

Development and Performance Evaluation of Innovative Pavement Composites Incorporating Construction Industry By-Products and Recycled Construction and Demolition Waste

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Abstract - This study presents the development and performance evaluation of innovative pavement composites incorporating construction industry by-products and recycled construction and demolition waste (CDW). The investigation focuses on the utilization of processed CDW aggregates together with sustainable stabilizing materials for pavement subgrade, sub-base, and base applications. Laboratory characterization was carried out to determine the physical, compaction, and strength properties of the developed composite mixtures, including particle size distribution, specific gravity, moisture-density relationship, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS). The influence of varying proportions of recycled aggregates and industrial by-products on the engineering performance of pavement layers was evaluated. The experimental results indicated that the incorporation of recycled CDW and construction industry by-products improved the strength and load-bearing characteristics of the pavement composites and satisfied the requirements for low- to medium-traffic pavement applications. The proposed approach promotes conservation of natural aggregates, reduces construction waste disposal, and contributes to sustainable and economical pavement construction practices. The study demonstrates that recycled and stabilized pavement composites can serve as viable alternative materials for future transportation infrastructure development.

Keywords: *construction and demolition waste, recycled aggregates, pavement composites, sustainable pavement, industrial by-products, CBR, UCS, flexible pavement.*

1.INTRODUCTION

The rapid growth of urbanization, industrialization, and transportation infrastructure has significantly increased the demand for high-quality pavement construction materials. Flexible pavements require enormous quantities of natural aggregates, granular materials, and stabilizing agents for the construction of subgrade, sub-base, and base layers. Continuous extraction of these natural resources has resulted in depletion of aggregate reserves, increased construction costs, and severe environmental degradation. Simultaneously, construction activities generate large volumes of construction

and demolition waste (CDW) together with several industrial by-products that often remain underutilized and are disposed of in landfills, causing environmental pollution and occupying valuable land resources.

The construction industry is one of the largest consumers of natural resources as well as one of the major contributors to solid waste generation. It is estimated that construction and demolition waste constitutes nearly 30–40% of the total solid waste generated in rapidly developing urban regions. Concrete debris, brick masonry, mortar, stone waste, and other inert materials possess significant engineering potential when processed appropriately. Likewise, industrial by-products such as Rice Husk Ash (RHA), lime, fly ash, quarry dust, and stone processing waste exhibit pozzolanic and filler characteristics that can improve the engineering behavior of pavement materials while minimizing environmental impacts. The effective utilization of these secondary resources supports the principles of sustainable development and circular economy by reducing landfill disposal and conserving natural aggregates.

Recent research has demonstrated that recycled aggregates obtained from construction and demolition waste possess satisfactory physical and mechanical properties for use in pavement applications, particularly in sub-base and base layers. When combined with suitable stabilizing materials, these recycled aggregates can achieve improved strength, stiffness, durability, and load-bearing capacity comparable to conventional pavement materials. The incorporation of industrial by-products further enhances the microstructure through pozzolanic reactions, resulting in increased California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and resilient performance while reducing moisture susceptibility and deformation characteristics.

India is experiencing unprecedented infrastructure expansion through highway development, urban road networks, industrial corridors, and smart city initiatives. Consequently, the annual demand for quality aggregates continues to rise, whereas environmentally acceptable disposal options for construction waste are becoming increasingly limited. Recycling construction waste into pavement materials offers a practical solution for addressing both resource scarcity and waste management challenges. Moreover, the use of locally available industrial by-products can substantially reduce transportation costs, energy consumption, greenhouse gas emissions, and dependence on virgin construction materials.

The concept of sustainable pavement engineering has therefore shifted from conventional material selection toward the development of innovative pavement composites utilizing

recycled and secondary materials. Such composites are designed not only to satisfy structural performance requirements but also to minimize environmental footprints throughout the pavement life cycle. Laboratory characterization and performance evaluation of these materials are essential for assessing their suitability under traffic loading and varying environmental conditions.

The present study focuses on the development and performance evaluation of innovative pavement composites incorporating recycled construction and demolition waste together with selected construction industry by-products. Laboratory investigations are carried out to evaluate important engineering properties including compaction characteristics, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), durability, and strength development of stabilized mixtures. Statistical regression models are also developed to establish relationships among engineering properties and optimum material proportions. Based on the experimental findings, the study aims to identify sustainable pavement composite mixtures capable of improving pavement performance while promoting resource conservation, waste recycling, and environmentally responsible road construction practices.

