CHAPTER 37

Performance Evaluation of Paver Blocks Made with Recycled Concrete Aggregate (RCA) and Recycled Concrete Fine Aggregate (RCFA)

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ABSTRACT

The construction sector consumes a vast number of natural aggregates and generates a large volume of construction and demolition (C&D) waste, leading to environmental degradation and resource depletion. Much of this waste is improperly managed, causing unsustainable disposal practices. This study investigates the sustainable production of paver blocks (as per IS 15658:2021 – Precast Concrete Blocks for Paving – Specification) by partially replacing natural aggregates with recycled concrete aggregates (RCA) and recycled fine aggregates (RFA) derived from C&D waste. The experimental program uses a Taguchi L9 orthogonal array design to optimize mix proportions and evaluate the effects of RCA and RFA replacement levels on the mechanical performance of paver blocks. The recycled aggregate-based paver blocks were tested and compared with conventional cement concrete paver blocks to determine an optimal mix that ensures structural integrity and sustainability. This research addresses a crucial issue in sustainable construction, promoting a circular economy by reusing waste materials and reducing dependence on virgin resources. The results are expected to demonstrate that incorporating RCA and RFA in paver block production not only minimizes environmental impact but also offers a cost-effective and eco-friendly alternative for modern construction practices.

Keywords: RCA , RCFA , Paver Block, Performance.

1.0 Introduction

Major consumer of natural aggregates, the construction industry is also a very great source of construction and demolition (C&D) waste.

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The high rate of urbanization in India has contributed to more rapid loss of natural resources, and more burdening landfills as a result of improper disposal of C&D waste. Recycled Concrete Aggregate (RCA) or Recycled Concrete Fine Aggregate (RCFA) that are the by-products of the demolished concrete also provide a viable substitute to the conventional fine aggregates in concrete products like paver blocks (Bayram & Greiff, 2023).

Paver blocks consist of concrete that is common in pavements, parking space, footways, and roads that are less busy. Their workability, compressive strength, density, and the properties of durability like water absorption are the main factors of their performance. The current research uses a Taguchi L9 orthogonal array (3 factors x 3 levels) to maximize mix ratios and determine the impact of RCA and RCFA substitution on the performance of paver blocks.

2.0 Significance and Objectives of the Research

2.1 Research significance

Recycling of RCA and RCFA helps to sustain the construction through eliminating the need to use virgin aggregates, decreasing the environmental impact, and fostering the ideas of the circular economy (Merecycled et al., 2012). Nevertheless, the uncertainty of the recycled aggregate properties is such that it requires experimental validation on a large scale, which should be controlled.

2.2 Objectives

The main objectives of this study are as follows:

1. To utilize Recycled Concrete Aggregate (RCA) and Recycled Concrete Fine Aggregate (RCFA) in the production of paver blocks.
2. To evaluate the compressive strength of paver blocks containing recycled aggregates.
3. To study the flexural strength of paver blocks produced with recycled aggregates.
4. To analyse the water absorption characteristics of the paver blocks.
5. To compare the performance of recycled aggregate paver blocks with conventional paver blocks.
6. To assess the feasibility of using RCA and RCFA for sustainable construction applications.

3.0 Materials and Experiment Process

3.1 Materials

1. Ordinary Portland cement (OPC).
2. Natural Coarse Aggregate (control)

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3. Recycled Concrete Aggregate (RCA).
4. Recycled Concrete Fine Aggregate (RCFA).
5. Potable water

The material properties were established according to the IS 2386 and the IS 4031 standards.

3.2 Experimental design

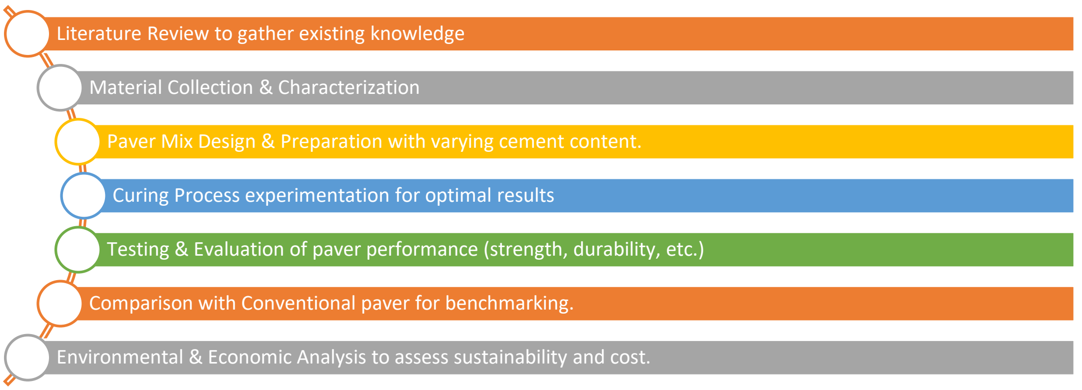
An orthogonal array of Taguchi L9 was accepted with three factors with three levels:

