SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V13I6P105
Volume 13 Issue 6, 59-72, June 2026
© 2026 Seventh Sense Research Group®

Original Article

Performance Assessment of Construction and Demolition Waste Blended with Murum Soil for Pavement Subgrade and Sub-Base Layers

Saloni S. Gidde[1], R. H. Jadhav[2]

[1,2]*Department of Civil Engineering, Bharati Vidyapeeth (Deemed to be University) College of Engineering, Pune, Maharashtra, India.*

[1]*Corresponding Author : phdsalonigidde@gmail.com*

Received: 07 March 2026 Revised: 06 April 2026 Accepted: 05 May 2026 Published: 30 June 2026

Abstract - *The high rate of urbanization and the development of urban infrastructure have led to the substantial growth in Construction and Demolition (C&D) waste, which creates the challenge of landfill utilization and natural resource depletion. Although previous studies have explored recycled aggregates, limited research exists on the direct use of untreated C&D waste blended with Murum soil under Indian conditions. This study investigates the engineering performance of C&D waste–Murum mixtures for pavement subgrade and sub-base applications. Four mix proportions (0%, 15%, 25%, and 50% C&D waste) were evaluated through laboratory tests, including compaction characteristics, Atterberg limits, free swell index, and soaked California Bearing Ratio (CBR) in accordance with Indian Standards. The results indicate that increasing C&D waste content reduces specific gravity, maximum dry density, and CBR, while optimum moisture content and plasticity characteristics increase. All mixes satisfy the minimum CBR requirement of 20% for sub-base applications, with an optimum replacement range of 15–25%. Further analysis shows that C&D waste can achieve cost savings of up to 26% and remains economically viable within a transportation distance of approximately 75 km. The addition of 2% lime stabilization enhances the strength of the material at a negligible additional cost. The findings confirm that C&D waste can be effectively utilized as a sustainable alternative material in pavement construction, promoting sustainable infrastructure development through resource conservation and cost efficiency.*

Keywords - *Bearing capacity, Construction and Demolition Waste, Pavement Subgrade, Resource conservation, Sustainable materials.*

1. Introduction

The rapid growth of urban infrastructure and construction activities around the world has caused an unprecedented rise in construction and demolition waste generation [1- 3]. This is a serious environmental problem because it leads to overuse of landfills and depletion of resources [4]. Reusing C and DW in roads is an effective option since it means less trash ends up in landfills, natural resources are saved, and more circular economy practices are put into place [5-7]. Over the past few years, researchers have studied many options, like recycled concrete aggregates, artificial sand [2, 8], brick and ceramic residues [9], dredged sediments and mixed debris [10, 11], to see if they are suitable as alternative materials for the layers below a pavement structure. G. Tavakoli et al. [12] examined impact-crushed waste and discovered that it satisfies the regulations for use in sub-base work, based on various properties and the low bearing capacity of C and DW compared to standard materials, which was shown in cyclic tests, but when geocell reinforcement was used, the cyclic response and bearing capacity were much closer to those achieved with traditional materials. In a similar way, Y. Yuan et al. [13] discovered that blending 100% recycled construction waste with cement-treated macadam can pass heavy traffic standards as soon as the appropriate amounts of cement and curing agents are added during production.

Investigations by E. Zhang et al. [14] demonstrated that cement-stabilized macadam compressive strength is decreased by replacing it with Reclaimed Clay Bricks (RCB), although occasionally indirect tensile strength and freeze-thawing resistance increase to a maximum with RCB replacement up to 50 percent due to pozzolanic action in RCB that enhances the interfacial transition zone. This matches the observations of Y. Abriak [2] that when combined with quicklime and road binders, dredged sediment and RAC mixes of a max of 20 percent can sustain weight and compress and pose no threat to the surrounding water or soil, and cannot be found guilty of failure to meet highway requirements in compressing and sustaining weight. S. Bellara et al. [1] noted in another study that using hydraulic binders to treat dam two wastes as a road

This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

subgrade provides the necessary mechanical features, reduces greenhouse gas emissions, and cuts down on natural resource use. C. Hidalgo [15] also proved that adding brick and ceramic tile wastes to the soil can make it just as strong as granular base materials, leading to thinner pavements and saving costs. X. Zhi et al. [16] concentrated on cement-stabilized permeable recycled aggregates for roads, showing that adding up to 30% recycled aggregates meets demands for strength and porosity, and cement mixers helped to increase concrete strength and performance.

Due to its composition, C and DW exhibit a wide variety of behaviors; according to H. Lunkes [17], compaction and chemical treatment can increase its strength, while ceramic particles decrease its deformability. C. Lu [18] did both unbound RCA and RCMB using cyclic deformation tests and found that, in general, 10% recycled clay masonry leads to favorable results, but this result depends on the way the materials are blended and on the ratio of materials. All studies together create a major basis for applying C and DW materials for road subgrade and base layers. The results demonstrated that sustainable construction methods can be used and that incorporating C and DW into roads is technically feasible. [12, 19-24].

The characteristics of processed RA, in particular RCA, have been investigated by many researchers, and it has been shown that suitable properties are achieved for use in sub-base and base layers, often complying with standard specifications when the aggregates are correctly graded or stabilized. Moreover, chemical stabilizers have been revealed to play a significant role in the strength and durability characteristics, such as cement, lime, and geopolymers. The behavior of recycled materials, however, is very much dependent on factors like composition, particle size distribution, and degree of processing, which can influence their overall performance and suitability for specific applications in construction. Less attention has been paid to mixed and untreated C&D waste, which constitutes the majority of real-world demolition material, particularly when combined with the locally available soils under region-specific conditions.

Although most studies have investigated and demonstrated the appropriateness of recycled aggregates in pavement applications, many reported studies have been limited to the use of processed, graded, or chemically stabilized products, with very little focus being directed towards the direct application of uncooked, heterogeneous C&D waste. This weakness is particularly significant in Indian conditions, where local materials such as murum soil are commonly used, but their interaction with mixed C&D waste has not been thoroughly studied.