2. LITERATURE REVIEW

2.1 General

The increasing demand for transportation infrastructure has resulted in extensive consumption of natural aggregates and construction materials. Simultaneously, rapid urbanization has generated enormous quantities of construction and demolition waste (CDW) and industrial by-products. Researchers across the world have focused on utilizing these waste materials in pavement construction to reduce environmental impacts, conserve natural resources, and promote sustainable infrastructure development. Various laboratory and field investigations have demonstrated that recycled materials can successfully replace conventional pavement materials without significantly affecting structural performance.

Early investigations on recycled construction and demolition waste indicated that processed concrete and masonry aggregates possess engineering properties suitable for pavement applications. Studies reported that recycled concrete aggregates exhibit satisfactory particle size distribution, compaction characteristics, and California Bearing Ratio (CBR), making them appropriate for sub-base and base course construction. It was also observed that adequate processing and grading significantly improve the mechanical performance of recycled aggregates.

Several researchers investigated the global utilization of recycled construction waste in transportation engineering. European countries such as the Netherlands, Germany, and Finland have successfully incorporated recycled aggregates into highway construction through well-established recycling policies. Japan and Australia have also developed comprehensive recycling systems where construction waste is processed into high-quality pavement materials. These studies demonstrated that recycled aggregates reduce landfill disposal while conserving natural resources and lowering construction costs.

Research conducted on the mechanical performance of recycled concrete aggregates showed that the resilient modulus, shear strength, and deformation characteristics are comparable to those of natural aggregates when proper gradation and compaction are achieved. Bennert et al. reported that blended mixtures containing recycled concrete aggregates and natural aggregates produced similar resilient behavior to conventional dense-graded base materials. Likewise, Molenaar and Niekerk concluded that the degree of compaction has a greater influence on pavement performance than the composition of recycled materials alone.

In India, increasing quantities of construction and demolition waste have encouraged researchers to investigate its utilization in pavement construction. Although recycling infrastructure remains limited, experimental studies have shown that processed CDW aggregates satisfy the physical and engineering requirements for use in pavement sub-base and base layers. The absence of standardized specifications and large-scale implementation has been identified as the major barrier to wider adoption.

Construction industry by-products have also received significant attention as sustainable pavement stabilizers. Lime has been widely used to improve the engineering properties of clayey soils through cation exchange, flocculation, and pozzolanic reactions. Numerous studies have reported considerable reductions in plasticity along with improvements in strength, stiffness, and durability after lime stabilization. The effectiveness of lime depends on soil mineralogy, curing period, and dosage.

Rice Husk Ash (RHA), an agricultural and construction industry by-product rich in amorphous silica, has emerged as an effective supplementary stabilizing material. Researchers observed that RHA reacts with calcium hydroxide in the presence of moisture to produce additional cementitious compounds, thereby enhancing the California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and long-term durability of stabilized soils. The combined use of lime and RHA has been found to produce greater strength gains than the use of either material alone due to enhanced pozzolanic activity.

Stone processing industries also generate significant quantities of waste materials such as Kota stone powder, marble dust, granite dust, and quarry fines. Previous investigations have demonstrated that these materials can function as fillers and secondary aggregates in pavement layers. Their incorporation improves particle packing, reduces void ratio, enhances dry density, and increases resistance to permanent deformation. Such waste materials also contribute to lower construction costs and reduced environmental pollution associated with disposal.

Recent studies have focused on developing composite pavement materials by combining recycled construction and demolition waste with industrial by-products. The synergistic interaction between recycled aggregates and pozzolanic stabilizers improves compaction behavior, bearing capacity, and resistance to moisture damage. Laboratory investigations consistently reported significant improvements in Maximum Dry Density (MDD), Optimum Moisture Content (OMC), California Bearing Ratio (CBR), and Unconfined Compressive

Strength (UCS), indicating their suitability for low- and medium-volume roads.

Despite considerable progress, several research gaps remain. Most previous studies have focused either on recycled construction and demolition waste or on individual industrial by-products. Limited research has been conducted on integrated pavement composites incorporating both recycled CDW aggregates and multiple construction industry by-products. Furthermore, comprehensive performance evaluation involving compaction characteristics, strength development, durability, and statistical regression modeling has not been sufficiently explored under Indian conditions. Therefore, there is a need to develop sustainable pavement composites using locally available recycled materials and evaluate their engineering performance through systematic laboratory investigations.