- RCA replacement (%)
- RCFA replacement (%)
- Cement content (fixed- mix independent)

This will reduce the number of experiments and yield statistical strength.

3.3 Research methodology

Figure 1: Flow Chart of Research Methodology



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3.4 Testing program

The following were the tests:

The water absorption and specifics gravity of RCA and RCFA.

- Slump cone test
- Compaction factor test
- Density Fresh and hardened Fresh.
- Paved block uptake of water.
- Compressive strength test (28 day)
- Split tensile strength and Flexural Strength
- Abrasion Value

All the tests were conducted according to the IS 15658: 2006 and IS 516.

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4.0 Discussion and Results of the Experiments

A workability characteristic is a property that is sought after but remains unstated. Workability is an attribute that is desired but not defined. The results of slump and compaction factor suggest that the workability decreases gradually with an increase in content of RCA and RCFA because of the enhancement of the water absorption of recycled aggregates and roughness of their surfaces, as was observed previously (Kadam et al., 2024).

4.1 Density characteristics

The fresh and hardened density values demonstrated a slight decrease with increase in the recycled content of aggregate, and it is because of the low specific gravity and porous structure of RCA and RCFA.(Tawalare et al., 2018)

The water absorption of paver blocks was studied, and the results are presented below. Water uptake rose as RCFA content rose because of finer particles and increased porosity. But still, the values were within the acceptable range in the case of non-structural and medium-traffic applications with pavers.

4.2 Strength performance- compressive

The outcomes of compressive strength will be added to the dataset when they are available. According to the literature, moderation levels of replacement will be sufficient to satisfy the requirements of the IS 15658 of paver blocks in pedestrian and light-traffic areas (Tawalare et al., 2018)

5.0 Experimental Data Table

Table 1: Summary of Experimental Results for Taguchi L9 Mixes

Mix ID	RCA (%)	RCFA (%)	Compressive Strength (MPa)
M1	0	0	33.245
M2	50	50	32.193
M3	50	75	31.164
M4	50	100	30.135
M5	75	50	30.576
M6	75	75	29.547
M7	75	100	28.518
M8	100	50	29.253
M9	100	75	28.224
M10	100	100	27.195

Source: Created by authors

Table 2: Water Absorption Test Results

Material	**Weight Before Oven Dry (g)**	**Weight After Oven Dry (g)**	**Difference (g)**	**Formula Used**	**Water Absorption (%)**
RFA (Recycled Fine Aggregate)	2010	1803.5	206.5	$\frac{SSD - OD}{OD} \times 100$	**11.45 %**
RCA (Recycled Coarse Aggregate)	2020	1978	42	$\frac{SSD - OD}{OD} \times 100$	**2.12 %**

Source: Created by authors

Table 3: Specific Gravity Test (Recycled Fine Aggregate)

Parameter	**Description**	**Value (g)**
W1	Weight of empty pycnometer	638.9
W2	Weight of pycnometer + dry aggregate	1140.8
W3	Weight of pycnometer + aggregate + water	1803.9
W4	Weight of pycnometer + water	1511.7
Specific Gravity (SG_FA)	Calculated value	**2.393**

Source: Created by authors

Table 4: Specific Gravity Test (Recycled Coarse Aggregate)

Parameter	**Description**	**Value (g)**
W1	Weight of empty pycnometer	633.8
W2	Weight of pycnometer + dry aggregate	1134.3
W3	Weight of pycnometer + aggregate + water	1822.8
W4	Weight of pycnometer + water	1504.8
Specific Gravity (SG_CA)	Calculated value	**2.742**

Source: Created by authors

4.0 Experimental Results and Discussion

4.1 Workability characteristics

Slump cone and compaction factor tests were used to determine the workability of fresh concrete mixes, and the findings revealed a steady decrease in the proportion of fresh concrete mixes with increasing proportions of RCA and RCFA. This decrease is due to the increased water uptake capacity and rough and sharp surface texture of the recycled aggregates due to the presence of old mortar. With a smaller particle size and larger porosity, RCA exhibited a stronger effect on loss of workability than RCA. The same tendencies were also mentioned in the recent literature, with higher levels of recycled aggregates leading to higher water requirements and decreased plasticity of concrete blends (Bayram & Greiff, 2023).

