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PERFORMANCE EVALUATION OF RECYCLED CONCRETE AGGREGATE IN PAVEMENT

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Abstract: The growing volume of construction and demolition waste poses a significant challenge in terms of environmental sustainability and resource management. This study investigates the feasibility of using recycled concrete aggregates (RCA) as a partial or full replacement for natural aggregates in concrete pavement applications. A series of laboratory tests—including workability, impact resistance, and compressive strength evaluations—were conducted to assess the physical and mechanical properties of RCA. The concrete mixes were designed according to IS standards with various replacement levels. Results showed that while RCA exhibited lower density and higher porosity compared to natural aggregates, the mix achieved satisfactory compressive strength, especially with adjusted water-cement ratios. The study highlights the viability of RCA in structural concrete applications and underscores the need for updated construction standards to facilitate its wider adoption.
Keywords: Recycled aggregate, concrete pavement, compressive strength, construction waste, sustainability, IS standards

INTRODUCTION

Concrete is the world's primary construction material, with aggregates making up 70-80% of its composition. Given this, recycling aggregates for construction offers significant environmental and economic benefits. This practice can help address the growing problem of waste materials, especially in countries like India, where 23.75 million tons of construction and demolition (C&D) waste are generated annually. Managing C&D waste is a major concern due to its increasing volume, a shortage of dumping sites, rising disposal and transportation costs, and environmental degradation. Recycling C&D waste is a recognized solution that conserves natural resources and reduces energy consumption in material production. In some nations, it's a standard alternative, particularly where construction aggregate is scarce. The construction industry in India produces an estimated 12 to 14.7 million tons of waste annually, with 7-8 million tons being concrete and brick waste. Recycled aggregate is created by crushing and processing inorganic particles from demolished structures like buildings, roads, and bridges, or even from disaster sites. The raw materials are transported to processing plants after being broken into large pieces. It's crucial that these materials are clean and free from contaminants like steel, wood, and soil.

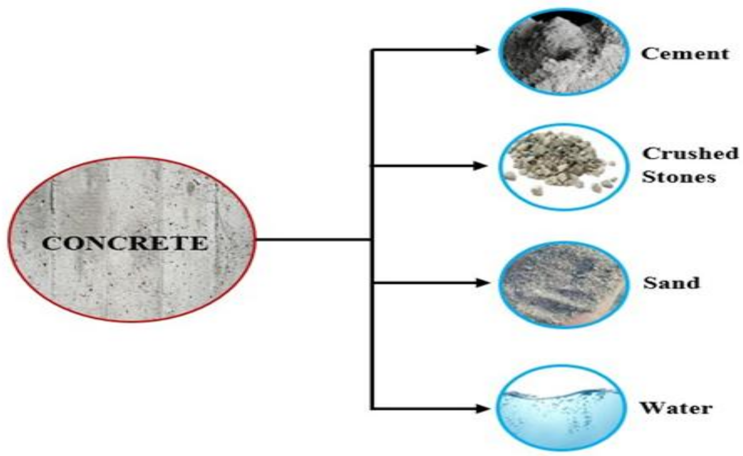

Fig No :1 Concrete mix preparation

APPLICATIONS OF RECYCLED AGGREGATE

Aggregate Base Course: Untreated recycled aggregates form the foundational layer for roadway pavements, providing crucial structural support.

Ready-Mix Concrete: They're suitable for use in residential slabs and foundations, sidewalks, curbs, and commercial paving, provided they meet aggregate approval standards.

Pipe Bedding: Recycled concrete offers a stable and firm foundation for laying underground utilities.

Paving Blocks: Some countries have successfully integrated recycled aggregates into the production of paving blocks.

Building Blocks: Recycled aggregates are also utilized in the manufacturing of building blocks.

SCOPE OF THE STUDY

- Address conservative restrictions in Indian construction codes.
- Evaluate performance of RCA in concrete mixes for pavement.
- Develop mix designs incorporating RCA to meet structural standards.
- Propose guidelines for effective use of RCA in Indian construction.

LITERATURE SURVEY

Sturtevant (2007) [1] conducted one of the earlier studies on rigid pavement performance using recycled concrete aggregates (RCA), confirming their viability in base layers and subbases with adequate strength. Similarly, Dhir et al. (2015) [13] presented a case study demonstrating RCA's applicability in full-depth concrete pavement construction.Smith and Jones (2020) [15] evaluated RCA for road pavement materials in South Africa, emphasizing local context and design adaptations, while Khalid and Abbas (2023) [9] performed a comparative study of fine and coarse RCA in Roller Compacted Concrete (RCC), highlighting changes in strength and compaction behavior. Zhou and Chen (2017) [2] studied the influence of aggregate type on the mechanical behavior of RCA concrete, identifying significant variations in compressive and flexural strength. Akbas et al. (2021) [3] used numerical modeling to predict nonlinear behavior in RCA pavements under heavy loads, linking stiffness parameters to performance.Fardin and Santos (2021) [4] examined fatigue and rutting behavior in RCC base pavements, showing RCA's potential with minor modifications. Wang and Zhang (2022) [12] further analyzed impact load responses in RCA-reinforced concrete pavement, confirming their dynamic resilience.