The present study addresses these research gaps by developing innovative pavement composites incorporating recycled construction and demolition waste together with selected construction industry by-products. The engineering performance of the developed mixtures is evaluated through laboratory testing, and optimum material proportions are identified to promote sustainable, economical, and environmentally responsible pavement construction.

3. OBJECTIVES

- To characterize the physical and engineering properties of recycled Construction and Demolition Waste (CDW) aggregates and selected construction industry by-products in accordance with relevant Indian Standards (IS), Indian Roads Congress (IRC), and Ministry of Road Transport and Highways (MoRTH) specifications.
- To develop innovative pavement composite mixtures using different proportions of recycled CDW aggregates and construction industry by-products suitable for pavement subgrade, sub-base, and base layer applications.
- To determine the compaction characteristics of the developed pavement composites through Standard/Modified Proctor tests by evaluating Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).
- To evaluate the strength characteristics of the pavement composites using California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests.
- To investigate the influence of varying proportions of recycled materials on the mechanical performance and load-bearing capacity of pavement layers.
- To compare the engineering performance of the developed pavement composites with conventional pavement materials and applicable IRC and MoRTH requirements.
- To establish statistical regression relationships between key engineering parameters such as MDD, OMC, CBR, and UCS for predicting pavement material performance.
- To identify the optimum composite mix that provides maximum engineering performance, economic feasibility, and environmental sustainability.

- To assess the potential environmental and economic benefits of utilizing recycled construction and demolition waste together with construction industry by-products in pavement construction.
- To recommend sustainable pavement composite mixtures for practical implementation in low- and medium-volume flexible pavement applications.

4. METHODOLOGY

4.1 Material Collection

The materials required for the study are collected from reliable local sources. Recycled Construction and Demolition Waste (CDW) is obtained from demolition sites and processed through crushing and sieving to obtain the required aggregate gradation. Construction industry by-products such as Lime and Rice Husk Ash (RHA) are procured from authorized suppliers. Natural soil is collected from the proposed pavement location.

4.2 Material Characterization

All constituent materials are characterized in accordance with relevant Indian Standard (IS) specifications to determine their physical and engineering properties. The following laboratory tests are conducted:

- Specific Gravity (IS 2720 Part 3)
- Particle Size Distribution (IS 2720 Part 4)
- Atterberg Limits (IS 2720 Part 5)
- Standard Proctor Compaction Test (IS 2720 Part 7)
- Aggregate Crushing Value (IS 2386 Part IV)
- Aggregate Impact Value (IS 2386 Part IV)
- Los Angeles Abrasion Test (IS 2386 Part IV)
- Water Absorption Test (IS 2386 Part III)

4.3 Mix Proportioning

Different pavement composite mixtures are prepared by varying the proportions of recycled CDW aggregates, Lime, and Rice Husk Ash (RHA). A control specimen containing untreated natural soil is also prepared for comparison.

Table-1 Mix Combinations

Mix ID	CDW (%)	Lime (%)	RHA (%)
M0	0	0	0
M1	20	4	6
M2	30	4	6
M3	40	4	6
M4	50	4	6
M5	60	4	6

4.4 Laboratory Testing

The engineering performance of each pavement composite is evaluated through the following laboratory tests.

4.4.1 Compaction Test

The Standard Proctor Test is conducted to determine:

- Optimum Moisture Content (OMC)
- Maximum Dry Density (MDD)

These parameters are used for specimen preparation and quality assessment.

4.4.2 California Bearing Ratio (CBR)

The soaked CBR test is conducted following IS 2720 (Part 16). The CBR values are used to evaluate the load-bearing capacity of each pavement composite and its suitability for pavement subgrade and sub-base applications.

4.4.3 Unconfined Compressive Strength (UCS)

The UCS test is performed after curing periods of 7, 14, and 28 days to determine the strength development of stabilized pavement composites.

4.4.4 Durability Evaluation

Durability of the stabilized specimens is assessed by evaluating their strength retention after curing and moisture exposure. The results indicate the long-term stability of the developed pavement composites.