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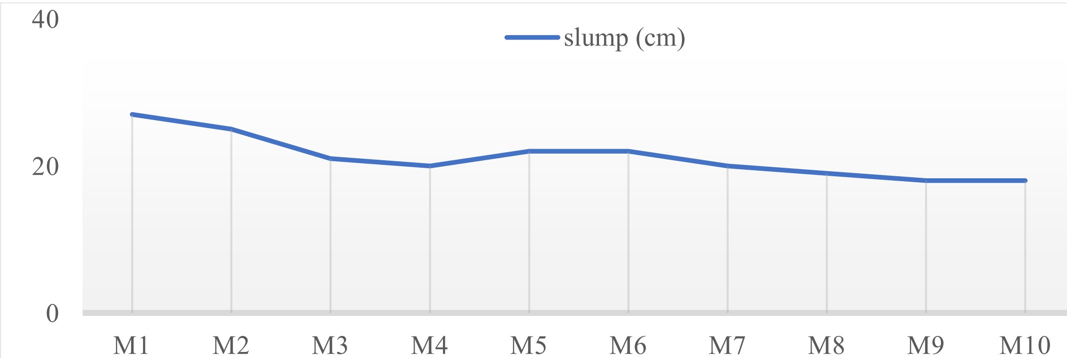
Figure 2: Workability vs Mix ID



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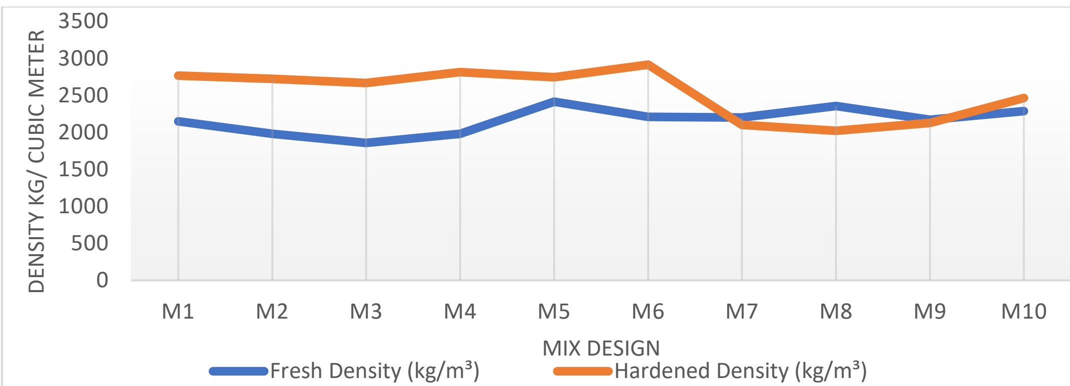
4.2 Density characteristics

Fresh and hardened density values of the paver blocks showed a slight declining tendency with level of replacement of RCA and RCFA. This tendency is mainly because the specific gravity of recycled aggregates and their porous microstructure are lower compared to those of natural aggregates. Adhered mortar and internal microcracks are also present in RCA that leads to a lower unit weight that has also been noted in other experimental studies of recycled aggregate paver blocks (Shrivastava & Chini, 2009).

