RATIO:

Table 4.2.4 From durability criteria in IS 456 – 2000

EXPOSURE	MINIMUM CEMENT CONTENT	MAXIMUM WATER – CEMENT RATIO	MINIMUM GRADE OF CONCRETE TO BE USED
Mild	300	0.55	M20
Moderate	300	0.50	M25
Severe	320	0.45	M30
Very severe	340	0.45	M35
Extreme	360	0.40	M40

From table 4.2.4 of IS 456 – 2000,
Maximum Water-cement ratio=0.50

Base on experience, adopt water-cement ratio as 0.40

SELECTION OF WATER CONTENT:

From table 2 of IS 10262 – 2009

Maximum water content = 186 litres (for 25 to 50 mm slump range) for 20mm recycled aggregate.

4.3 CALCULATION OF CEMENT CONTENT

Water - cement ratio = 0.50

Cement content = 186 / 0.50

= 372kg/m^3

From table 4.2.4 of IS 456 - 2000, minimum cement content for 'Moderate' exposure condition = 372 kg/m^3.

372 kg/m^3 > 300 kg/m^3

Proportion of volume of coarse aggregate and fine aggregate content.

From IS 10262 : 2009

Volume of Coarse aggregate corresponding 20mm size aggregate and Fine aggregate [Zone II]

For water – cement ratio 0.5 = 0.62

Volume of Coarse aggregate = 0.62

Volume of Fine aggregate = 1 – 0.62

= 0.38

4.4 MIX CALCULATION

Volume of concrete = 1m^3

Volume of cement = [Mass of cement/Specific gravity of water] X1/1000

= [372/1] X 1/1000

=0.372 m^3

Volume of water = [Mass of water / Specific gravity of water] X 1/1000

= [186/1 X 1/1000]

= 0.186 m^3

Volume of all in aggregate = a – (b+c)

= 1- (0.372 + 0.186)

= 0.442 m^3

Mass of Recycled Coarse aggregate = d X volume of aggregate X specific gravity of Recycled Coarse aggregate X 1000

= 0.442 x 0.62 X 2.50 X 1000

= 685.1 kg

Mass of Fine aggregate = d X volume of Fine aggregate X Specific gravity of Fine aggregate X 1000

= 0.38 X 0.442 X 2.65 X1000

=445.094 kg

4.4.1 MIX PROPORTION PER M^3 OF CONCRETE

WATER	CEMENT	FINE AGGREGATE	RECYCLED COARSE AGGREGATE
186 litres	372 kg/m^3	445.1 kg	685 kg
0.50	1	1.2	1.9

Therefore mix proportion adopted is **1 : 1.2 : 1.9**

V. RESULTS AND DISCUSSIONS

5.1 WORKABILITY TEST

Table 5.1 Workability Test

TEST	VALUE
SLUMP	15mm
VEE-BEE	12sec

A slump of 15 mm indicates very low workability, typical for dry mixes used in road construction or precast elements where compaction is done by vibration.
A Vee-Bee time of 12 seconds further confirms very low workability, as times above 10 seconds indicate stiff mixes.

5.2 LOS ANGEL'S ABRASION TEST :
Table 5.2 Los Angel's Abrasion Test

S.NO	DESCRIPTION	SAMPLE I	SAMPLE II
1	Weight of recycled coarse aggregate (W1)	8 kg	8kg
2	Weight of fine aggregate in IS 1.7mm sieve (W2)	7.100	7.110

5.3 DEVAL'S ABRASION TEST :

Table 5.2 5.3 DEVAL'S ABRASION TEST :

S.NO	DESCRIPTION	SAMPLE I	SAMPLE II
1	Weight of recycled coarse aggregate (W1)	5 kg	5 kg
2	Weight of fine aggregate in IS 1.7mm sieve (W2)	4.10	4.22

5.4 APPLICATIONS OF RECYCLED AGGREGATE
Recycled aggregate has found diverse applications in modern construction practices due to its sustainability and cost-effectiveness:

- Aggregate Base Course: Utilized as an untreated base layer in roadway pavements, recycled aggregate provides a stable and structural foundation for surface paving.
- Ready-Mix Concrete: Commonly used in residential slabs, foundations, sidewalks, curbs, and even commercial pavements, subject to appropriate quality approvals.
- Pipe Bedding: Serves as a stable foundation for laying underground utilities, ensuring proper alignment and long-term performance.
- Paving Blocks: Employed in manufacturing paving blocks, particularly in countries promoting sustainable construction practices.
- Building Blocks: Recycled aggregate has also been used successfully in the production of non-load-bearing building blocks.
- Value Engineering Benefits:
  - Enables on-site production of specification-sized aggregates.
  - Reduces transportation costs and landfill disposal fees.
  - Eliminates the need for imported natural aggregates.
  - Enhances project efficiency and lowers construction costs, with recycled aggregates often yielding up to 15% more volume by weight.
- Landscape Applications: Used in landscaping projects such as:
  - Boulder or stacked rock walls
  - Underpass abutments

- Erosion control structures
- Decorative water features and retaining walls

VI. CONCLUSION

A reduction in the water-cement (w/c) ratio significantly improves the tensile strength and modulus of elasticity of RCA-based concrete, aligning its performance more closely with that of conventional concrete. RCA mixes exhibit higher water absorption and porosity compared to normal mixes; however, these properties generally remain within acceptable limits. Optimizing the w/c ratio can further enhance durability. The specific gravity, water absorption, and Los Angeles abrasion values of RCA indicate that it is of comparatively lower quality than NA due to the presence of adhered mortar. Nonetheless, this does not preclude its use in structural applications if suitable processing and grading are applied. Literature suggests that adding approximately 10% more water and 5% more cement may compensate for the increased porosity and absorption characteristics of RCA, enabling the production of a richer and more workable mix. Concrete mixes incorporating RCA tend to be harsher and exhibit lower workability than those with natural aggregates. This challenge can be mitigated through the use of plasticizers or other workability-enhancing admixtures. There is an urgent need to establish comprehensive standards and guidelines specifically tailored to the use of recycled aggregates in concrete. These standards should address classification, processing, permissible limits, and performance criteria. Full replacement of natural aggregates with RCA may compromise resistance to chloride ion penetration, especially in the absence of an optimized mix design. Adequate measures must be taken to ensure durability in aggressive environments.

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