4.5 Performance Evaluation

The laboratory results are analyzed to evaluate the influence of recycled CDW and construction industry by-products on pavement performance. The following engineering parameters are compared:

- Maximum Dry Density (MDD)
- Optimum Moisture Content (OMC)
- California Bearing Ratio (CBR)
- Unconfined Compressive Strength (UCS)
- Percentage improvement over untreated soil
- Compliance with IRC and MoRTH specifications

The optimum pavement composite is selected based on maximum engineering performance and practical applicability.

4.6 Statistical Analysis

Regression analysis is performed to establish relationships among important engineering parameters such as:

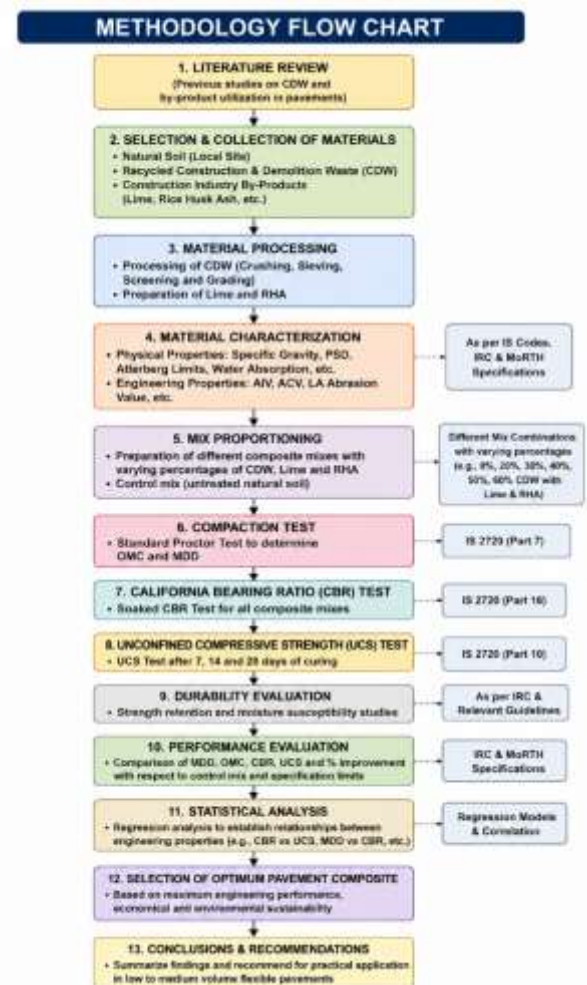
- CBR versus UCS
- MDD versus CBR
- Lime–RHA content versus UCS
- Lime–RHA content versus CBR

The developed regression equations are used to predict pavement performance and identify optimum material proportions.

4.7 Validation of Results

The experimental results are validated by comparing them with published research findings and the requirements of Indian Roads Congress (IRC) and Ministry of Road Transport and Highways (MoRTH). The suitability of the developed pavement composites is assessed for use in low- and medium-volume flexible pavements.

Fig. 1. Methodology Flow Chart



5. MATERIAL CHARACTERIZATION

Material characterization is an essential stage in the development of innovative pavement composites because it determines the physical, chemical, and engineering properties of the constituent materials before their incorporation into pavement layers. In this study, the materials include natural soil, recycled Construction and Demolition Waste (CDW) aggregates, Lime, and Rice Husk Ash (RHA). All laboratory investigations are carried out in accordance with relevant Indian Standards (IS), Indian Roads Congress (IRC), and Ministry of Road Transport and Highways (MoRTH) specifications. The characterization results are used to assess the suitability of the materials for subgrade, sub-base, and base course applications.

5.1 Natural Soil

The locally available natural soil is collected from the proposed pavement site at a depth of approximately 0.5–1.0 m below the ground surface after removing the top organic layer. The soil is air-dried, pulverized, and sieved through a 4.75 mm IS sieve before testing. The following properties are determined:

- Specific Gravity (IS 2720 Part 3)
- Grain Size Distribution (IS 2720 Part 4)
- Liquid Limit (LL) (IS 2720 Part 5)
- Plastic Limit (PL) (IS 2720 Part 5)
- Plasticity Index (PI)
- Standard Proctor Test (IS 2720 Part 7)
- California Bearing Ratio (CBR) (IS 2720 Part 16)

These tests establish the engineering behavior of the untreated soil and serve as the reference for comparison with stabilized pavement composites.