The variability in composition, particle size distribution, and mechanical behavior of untreated C&D waste creates a degree of uncertainty that surrounds the engineering performance of untreated C&D waste, and the available literature rarely considers the combined effects of the physical properties, compaction behavior, and strength properties using standardized Indian testing procedures. In this regard, the current research will fill these gaps by critically reviewing Murum blends made from untreated C&D waste using laboratory analysis and further reinforcing the analysis with the application of statistical modeling, economic analysis, and transportation feasibility. The novelty of the present study is that it uses untreated, heterogeneous C&D wastes mixed with Murum soil under Indian conditions and without prior processing or stabilization. The combination of statistical modeling and economic feasibility further increases its relevance in real-life pavement design and implementation.

2. Comparative Analysis with International Studies

Table 1 presents a comparison of compaction characteristics and strength properties reported in previous studies and compares them with the findings of the present investigation.

Table 1. Literature comparison

Reference	Material Type	Pavement Application	Key Parameters	Reported Values	Major Findings	Relation to Present Study
[25]	RCA, Mixed debris	Base/Subbase	CBR	RCA = 97–138%; MD = 62–94%; NA = 152%	Recycled aggregates showed adequate bearing capacity for pavement layers	A similar reduction trend was observed when weaker recycled materials were blended with natural aggregates
[26]	RCA	Subbase	CBR	118–160%	RCA satisfied road authority requirements for subbase layers	Supports feasibility in pavement construction
[27]	RCA, RMC	Base/Subbase	CBR	RCA ≈ 100%; RMC ≈ 74%	Strength varies depending on the composition of	Explains variation in strength observed in

					recycled aggregates	Murum–C&D mixtures
[28]	Mixed recycled aggregates	Base/Subbase	CBR	Mixed RA = 68%; RCA = 138%	Mixed recycled aggregates show lower strength than pure RCA	Similar behavior observed in blended Murum–C&D mixtures
[29]	RCA	Base/Subbase	CBR	90–143%; 120–215%	CBR increases with compaction and moisture conditions	Indicates the importance of compaction conditions in recycled materials
[30]	RCA	Base/Subbase	CBR	155–196% soaked; 241% unsoaked	Strength decreases under soaked conditions	A similar soaked CBR reduction was observed in the present study
[31]	RCA, Crushed brick	Base/Subbase	CBR	RCA = 172%; CB = 135%	Material composition significantly affects strength	Confirms the influence of material composition on bearing capacity
[32]	RCA/RMC blend	Base/Subbase	CBR	153–69.5% depending on blend ratio	Strength decreases with an increasing weaker material fraction	A similar decrease in CBR was observed with increasing C&D waste content
[33]	Recycled C&D aggregates	Base/Subbase	LAA, WA, CBR	LAA = 25.4–28.3%; WA = 4–6.3%; CBR = 72.3–85.4%	Recycled aggregates showed acceptable mechanical performance	Supports the use of said material in pavement layers
[34]	Recycled aggregates	Base/Subbase	MDD, OMC, CBR	MDD = 1760–1860 kg/m³; OMC = 10.5–14.5%; CBR = 56–65.5%	Mechanical properties comparable to natural aggregates	Similar compaction trends were observed in the present study
[35]	Recycled aggregates	Base/Subbase	WA, LAA, CBR	WA = 4.1%; LAA = 36.3%; CBR = 158–242%	Self-cementing properties improved the strength after compaction	Indicates stabilization can improve recycled material strength
[36]	RCA	Base layer (Fly ash geopolymer)	LAA, MDD, OMC, CBR	LAA = 38.9%; MDD = 1770 kg/m³; OMC = 11.7%; CBR = 190%	Geopolymer stabilization significantly improved the strength	Demonstrates the potential of chemical stabilization for recycled materials
[37]	Recycled C&D aggregates	Base/Subbase (Cement)	LAA, MDD, OMC, CBR	"LAA = 27%; MDD = 1790 kg/m³; OMC = 13.4%; CBR = 49.5–88.6%"	Cement stabilization improved bearing capacity	Suggests stabilization could enhance Murum–C&D mixtures
[38]	RCA and natural aggregates	Base/Subbase	WA, LAA, CBR	WA = 2.8–4.6%; LAA = 40.3–46.6%;	Higher RCA content increased deformation but remained usable	Supports feasibility in pavement layers

				CBR = 114–133.7%		
[39]	RCA and recycled brick	Base/Subbase	MDD, OMC, CBR	MDD = 2020 kg/m³; OMC = 9.9%; CBR = 248–291%	Processed aggregates exhibited very high strength	Higher strength than untreated mixtures used in the present study
[40]	Recycled C&D aggregates	Base layer (Cement)	pH, CBR, UCS	pH = 11.3–12; CBR = 370–531%	Cement-treated aggregates achieved very high strength	Shows stabilization can significantly enhance recycled aggregate performance
[41]	RCA and crushed brick	Base layer (Slag and fly ash geopolymer)	WA, MDD, OMC, pH	WA = 4.6–10.8%; MDD = 1880–2020 kg/m³; OMC = 9.5–12.1%; pH = 7.2–10.1	Stabilized recycled aggregates showed improved strength and durability	Indicates processed materials achieve higher performance than untreated mixtures
Present Study	Murum + C&D waste	Subgrade/Subbase	MDD, OMC, CBR	MDD = 1.99–1.87 g/cc; OMC = 11.5–14%; CBR = 35.23–25.53%	Increasing C&D content reduces density and strength but still meets IRC subbase requirements	Demonstrates the suitability of Murum–C&D blends for low-volume road construction

As shown in Table 2, many previous studies reported higher CBR values primarily attributed to processed or stabilized recycled aggregates. In contrast, the present study used untreated C&D waste blended with Murum soil, which explains the comparatively lower but still acceptable bearing capacity values for subbase applications.

2.1. Research Gap

Although there is a considerable literature base examining the reuse of C and DW in pavement applications, most of the studies have concentrated on processed recycled aggregates, chemically stabilized mixtures, or geocell-reinforced systems with little consideration of untreated, mixed C and DW blended directly with natural soils. Crucially, there is no comprehensive study of the engineering behavior of Murum soil mixed with varying proportions of C and DW, even though Murum is widely used all over Maharashtra as subgrade and sub-base material. Existing research mainly assesses the strength parameters like CBR or modulus but lacks integration of physical characteristics like plasticity, swelling potential, compaction behavior, and gradation change in the standardized testing procedures of India. Moreover, the inherent heterogeneity of C and DW and its effect on the soil performance have not yet been well investigated, leading to uncertainty in the engineering suitability and optimum replacement levels of C and DW. As regional factors such as soil, composition of waste, climate, and traffic conditions influence performance to a great extent, results obtained from international studies cannot be directly applied to Indian situations. Therefore, there is a clear research gap with respect to the development of experimentally validated, context-specific understanding of C and DW-Murum blends to make reliable recommendations for sustainable pavement construction practices in India.