Juveria et al. (2023) [5] explored the use of RCA mixed with waste tire rubber for enhanced pavement flexibility and impact resistance. Xu et al. (2022) [8] chemically upcycled PET plastics with RCA in asphalt pavements, improving resistance to moisture damage and thermal sensitivity.Chereddy et al. (2024) [10] developed geopolymer concrete using fly ash and RCA, showcasing sustainable alternatives for pavement-grade concrete. Zhao and Chen (2021) [16] assessed porous asphalt with RCA and fly ash, confirming sufficient porosity and strength for drainage applications. Li and Liu (2019) [14] studied cold region performance of green concrete incorporating RCA, noting reduced frost damage and energy savings.
Al-Kaabi (2023) [11] experimentally validated the performance of RCA concrete, reporting stable behavior under various environmental exposures. Nwakaire et al. (2020) [6] presented a detailed review on RCA for highway applications, identifying barriers and optimization opportunities in mix design and field deployment. Tam and Tam (2008) [22] comprehensively discussed applications, advantages, and limitations of RCA in concrete, setting foundational guidelines. Poon et al. (2004) [23] examined the interfacial transition zone (ITZ) between old and new paste in RCA concrete, noting its influence on compressive strength. Xiao et al. (2012) [21] reviewed RCA mechanical properties including bond strength, fracture energy, and performance under high temperatures. Etxeberria et al. (2007) [24] investigated how RCA production methods affect particle quality and mix performance. Ajdukiewicz and Kliszczewicz (2002) [26] explored RCA in high-strength/high-performance concrete (HS/HPC), concluding that pre-treatment can mitigate strength losses.Limbachiya et al. (2000) [25] also supported RCA's use in high-strength mixes, provided adjustments in grading and water-cement ratio are made. Silva et al. (2015) [27] and Evangelista & de Brito (2007) [28] studied recycled aggregates in mortars and masonry applications, confirming that fine RCA can be used successfully in rendering with slight compromise on mechanical strength.Sharma & Singla (2014) [17], Sonawane & Pimplikar (2011) [18], Sellakkannu & Subramani (2016) [19], and Upadhyay & Lalwani (2015) [20] provided valuable insight into RCA use in India. They observed challenges such as lack of standard codes and contamination control, but also noted potential economic and environmental benefits.

METHODOLOGY

TESTS ON RECYCLED CONCRETE AGGREGATE

1. **Shape and Texture**- RCA aggregates, both coarse and fine, tend to be very angular and rough due to the crushing of the virgin aggregate particles and the presence of cement pastethat continues to cling to the surfaces of the aggregate.
2. **Absorption Capacity**- The amount of water that an aggregate can absorb is called absorption capacity. The porous nature of the cement paste portion of the recycled aggregates increases its absorption capacity. Limiting the use of recycled fine aggregate will also reduce the absorption capacity of the aggregate.
3. **Specific Gravity**-It is a measure of the density of an aggregate. The lower specific gravity of RCA is due to the crushed mortar present in and on the aggregate particles which makes it less dense than NA because of its porosity and entrained air structure.
4.**L.A. Abrasion Mass Loss**- The loss for RCA is usually higher than NA. In general, the greater the loss the softer the aggregate and the less suitable it is for concrete.
5. **Chloride Content**- There is concern that RCA with high chloride contents may affect the durability of the new concrete and the corrosion of steel in new concrete.

MIX DESIGN OF CONCRETE

Stipulation 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

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

TARGET STRENGTH FOR MIX PROPORTION

FCK^1 = FCK + 1.65 S
Where FCK^1 = Target average compressive strength at 28 days.

FCK = Grade of cement.
S = Standard deviation.

TABLE 1 STANDARD DEVIATION

GRADE OF CONCRETE	**M10 M15**	**M20 M25**	**M30 M35 M40 M45 M50**
Standard deviation ,s , Mpa	3.5	4.0	5.0

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

TABLE 2 SELECTION OF WATER – CEMENT RATIO

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

Water-cement ratio=0.50
Based on experience , water-cement ratio as 0.40

SELECTION OF WATER CONTENT:

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

CALCULATION OF CEMENT CONTENT

Water - cement ratio = 0.50
Cement content = 186 / 0.50
= 372kg/m^3

Proportion of volume of coarse aggregate and fine aggregate content.