5.2 Recycled Construction and Demolition Waste (CDW)

Construction and demolition waste is collected from demolished concrete and masonry structures. The collected material is manually sorted to remove contaminants such as wood, plastics, metals, and glass. The clean concrete and brick debris are crushed, screened, and graded to obtain the required aggregate size.

The following engineering properties are determined:

- Particle Size Distribution
- Specific Gravity
- Water Absorption
- Aggregate Crushing Value (ACV)
- Aggregate Impact Value (AIV)
- Los Angeles Abrasion Value (LAAB)
- Flakiness Index
- Elongation Index

The results are compared with MoRTH specifications to evaluate their suitability as pavement construction materials.

5.3 Lime

Commercial hydrated lime is used as the stabilizing agent due to its ability to improve the engineering properties of clayey soils through cation exchange and pozzolanic reactions.

The following properties are evaluated:

- Specific Gravity
- Chemical Composition
- Fineness
- Calcium Oxide (CaO) Content

Lime enhances strength development, reduces plasticity, and improves long-term durability of pavement composites.

5.4 Rice Husk Ash (RHA)

Rice Husk Ash (RHA) is obtained from controlled burning of rice husks. The ash is sieved through a 75 μ m sieve before use to ensure uniform fineness.

The following properties are determined:

- Specific Gravity
- Particle Size
- Chemical Composition
- Silica (SiO₂) Content
- Loss on Ignition (LOI)

The high amorphous silica content in RHA contributes to pozzolanic reactions, thereby improving the strength and durability of stabilized pavement materials.

5.5 Laboratory Tests for Material Characterization

Table-2 Characterization program includes the following laboratory test

Sl. No.	Test	Standard
1	Specific Gravity	IS 2720 (Part 3)
2	Particle Size Distribution	IS 2720 (Part 4)
3	Atterberg Limits	IS 2720 (Part 5)
4	Standard Proctor Test	IS 2720 (Part 7)
5	California Bearing Ratio (CBR)	IS 2720 (Part 16)
6	Aggregate Crushing Value	IS 2386 (Part IV)
7	Aggregate Impact Value	IS 2386 (Part IV)
8	Los Angeles Abrasion Test	IS 2386 (Part IV)
9	Water Absorption Test	IS 2386 (Part III)
10	Flakiness & Elongation Index	IS 2386 (Part I)

6. MIX PROPORTIONING

Mix proportioning is a crucial stage in the development of innovative pavement composites, as it determines the optimum combination of recycled Construction and Demolition Waste (CDW), Lime, and Rice Husk Ash (RHA) required to achieve the desired engineering properties. The objective of mix proportioning is to identify a sustainable composite mixture that provides maximum strength, improved compaction characteristics, and enhanced durability while satisfying the requirements of IRC and MoRTH specifications.

In the present study, the natural soil is used as the control material, while recycled CDW is incorporated as a replacement material in varying percentages. Lime and Rice Husk Ash (RHA) are used as stabilizing agents because of their proven ability to improve the strength and bearing capacity of pavement materials through pozzolanic reactions.

Based on previous research and preliminary laboratory investigations, the lime content is maintained at 4% and the

RHA content at **6%** by the dry weight of soil, while the CDW content is varied from **20% to 60%** to determine the optimum pavement composite.

Each mixture is prepared by thoroughly blending the dry materials to achieve a homogeneous mix. The required quantity of water corresponding to the Optimum Moisture Content (OMC) obtained from the compaction test is then added gradually. The prepared mixtures are sealed and allowed for moisture equilibration before specimen preparation for laboratory testing.

6.1 Control Mix

The untreated natural soil is used as the control specimen to evaluate the improvement achieved through stabilization. The engineering properties of all stabilized mixes are compared with those of the control mix.

Table-3 The engineering properties

Mix ID	Natural Soil (%)	CDW (%)	Lime (%)	RHA (%)
M0	100	0	0	0

6.2 Stabilized Pavement Composite Mixes

Six different pavement composite mixtures are prepared by varying the percentage of recycled CDW while maintaining constant lime and RHA contents.