3. Methodology

3.1. Materials

Murum soil was collected locally, air-dried, pulverized, and sieved. Aggregate from C&DW contains crushed concrete (≈ 40-50%), crushed brick fragments (≈ 30-40%), mortar particles (≈ 10-20%), and minor components. The aggregate was washed, oven-dried at 105°C, pulverized, and screened for aggregate 4.75 mm. A gradation that permitted optimum mixing.

3.2. Mix Proportions

Four mixes were prepared (by weight):

- 100% Murum
- 85% Murum + 15% C&DW
- 75% Murum + 25% C&DW
- 50% Murum + 50% C&DW

These proportions were selected to identify the optimum replacement level based on strength and performance.

3.3. Sample Preparation and Experimental Program

Materials were first placed in a mixing pan and allowed to dry mix. Water was introduced gradually to yield a moist, workable consistency across each mix. Samples were prepared using the Modified Proctor test method. Material was conditioned for varying time spans before each compaction attempt. A standard approach was maintained in preparing samples using this method; specimens were compacted manually (IS 2720-Part 8) and also statically (ASTM D1557, ASTM D1883) according to prescribed procedures.

3.4. Replication and Variability

All tests were performed in triplicate, and average values were reported. Variations were within acceptable limits. Minor variations were mainly caused by the heterogeneous composition of C&D waste.

3.5. Data Analysis

Results were analyzed using comparative and graphical methods to assess the effect of C&DW content. Trends were evaluated to establish relationships between mix composition and engineering properties.

4. Performance Evaluation and Statistical Analysis

The paper is a comparative analysis of the important parameters of soil tests of various compositions of the Murum and C and D waste.

A graphical representation and a summary of findings are provided with each parameter. See Table 2.

Table 2. Test results (Source- Author)

Test Parameter	100% Murum, 0% C and D Waste	85% Murum, 15% C and D Waste	75% Murum, 25% C and D Waste	50% Murum, 50% C and D Waste	IS Code
Specific Gravity	2.66	2.65	2.64	2.62	IS 2720 (Part 3/Sec1)-1980
Water Content (%)	5.42	10.04	8.29	7.11	IS 2720 (Part 2)-1973
Maximum Dry Density (g/cc)	1.99	1.95	1.93	1.87	IS 2720 (Pa. 8)-1983
Optimum Moisture Content (%)	11.5	12	12.5	14	
Liquid Limit (%)	33.25	35	36.75	39.5	IS 2720 (Part 5)-1985
Plastic Limit (%)	Non-Plastic	Non-Plastic	Non-Plastic	Non-Plastic	
Plasticity Index (%)	-	-	-	-	
Free Swell Index (%)	0	9.09	9.09	10	IS 2720 (Part 40)-1977
Soaked CBR (%)	35.23	34.03	31.35	25.53	IS 2720 (Part 16)-1987
% Gravel	51.3	51.2	48	37.9	IS 2720 (Part 4)-l985
% Sand	45.1	43.3	43.7	49.6	
% Silt and Clay	5.6	5.5	8.3	12.5	

4.1. Physical Properties

4.1.1. Specific Gravity

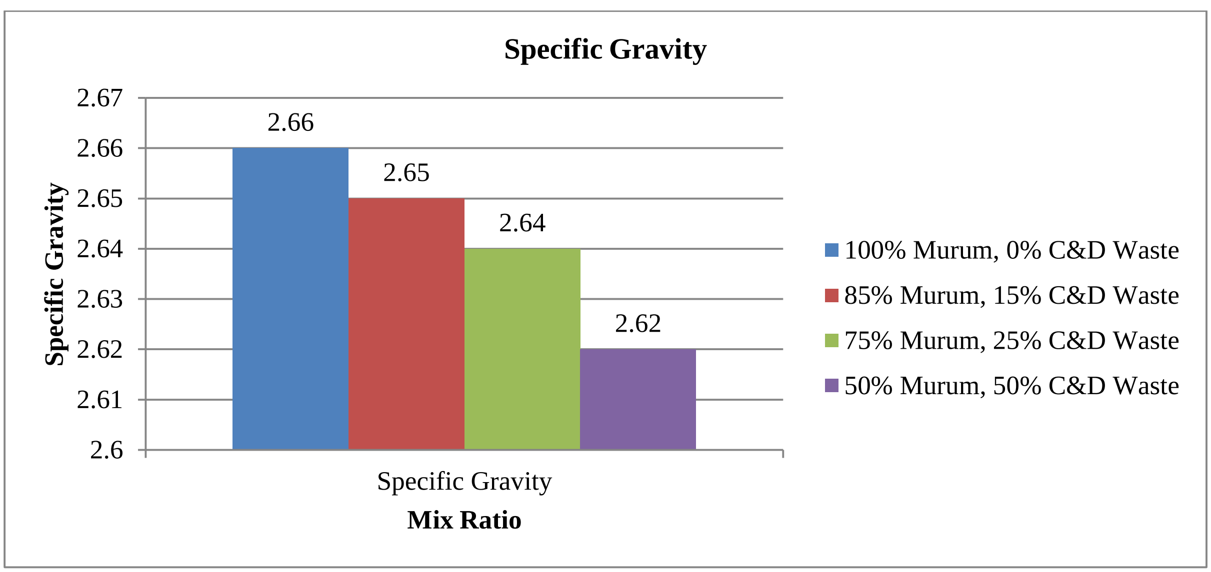

Fig. 1 Test result of specific gravity (Source- Author)

Figure 1 illustrates that the parameter Specific Gravity reaches its maximum value of 2.66 at 100% Murum and 0% C and D waste, while its minimum value of 2.62 occurs at 50% Murum and 50% C and D waste. Increasing C&D waste contents decreases the specific gravity of the mixtures due to the relatively low density and high porosity of the recycled materials compared to natural Murum soil.