For water – cement ratio 0.5 = 0.62
Volume of Coarse aggregate = 0.62

Volume of Fine aggregate = 1 – 0.62 =0.38

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

TABLE 3 -MIX PROPORTION PER M³ 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**

RESULTS AND DISCUSSIONS

The results for concrete pavement based on workability test , Impact test, Compressive strength calculation based on day basis method for Concrete Cylinder and Concrete cube.

TABLE 4-WORKABILITY TEST

TEST	VALUE
SLUMP	15mm
VEE-BEE	12sec

TABLE 4-IMPACT TEST

S.NO	DESCRIPTION	SAMPLE I	SAMPLE II	SAMPLE III
1	Weight of empty cup (w_1)	1.690	1.690	1.690
2	Weight of empty cup & recycled aggregate (w_2)	1.986	1.970	1.951
3	Weight of Recycled aggregate (A)	0.296	0.280	0.261

4	Weight of Recycled aggregate through IS sieve 2.36 (B)	0.081	0.071	0.077
5	Recycled aggregate impact value through (B/A X 100)	27.36	25.35	29.50

TABLE 5 - COMPRESSIVE STRENGTH OF CONCRETE CUBE (7 DAYS)

S.NO	SIZE OF THE SPECIMEN (mm)	AREA OF THE SPECIMEN (mm^2)	LOAD (KN)	COMPRESSIVE STRENGTH (N/mm^2)
1	150 X150	22500	$412.02X10^3$	18.31
2	150 X 150	22500	$392.40X10^3$	17.44
3	150 X 150	22500	$568.98X10^3$	25.28

TABLE 6-COMPRESSIVE STRENGTH OF CONCRETE CYLINDER (7 DAYS)

S.NO	DIAMETER OF THE SPECIMEN (CYLINDER)(mm)	AREA OF THE SPECIMEN (mm^2)	LOAD (KN)	COMPRESSIVE STRENGTH (N/mm^2)
1	$2X\pi X(50^2)+2X\pi X50X200$	62847.56	78480	1.248
2	$2X\pi X(50^2)+2X\pi X50X200$	62847.56	78480	1.248
3	$2X\pi X(50^2)+2X\pi X50X200$	62847.56	88290	1.404

TABLE 7-COMPRESSIVE STRENGTH OF CONCRETE CUBE (28 DAYS)

S.NO	SIZE OF THE SPECIMEN (mm)	AREA OF THE SPECIMEN (mm^2)	LOAD (KN)	COMPRESSIVE STRENGTH (N/mm^2)
1	150 X150	22500	$667.08X10^3$	29.65
2	150 X 150	22500	$686.70X10^3$	30.52
3	150 X 150	22500	$696.51X10^3$	30.95

TABLE 8-COMPRESSIVE STRENGTH OF CONCRETE CYLINDER (28 DAYS)

S.NO	DIAMETER OF THE SPECIMEN (CYLINDER)(mm)	AREA OF THE SPECIMEN (mm^2)	LOAD (KN)	COMPRESSIVE STRENGTH (N/mm^2)
1	$2X\pi X(50^2)+2X\pi X50X200$	62847.56	117720	1.873

2	$2X\pi X(50^2)+2X\pi X50X200$	62847.56	127530	2.029
3	$2X\pi X(50^2)+2X\pi X50X200$	62847.56	117720	1.873

CONCLUSION

Reducing the water-cement (w/c) ratio in recycled concrete aggregate (RCA) mixes enhances key mechanical properties such as tensile strength and modulus of elasticity, making them more comparable to those of natural aggregate (NA) mixes.RCA mixes exhibit higher water absorption and porosity than conventional mixes due to the presence of adhered mortar. Tests on specific gravity, water absorption, and Los Angeles abrasion clearly indicate that RCA is of lower physical quality than NA. Based on prior research, incorporating 10% additional water and 5% extra cement in RCA mixes is advisable to enhance workability and ensure adequate strength development, especially in structural applications.RCA mixes tend to be harsh and less workable than those using natural aggregates. There is a pressing need to develop and implement specific codes and standards for the use of RCA in concrete, particularly for structural and pavement applications. This will promote safer and more widespread adoption.
While RCA can be used effectively in concrete, full replacement (100%) of NA with RCA may negatively impact the material's resistance to chloride penetration, especially in aggressive environments. Therefore, such applications require careful design and testing to ensure long-term durability.

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