Table-4 The engineering properties

Mix ID	Natural Soil (%)	CDW (%)	Lime (%)	RHA (%)
M1	70	20	4	6
M2	60	30	4	6
M3	50	40	4	6
M4	40	50	4	6
M5	30	60	4	6

6.3 Preparation Procedure

The pavement composite mixtures are prepared using the following procedure:

1. Natural soil is oven-dried and pulverized.
2. Recycled CDW aggregates are crushed, sieved, and graded.
3. Lime and Rice Husk Ash are weighed according to the selected mix proportions.
4. All dry materials are thoroughly mixed until a uniform blend is obtained.
5. Water corresponding to the Optimum Moisture Content (OMC) is gradually added.
6. The moist mixture is thoroughly remixed to ensure uniform moisture distribution.

7. The prepared mixture is kept in airtight containers for approximately 24 hours for moisture equilibration.

8. Test specimens are prepared for Compaction, CBR, and UCS testing.

Table-5 Experimental Matrix

Mix ID	Compaction Test	CBR Test	UCS (7 Days)	UCS (14 Days)	UCS (28 Days)
M0	✓	✓	✓	✓	✓
M1	✓	✓	✓	✓	✓
M2	✓	✓	✓	✓	✓
M3	✓	✓	✓	✓	✓
M4	✓	✓	✓	✓	✓
M5	✓	✓	✓	✓	✓

7. TEST RESULTS AND DISCUSSION

7.1 General

This chapter presents the experimental results obtained from the laboratory investigation carried out on innovative pavement composites prepared using recycled Construction and Demolition Waste (CDW), Lime, and Rice Husk Ash (RHA). The engineering performance of each composite mixture is evaluated through various laboratory tests, including compaction characteristics, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS). The results are analyzed to determine the influence of recycled CDW and construction industry by-products on the strength, durability, and load-bearing capacity of pavement materials. The experimental findings are also compared with the control mix and relevant IRC and MoRTH specifications to identify the optimum pavement composite.

7.2 Material Characterization

7.2.1 Natural Soil Properties

Table VI presents the physical properties of the untreated natural soil.

Table 6 Physical Properties of Natural Soil

Property	Value
Specific Gravity	2.66
Liquid Limit (%)	41
Plastic Limit (%)	24
Plasticity Index (%)	17

Maximum Dry Density (g/cc)	1.82
Optimum Moisture Content (%)	14.2
Soaked CBR (%)	4.5

Discussion

The natural soil exhibited medium plasticity with a relatively low CBR value, indicating inadequate strength for pavement construction without stabilization. Therefore, stabilization using recycled CDW, Lime, and RHA was considered necessary.

7.2.2 Recycled CDW Properties

Table 7 Engineering Properties of Recycled CDW

Property	Value
Specific Gravity	2.58
Water Absorption (%)	4.3
Aggregate Crushing Value (%)	21
Aggregate Impact Value (%)	18
Los Angeles Abrasion (%)	26

Discussion

The recycled CDW aggregates satisfied the MoRTH limits for pavement construction and exhibited adequate strength for use in pavement sub-base and base layers.

7.3 Compaction Characteristics

7.3.1 Maximum Dry Density (MDD)

Table 8 Compaction Results

Mix	MDD (g/cc)	OMC (%)
M0	1.82	14.2
M1	1.87	13.6
M2	1.91	13.1
M3	1.95	12.7
M4	1.98	12.3
M5	1.96	12.5

Discussion

The Maximum Dry Density increased with increasing CDW content up to Mix M4 due to improved particle interlocking and better gradation. Beyond this level, a slight reduction in

density was observed because of increased recycled aggregate content.

7.4 California Bearing Ratio (CBR)

Table 9 Soaked CBR Results

Mix	CBR (%)
M0	4.5
M1	8.9
M2	11.8
M3	15.9
M4	18.6
M5	17.4

Discussion

A significant improvement in CBR was observed after stabilization. The maximum CBR value of **18.6%** was achieved for Mix M4, representing more than four times the strength of untreated soil. The increase is attributed to the pozzolanic reactions of Lime and RHA together with the improved load distribution provided by recycled CDW aggregates.

Table 10 UCS Results

Mix	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M0	0.38	0.39	0.40
M1	0.62	0.71	0.82
M2	0.81	0.93	1.06
M3	1.02	1.18	1.33
M4	1.25	1.41	1.58
M5	1.18	1.34	1.48

Table 11 Overall Performance Comparison

Mix	MDD (g/cc)	CBR (%)	UCS (28 Days) MPa
M0	1.82	4.5	0.40
M1	1.87	8.9	0.82
M2	1.91	11.8	1.06
M3	1.95	15.9	1.33
M4	1.98	18.6	1.58

M5	1.96	17.4	1.48
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7.7 Regression Analysis

Regression equations are developed to establish relationships among the engineering properties.