Construction and demolition waste can traditionally contain fragments of mortar, particles of bricks, and porous concrete residues, which decrease the overall blend density.

4.1.2. Water Content (%)

Figure 2 shows the parameter' Water Content,' showing its maximum value (10.04) at 85% Murum and 15% C and D waste, and its minimum value (5.42) at 100% Murum and 0% C and D waste. The rise in water content of mixtures with C&D waste is primarily attributed to the higher water-absorbing capacity of the recycled aggregates. Particles such as crushed brick and concrete have rough surfaces and micro-pores, which tend to hold more moisture than natural granular materials. Consequently, the mixtures need more water to obtain proper compaction and particle lubrication in the mixing.

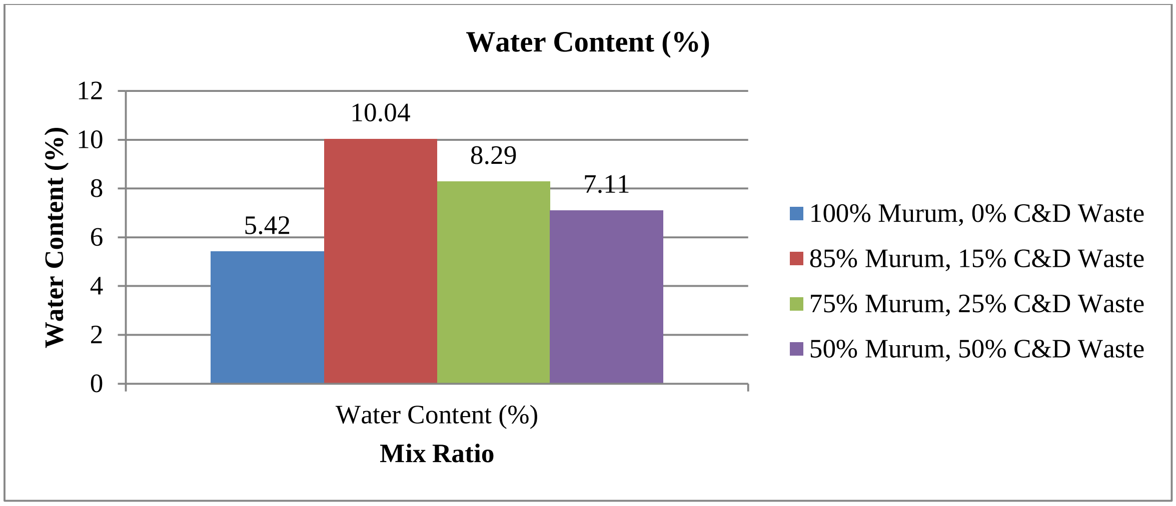

Fig. 2 Test result of water content (Source- Author)

4.1.3. Sand, Silt and Clay, Gravel (%)

Figure 3 shows the parameter '% Sand' shows its maximum value (49.60) at 50% Murum and 50% C and D waste, and its minimum value (43.30) at 85% Murum and 15% C and D waste. The parameter '% Silt and Clay' shows its maximum value (12.50) at 50% Murum and 50% C and D waste and minimum value (5.50) at 85% Murum and 15% C and D waste. The parameter '% Gravel' shows its maximum value (51.30) at 100% Murum and 0% C and D waste, and its minimum value (37.90) at 50% Murum and 50% C and D waste. The results of grain size distribution show a gradual decrease in gravel fraction and an increase in sand and fine particles with increasing C&D waste content. This change in grade is mostly due to the crushing of brick fragments and mortar particles in the recycled material. The reduction of coarse aggregate fraction may affect the bearing performance blend by the reduction of aggregate interlock, which is a part of the reason for the reduction of CBR values in higher replacement levels.

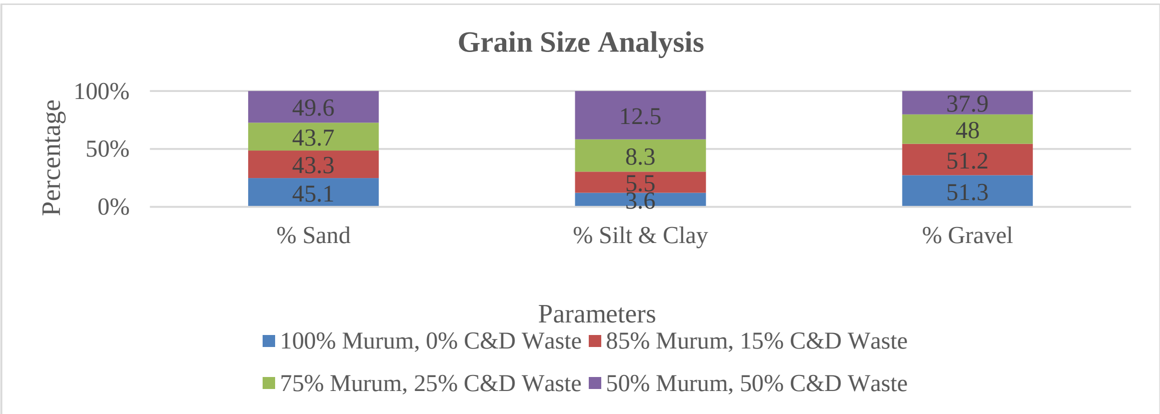

Fig. 3 Test result of Sand, Silt, and Clay, Gravel (Source- Author)

4.2. Compaction Characteristics

4.2.1. Maximum Dry Density (g/cc)

Figure 4 shows MDD, its maximum value (1.99) at 100% Murum and 0% C and D waste, and its minimum value (1.87) at 50% Murum and 50% C and D waste. The gradual decrease with an increase in C&D waste proportion indicates that the recycled materials are of lower unit weight as compared to natural Murum soil. The porosity of mortar and brick particles creates a less compacted density of the mixture. Similar observations were reported in studies on recycled aggregates used in pavement layers, in which a higher recycled content means a lower compaction density.