Figure 3: Density vs Mix ID



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4.3 Paver blocks absorption of water

The absorption of hardened paver blocks by water was also greater when the content of RCFA was increased because recycled fine aggregates contained finer particles and had

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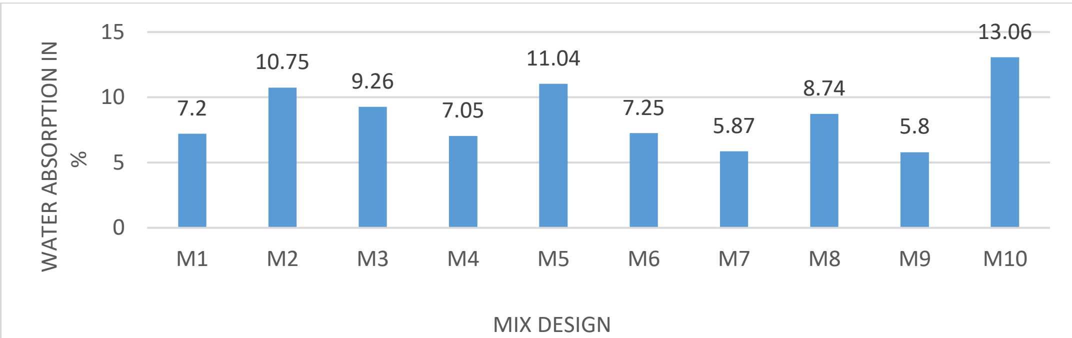
greater porosity. However, the obtained values did not exceed the allowable levels given in non-structural and medium-traffic paver utilization, which is consistent with the recent results on RCA-RCFA-based paver blocks (Tawalare et al., 2018)

Figure 4: Water Absorption vs Mix ID



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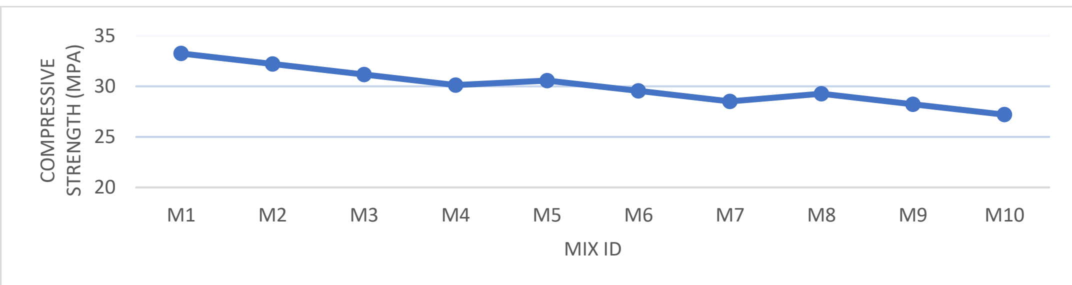
4.4 Compressive strength performance

The findings of compressive strength show a gradual decrease of compressive strength with the level of RCA and RCFA replacement.

Figure 5: Compressive Strength vs Mix ID



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Nevertheless, mixes with medium replacement levels (up to about 50 percent) showed strengths that could be used in pedestrian and light-traffic applications, meeting the standards of IS 15658. The observation aligns with the modern research and reports that recycled aggregate content optimized by incorporating sufficient mechanical performance and increasing sustainability (Bayram & Greiff, 2023).

Purpose: Shows overall strength variation across Taguchi L9 mixes.