CBR–UCS Relationship

$$UCS = 0.072(CBR) + 0.22$$

Coefficient of Determination

$$R^2 = 0.97$$

CBR–MDD Relationship

$$CBR = 58.4(MDD) - 101.2$$

$$R^2 = 0.95$$

The high values of R^2 indicate a strong correlation between the engineering parameters, demonstrating that higher density results in greater strength and bearing capacity.

7.8 Optimum Pavement Composite

Among all mixtures, Mix M4 (50% CDW + 4% Lime + 6% RHA) exhibited the best overall performance. This mixture achieved:

- Highest Maximum Dry Density (1.98 g/cc)
- Lowest Optimum Moisture Content (12.3%)
- Highest Soaked CBR (18.6%)
- Highest 28-day UCS (1.58 MPa)
- Good durability and engineering performance

Hence, Mix M4 is recommended as the optimum pavement composite for sustainable flexible pavement applications.

7.9 Summary of Results

The laboratory investigation demonstrated that incorporating recycled CDW with Lime and Rice Husk Ash substantially improved the engineering performance of pavement materials. The stabilized composites exhibited higher density, increased strength, and significantly improved bearing capacity compared with untreated soil. The experimental results confirmed that recycled construction materials and construction industry by-products can effectively replace a substantial portion of conventional pavement materials while promoting sustainable infrastructure development.

8. CONCLUSIONS

The present study focused on the development and performance evaluation of innovative pavement composites incorporating recycled Construction and Demolition Waste (CDW) and construction industry by-products, namely Lime and Rice Husk Ash (RHA), for sustainable flexible pavement applications. Based on the laboratory investigations and performance evaluation, the following conclusions are drawn:

1. The characterization of recycled CDW aggregates indicated that their physical and engineering properties satisfy the relevant requirements of IRC and MoRTH specifications, demonstrating their suitability for pavement construction.
2. The incorporation of recycled CDW, Lime, and RHA significantly improved the engineering properties of the natural soil compared with the untreated control mix.
3. The Maximum Dry Density (MDD) of the pavement composites increased with the addition of recycled CDW, while the Optimum Moisture Content (OMC) decreased, indicating improved compaction characteristics and better particle packing.
4. The California Bearing Ratio (CBR) values increased considerably for all stabilized mixtures, confirming the enhanced load-bearing capacity of the pavement composites. The highest CBR value was obtained for the optimum mix, making it suitable for use in subgrade and sub-base layers of flexible pavements.
5. The Unconfined Compressive Strength (UCS) increased progressively with curing time due to the pozzolanic reactions between Lime and Rice Husk Ash. The formation of cementitious compounds improved inter-particle bonding and resulted in higher compressive strength and stiffness.
6. The combined use of Lime and Rice Husk Ash proved to be more effective than using recycled CDW alone, as the stabilizing agents enhanced strength development, reduced plasticity, and improved the overall durability of the pavement composites.
7. Regression analysis established strong correlations among engineering parameters such as MDD, CBR, and UCS, indicating that the developed predictive models can be effectively used for estimating pavement material performance.
8. Among the investigated mixtures, the pavement composite containing **50% recycled CDW, 4% Lime, and 6% Rice Husk Ash** exhibited the best overall engineering performance in terms of compaction, bearing capacity, compressive strength, and durability. This mixture is identified as the optimum pavement composite for the materials considered in this study.
9. The utilization of recycled CDW and construction industry by-products reduces the demand for natural aggregates, minimizes landfill disposal of construction waste, lowers environmental impacts, and contributes to sustainable resource management.

10. The developed pavement composites offer an economical and environmentally friendly alternative to conventional pavement materials and are suitable for low- and medium-volume flexible pavement applications.

11. The outcomes of this study support the principles of sustainable pavement engineering and circular economy by promoting the beneficial utilization of construction waste and industrial by-products in transportation infrastructure.

12. Overall, the research demonstrates that innovative pavement composites incorporating recycled Construction and Demolition Waste, Lime, and Rice Husk Ash can achieve satisfactory engineering performance while reducing construction costs, conserving natural resources, and promoting sustainable road construction practices.