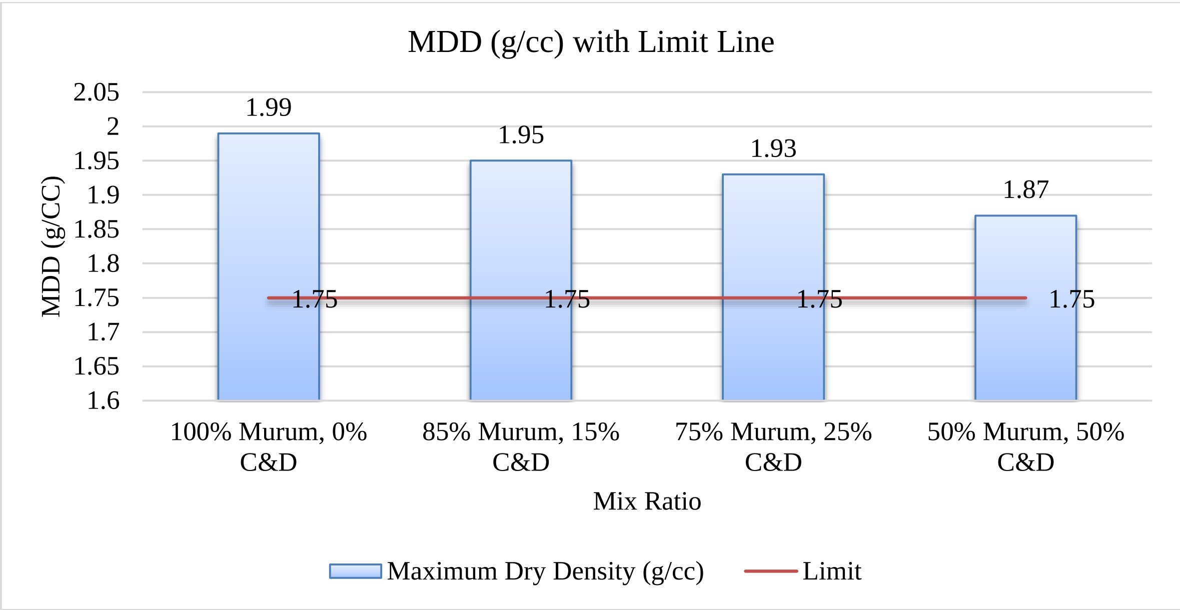

Fig. 4 Test result of MDD (Source- Author)

4.2.2. Optimum Moisture Content (%)

The OMC parameter in Figure 5 has a maximum value of 14.00 when there is 50% Murum and 50% C and D waste, and a minimum value of 11.50 when there is 100% Murum and 0% C and D waste. The increase in the optimum moisture content with increased C&D waste content is primarily related to the porous nature and rough surface textural characteristics of recycled particles. These materials absorb more water in compaction and thus require a higher moisture content to obtain the MDD. This behavior is rather typical for recycled aggregate mixtures at pavement sub-base usage.

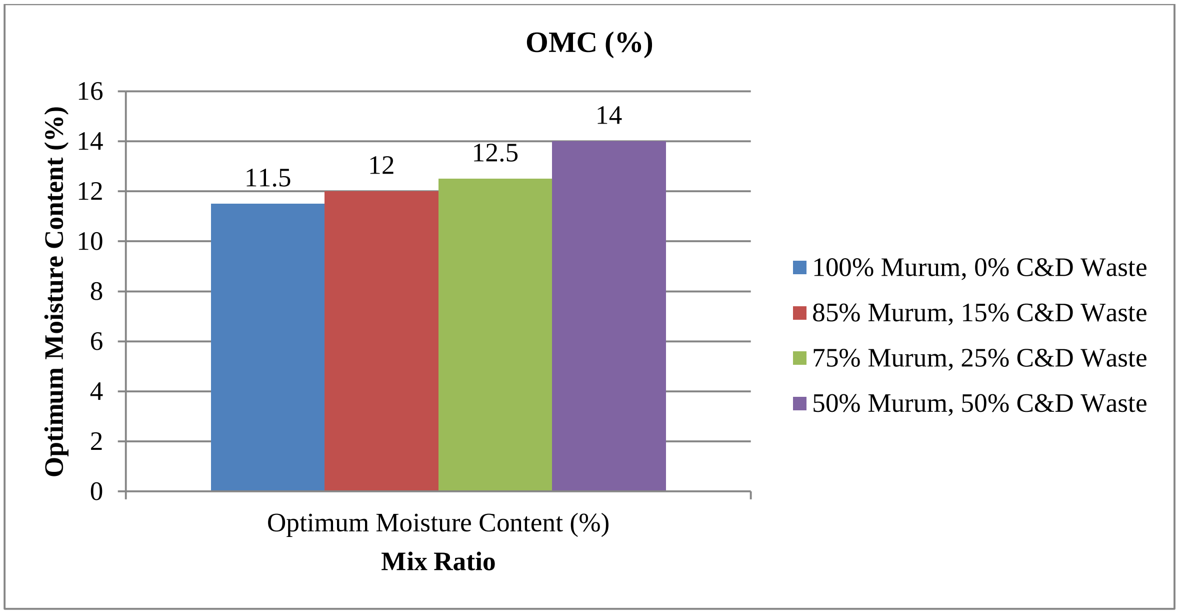

Fig. 5 Test result of optimum moisture content (Source- Author)

4.3. Plasticity and Swelling Behavior

4.3.1. Liquid Limit (%)

Figure 6 illustrates that the parameter' Liquid Limit' reaches its maximum value of 39.50 at a mixture of 50% Murum and 50% C and D waste, while its minimum value of 33.25 occurs at 100% Murum and 0% C and D waste. The rise in liquid limit with an increase in the proportion of C&D waste is indicative of a gradual increase in the fine particle content of a mixture. Materials like crushed brick dust and cement mortar add to the fine fraction and therefore increase the plasticity characteristics. However, the values are within acceptable limits for pavement subgrade and sub-base materials.