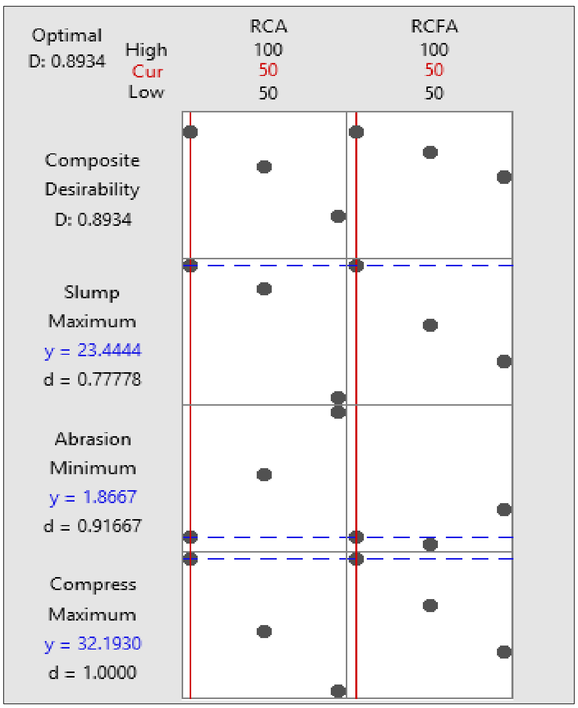
5.0 Master Experimental Data Table

Table 5: Summary of Experimental Results for Taguchi L9 Mixes

		Virgin Aggregate		Recycled Aggregates										
Mix	Cement	Fine Aggregate	Coarse Aggregate	RCFA	RCA	Water	Fresh Density (kg/m³)	Hardened Density (kg/m³)	Compressive Strength (MPa)	Split Tensile Strength (MPa)	Flexural Strength (MPa)	Abrasion Value (mm)	Water Absorption (%)	Slump (mm)
M1	100	100	100	0	0	40	2150	2764	33.245	3.12	4.65	1.6	7.2	27
M2	100	50	50	50	50	40	1979	2721	32.193	3.21	4.5	1.8	10.75	25
M3	100	50	25	50	75	40	1857	2667	31.164	3.1	4.36	1.9	9.26	21
M4	100	50	0	50	100	40	1979	2814	30.135	3	4.22	2	7.05	20
M5	100	25	50	75	50	40	2414	2743	30.576	3.05	4.28	2.2	11.04	22
M6	100	25	25	75	75	40	2207	2914	29.547	2.95	4.14	2.1	7.25	22
M7	100	25	0	75	100	40	2200	2100	28.518	2.85	3.99	2.3	5.87	20
M8	100	0	50	100	50	40	2357	2021	29.253	2.92	4.09	2.5	8.74	19
M9	100	0	25	100	75	40	2171	2129	28.224	2.82	3.95	2.4	5.8	18
M10	100	0	0	100	100	40	2287	2465	27.195	2.72	3.81	2.6	13.06	18

Source: Created by authors

Figure 6: Multi-Response Optimization Plot (Taguchi Response Optimizer)



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6.0 ANOVA Analysis

Table 6: ANOVA Summary

Response	Recycled Concrete Aggregate P-value	Recycled Concrete Fine Aggregate P-value	R^2
Compressive Strength	*	*	100%
Abrasion	0.001	0.049	97.78%
Slump	0.048	0.138	83.98%

Source: Created by authors

The ANOVA results indicate that Recycled Concrete Aggregate is statistically significant for abrasion and slump because its P-values are below 0.05. For abrasion, Recycled Concrete Aggregate shows very high significance (0.001), while Recycled Concrete Fine Aggregate, is also significant (0.049). For slump, Recycled Concrete Aggregate is significant whereas Recycled Concrete Fine Aggregate, is less significant. The high R^2 values confirm that the regression model explains most of the response variation, indicating strong reliability of the optimization model.

Table 7: parameter of 3 tests

Response	Goal	Lower	Target	Upper	Weight	Importance
Slump	Maximum	18.000	25.000		1	1
Abrasion Value	Minimum		1.800	2.6	1	1
Compressive Strength	Maximum	27.195	32.193		1	1

Source: Created by authors

Table 8: Final Optimized Mix

Recycled Concrete Aggregate	Recycled Concrete Fine Aggregate	Slump	Abrasion	Compressive Strength	Desirability
50	50	23.444	1.867	32.193	0.893

Source: Created by authors

The multi-response optimization selected 50% Recycled Concrete Aggregate and 50% Recycled Concrete Fine Aggregate, as the optimum mix because it simultaneously produced the highest compressive strength, acceptable abrasion resistance, and suitable workability. The desirability value of 0.893 indicates that the selected mix is very close to ideal optimization. This confirms that moderate recycled aggregate replacement provides the best balance between sustainability and engineering performance for M30 grade paver blocks.

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7.0 Conclusions

The current research will ascertain that Recycled Concrete Aggregate (RCA) and Recycled Concrete Fine Aggregate (RCFA) can be successfully used in the manufacturing of concrete paver blocks on a controlled basis when used in the specific proportions that will aid in the sustainable construction (Tawalare et al., 2018). The findings show that increment in the contents of RCA and RCFA results in slight decrease in workability, density and compressive strength because of the increased porosity and water absorption, but mixes with intermediate replacement rates (up to 50 percent) gave performances suitable in pedestrian and light-traffic applications. Taguchi L9 orthogonal array was also an efficient optimization tool that allowed to do systematic analysis of multiple variables with less effort during experiments. These results coincide with the latest research on the viability of the recycled aggregates in the concrete products and encourage the principles of the circular economy and preservation of the resources (Kadam et al., 2024).

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