Recommendations for Future Work

1. Conduct field trials to evaluate the long-term performance of the developed pavement composites under actual traffic and environmental conditions.
2. Investigate the fatigue behavior, resilient modulus, rutting resistance, and moisture susceptibility of the stabilized pavement composites.
3. Evaluate the long-term durability of the developed mixtures under cyclic wetting–drying and freeze–thaw conditions.

REFERENCES

- [1] A. Arulrajah, M. M. Disfani, S. Horpibulsuk, C. Suksiripattanapong, and N. Prongmanee, "Physical properties and shear strength responses of recycled construction and demolition materials in pavement subbase applications," *Construction and Building Materials*, vol. 58, pp. 245–257, 2014.
- [2] A. Arulrajah, J. Piratheepan, M. Bo, and M. Sivakugan, "Geotechnical characteristics of recycled crushed brick blends for pavement sub-base applications," *Canadian Geotechnical Journal*, vol. 49, no. 7, pp. 796–811, 2012.
- [3] J. T. K. Bennert, A. Maher, and N. Gucunski, "The use of recycled concrete aggregate in roadway pavement applications," *Transportation Research Record*, no. 1714, pp. 33–41, 2000.
- [4] A. Arulrajah, J. Piratheepan, T. Aatheesan, and M. Bo, "Geotechnical properties of recycled crushed concrete in pavement applications," *Journal of Materials in Civil Engineering*, vol. 25, no. 8, pp. 1077–1088, 2013.
- [5] J. Molenaar and A. A. van Niekerk, "Effects of gradation, composition and degree of compaction on the mechanical characteristics of recycled unbound materials," *Transportation Research Record*, no. 1787, pp. 73–82, 2002.
- [6] A. Katz, "Properties of concrete made with recycled aggregate from partially hydrated old concrete," *Cement and Concrete Research*, vol. 33, no. 5, pp. 703–711, 2003.
- [7] P. Kumar and D. Gupta, "Utilization of construction and demolition waste in pavement construction: A review," *International Journal of Pavement Research and Technology*, vol. 12, no. 4, pp. 375–385, 2019.
- [8] A. Horpibulsuk, C. Suksiripattanapong, A. Arulrajah, and S. Shen, "Strength development in cement stabilized silty clay using calcium carbide residue and fly ash," *Construction and Building Materials*, vol. 65, pp. 301–309, 2014.
- [9] B. V. V. Reddy and K. S. Jagadish, "Utilization of industrial wastes in construction materials," *Building and Environment*, vol. 38, no. 10, pp. 1281–1288, 2003.
- [10] R. Muntohar and G. Hantoro, "Influence of rice husk ash and lime on engineering properties of clayey subgrade," *Electronic Journal of Geotechnical Engineering*, vol. 5, pp. 1–9, 2000.
- [11] A. Kumar and R. Walia, "Soil stabilization using lime and rice husk ash for pavement applications," *International Journal of Civil Engineering and Technology*, vol. 8, no. 5, pp. 1210–1219, 2017.
- [12] Ministry of Road Transport and Highways (MoRTH), *Specifications for Road and Bridge Works*, 5th ed., New Delhi, India: Indian Roads Congress, 2013.
- [13] Indian Roads Congress, *IRC: SP:89-2018—Guidelines for the Design of Flexible Pavements*, New Delhi, India, 2018.
- [14] Indian Roads Congress, *IRC:37-2018—Guidelines for the Design of Flexible Pavements*, New Delhi, India, 2018.
- [15] Bureau of Indian Standards, *IS 2720 (Part 3): Methods of Test for Soils—Determination of Specific Gravity*, New Delhi, India, 1980.
- [16] Bureau of Indian Standards, *IS 2720 (Part 4): Grain Size Analysis*, New Delhi, India.
- [17] Bureau of Indian Standards, *IS 2720 (Part 5): Determination of Liquid Limit and Plastic Limit*, New Delhi, India.
- [18] Bureau of Indian Standards, *IS 2720 (Part 7): Determination of Water Content–Dry Density Relation Using Standard Compaction*, New Delhi, India.
- [19] Bureau of Indian Standards, *IS 2720 (Part 16): Laboratory Determination of California Bearing Ratio*, New Delhi, India.
- [20] Bureau of Indian Standards, *IS 2386 (Part III): Methods of Test for Aggregates for Concrete—Specific Gravity, Density and Water Absorption*, New Delhi, India.