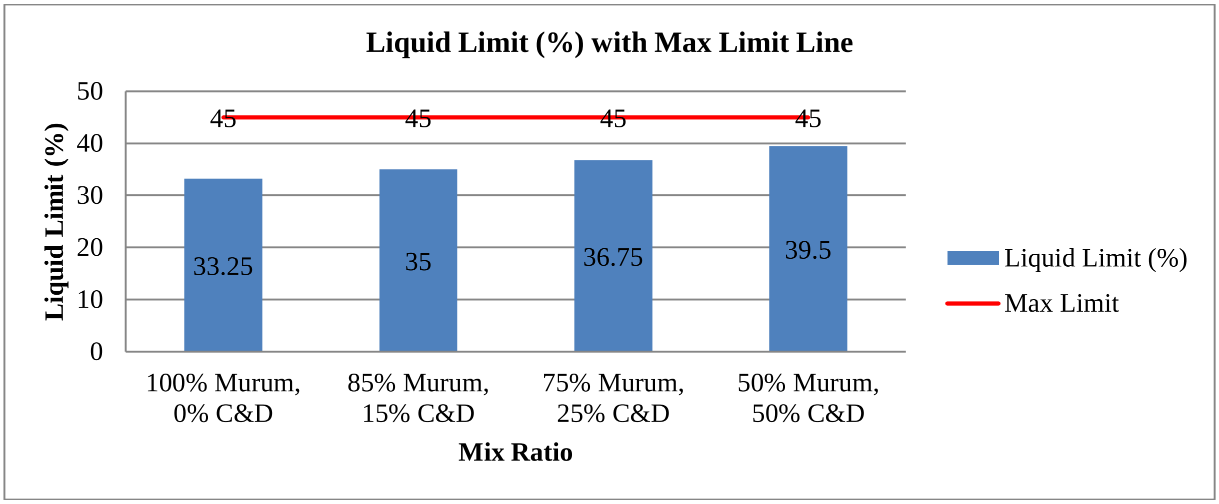

Fig. 6 Test result of liquid limit (Source- Author)

4.3.2. Free Swell Index (%)

Figure 7, described as the 'Free Swell Index,' shows its maximum value (10.00) at 50% Murum and 50% C and D waste, and its minimum value (0.00) at 100% Murum and 0% C and D waste. The rise in free swell index with the rise in C&D waste content indicates the presence of a higher percentage of fines and clay-like particles in the mixture. These particles tend to absorb water and expand under wet conditions, which results in the higher swelling potential. However, the observed values still lie at a relatively low level, suggesting the swelling behavior is still at an acceptable level for pavement applications.

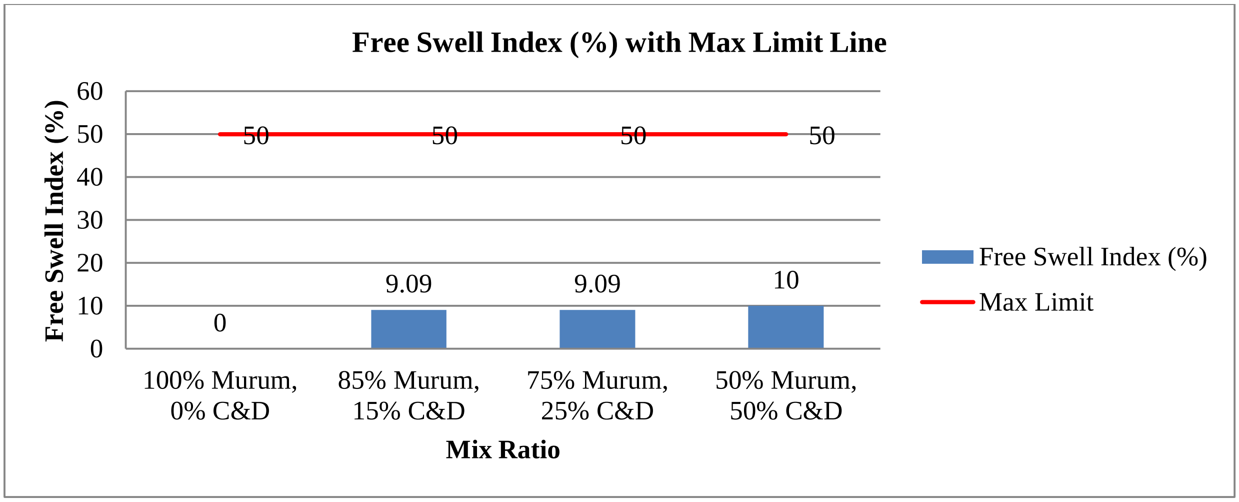

Fig. 7 Test result of free swell index (Source- Author)

4.4. Strength Characteristics

4.4.1. Soaked CBR (%)

Figure 8 tells about the parameter 'Soaked CBR (%, showing its maximum value (35.23) at 100% Murum and 0% C and D waste, and its minimum value (25.53) at 50% Murum and 50% C and D waste. The soaked CBR values are found to decrease with increasing C&D waste content as a result of a reduction in the inter-particle friction and aggregate interlocking due to the presence of weaker recycled particles. The reduction in gravel fraction and increase in finer particles are also responsible for the reduction in bearing capacity. Nevertheless, even when replaced by 50%, the R values remained above the minimum specified Limit of 20% required as per IRC and MoRTH for sub-base layers, which implies that the material can be used in low-volume road construction.

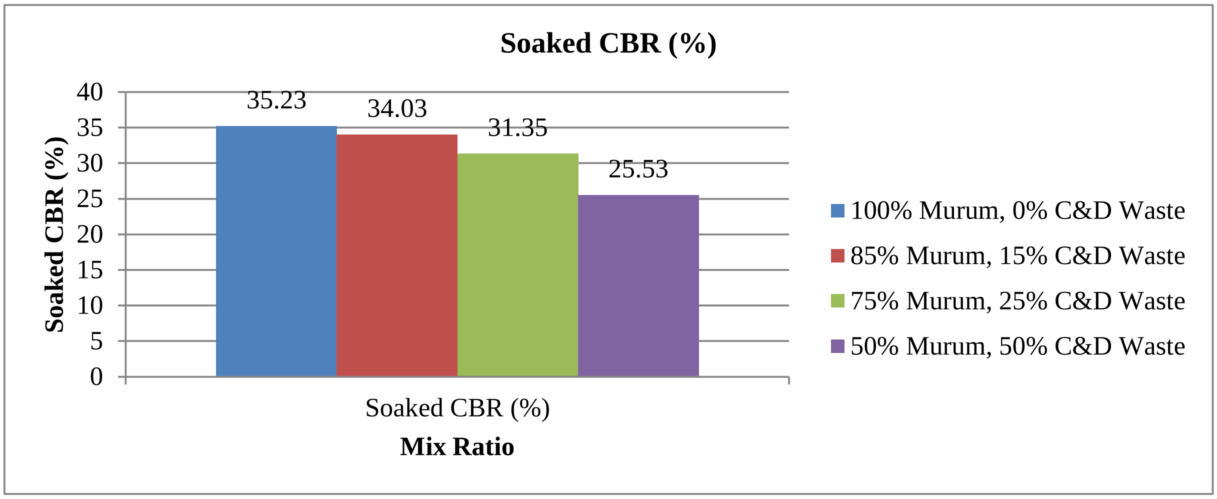

Fig. 8 Test result of soaked CBR (Source- Author)

4.5. Key Findings

1) Specific gravity declines by a small value with an increase in C and DW content (2.66 - 2.62). Nevertheless, it is still suitably applicable in the subgrade/sub-base.
2) MDD declines (1.99 - 1.87 g/cc), and OMC rises (11.5 - 14%). This means more water is required for compaction, typical of recycled materials.
3) Liquid Limit increases with C and D W content (33.25% → 39.5%), suggesting higher fines and lower stability in higher blends.
4) Free Swell Index increases up to 10% for 50% C and D W, which indicates potential swelling problems in wet conditions.
5) Soaked CBR decreases significantly (35.23% → 25.53%) with more C and DW. According to IRC ("Indian Road Congress") and MoRTH ("Ministry of Road and Transport and Highways") guidelines, a soaked CBR above 20% is still acceptable for sub-base layers but not enough for high-strength base courses.
6) The fraction of gravel decreases (51.3% - 37.9%) with increased C and DW, undermining the interlock of aggregates.

4.6. Assessment of Suitability

1) 100% Murum (CBR ~ 35%) → Suitable for rural roads (low to medium traffic) as subgrade or sub-base without stabilization.
2) 85% Murum + 15% C and DW (CBR ~ 34%) → Acceptable for low-traffic bituminous surfaced roads (village or district roads) as sub-base.
3) 75% Murum + 25% C and DW (CBR ~ 31%) → Suitable for low-volume rural roads, farm roads, and light-traffic unpaved roads. It could also be used in cement-stabilized sub-bases for higher categories.
4) 50% Murum + 50% C and DW (CBR ~ 25.5%) → Borderline for subgrade layers in rural or temporary access roads. Needs stabilization (lime/cement/geogrid) for durability in higher-traffic applications.

5. Optimization and Statistical Analysis

Descriptive Statistics ▼

Descriptive Statistics ▼

	CDW_%	MDD	OMC	Specific_Gravity	FSI
Valid	4	4	4	4	4
Missing	0	0	0	0	0
Mean	22.50	1.935	12.50	2.643	7.045
Std. Deviation	21.02	0.050	1.080	0.017	4.716
Minimum	0.000	1.870	11.50	2.620	0.000
Maximum	50.00	1.990	14.00	2.660	10.00

Fig. 9 Descriptive statistics

JASP software evaluates the variability and consistency of the experimental data obtained from various proportions of C&D waste through statistical analysis.

Descriptive statistical analysis was performed to assess the variability of key engineering properties with varying C&D waste content. The results in Figure 9 show that the mean value of the MDD is 1.935 g/cc with a low standard deviation, which is 0.050, indicating high consistency. The OMC had a mean of 12.50% with moderate variation (SD = 1.08). Specific gravity was very consistent with a mean of 2.643 and a low range (SD = 0.017). Conversely, the Free Swell Index (FSI) was found to have greater variation (mean = 7.045, SD = 4.716), primarily due to the increase in fine content, which was associated with higher proportions of C&D waste. In general, the results indicate acceptable experimental reliability and consistency across all parameters. Overall, the low standard deviation observed for density and specific gravity confirms the uniformity of material preparation and testing procedures.

5.1. Regression Analysis

Linear Regression

Model Summary - CBR_%

Model	R	R^2	Adjusted R^2	RMSE
M_0	0.000	0.000	0.000	4.319
M_1	0.982	0.964	0.947	0.997

Note. M_1 includes CDW_%

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
M_1	Regression	53.985	1	53.985	54.32	.018
	Residual	1.988	2	0.994		
	Total	55.972	3			

Note. M_1 includes CDW_%
Note. The intercept model is omitted, as no meaningful information can be shown.

Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p	95% CI Lower	95% CI Upper
M_0	(Intercept)	31.535	2.160		14.601	< .001	24.662	38.408
M_1	(Intercept)	36.077	0.793		45.517	< .001	32.666	39.487
	CDW_%	−0.202	0.027	−0.982	−7.370	.018	−0.320	−0.084

Fig. 10 Linear regression analysis

JASP software was utilized for linear regression analysis to determine the relationship between C&D waste content and soaked CBR values. Figure 10 shows that the regression model has a strong coefficient of determination ($R^2 = 0.964$), indicating that the percentage of C&D waste explains 96.4 percent of the variation in CBR. A regression model was found to be significant ($p = 0.018 < 0.05$). The derived regression Equation (1) is:

$$CBR = 36.077 - 0.202(CDW\%) \quad (1)$$

Since the 95% confidence interval (–0.320 to –0.084) did not cross zero, the regression model was considered statistically significant and reliable. The negative coefficient reflects that the strength decreases with increasing C&D waste content.

6. Sustainability Assessment

The Sustainability of utilizing C&D waste as a partial substitution for Murum soil was assessed based on experimental performance, particularly soaked CBR values, and the extent of natural material substitution. The assessment focuses on identifying an optimum replacement level that balances engineering performance with environmental benefits as follows.

1) 100% Murum → High use of natural resources without the use of waste; environmentally unsustainable, although with high CBR (~35%).
2) 85% Murum + 15% C&DW → Optimal sustainable mix; negligible decrease in CBR (~34 percent) with significant decrease in the usage of natural materials; can be used in practice.
3) 75% Murum + 25% C&DW → More waste utilization with moderate reduction in CBR (~31%); acceptable with low-volume roads with a sustainability benefit.
4) 50% Murum + 50% C&DW → 50% waste utilization but a substantial decrease in CBR (~25.5%); it needs to be stabilized to be used in long-term performance.

7. Economic Feasibility

The case study of economic and implementation feasibility of using C&D waste was conducted on the basis of a case study of D.P. road development at Mundwa, Pune, a location with a base project cost of 11.44 crore using conventional materials. The cost estimation included major pavement components such as earthwork (63,151.2 m^3 at ₹1,189/m^3 = ₹75,086,776.80), granular sub-base (6,902.52 m^3 and 6,827.52 m^3 at ₹2,667/m^3 = ₹18,409,020.84 and ₹18,208,995.84), and wet mix macadam (1,014.26 m^3 at ₹2,690/m^3 = ₹2,728,359.40), calculated as per SSR (2023–2024) rates. This unit cost analysis indicates that processed C&D waste, including collection, handling, and transportation, costs approximately 693/m^3, which is very low compared to the conventional Murum (1189/m^3). When these quantities are replaced item-by-item, the total project cost will decrease gradually, achieving a savings of about 90.70 lakh

(7.93%), 151.13 lakh (13.20%), and 302.44 lakh (26.42%) at 15% replacement, 25% replacement, and 50% replacement, respectively, which demonstrates significant economic benefits. Analysis of transport cost shows in Figure 11 that C&D waste can be economical until around 75 km (one-way). The maximum allowable transportation cost was therefore calculated as ₹894/m³ (₹1,189 − ₹295), beyond which the use of C&D waste becomes uneconomical. With a transport cost rate of approximately ₹11.67/m³/km, the feasible transportation distance is estimated to be around 75 km, confirming the practical applicability of C&D waste in urban and peri-urban road projects.

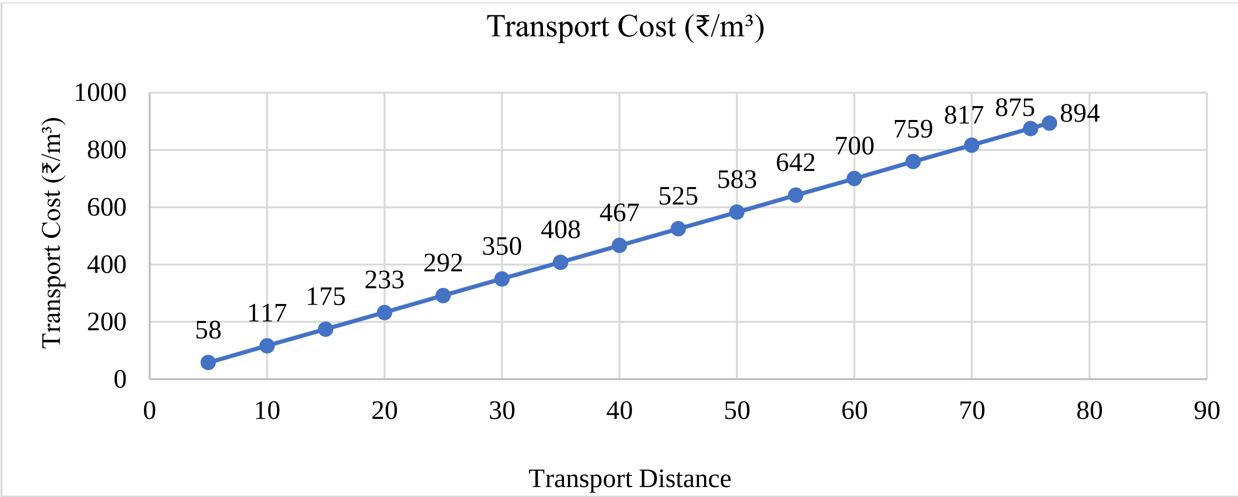

Fig. 11 Distance calculation

However, engineering analysis has demonstrated that untreated C&D waste fails to meet the strength requirement of base layers. To overcome this drawback, WMM layer 2% lime stabilization was added, which reduces the effective material cost to about ₹945/m³, but only leads to a small increase in the overall project cost (less than 0.2, i.e., ₹38,000-1.27 lakh). Therefore, while maximum cost savings can be achieved by increasing the replacement levels of Murum with C&D waste, a comprehensive evaluation of cost, strength, and implementation feasibility will show that replacing 15-25 percent of Murum with C&D waste is the most practical and balanced solution for creating sustainable pavements.

8. Field Performance and Durability

The field performance of C&D waste-based mixes was assessed in terms of the strength characteristics derived in laboratory environments and their expected behavior in field conditions. The results show that mixes of 15–25% C&D waste replacement, which have soaked CBR values in the range between 31 and 34%, are suitable in subgrade and subbase applications for low- to medium-traffic roads as per IRC guidelines. Such mixes should have acceptable load distribution and be able to resist deformation under normal service conditions. Nevertheless, at higher replacement levels (50% C&D waste, CBR = 25.5%), a more pronounced decrease in strength is observed, and this might result in greater deformation and shorter service life when subjected to repeated loading of traffic. C&D waste can also be more likely to become degraded and vulnerable to moisture penetration when cycling wet and dry due to porous materials, such as brick and mortar waste.

Durability-wise, untreated C&D waste mixes can be used in the lower layer of pavement, but to achieve better performance in the long term, particularly in base layers, stabilization methods like lime treatment should be used. The addition of 2% lime helps increase inter-particle bonding and reduces the sensitivity to moisture, thus improving rutting and structural deterioration resistance. Environmentally, the leaching potential of the processed C&D waste is low, since it is mainly composed of inert materials, which include concrete, brick, and mortar. These materials normally have no harmful contaminants, as per the normal field conditions. Nevertheless, a slight alkalinity can be measured because of the existence of cementitious compounds. Past investigations have indicated that, properly processed and utilized as part of the pavement layers, there is no significant threat in terms of contamination of groundwater or toxicity of the leachate. Its regulated application, therefore, as a subgrade and subbase layer, is deemed environmentally friendly.

In general, the research has shown that the level of controlled use of C&D waste, especially between 15 and 25% substitution, provides sufficient field performance and durability and does not compromise the structural integrity and serviceability of the pavement systems.

9. Advanced Material Characterization

Advanced techniques of characterizing materials can be further used to understand the performance of C&D waste-Murum mixes, but these analyses were not carried out in the present study. The implicated decrease in strength with the augmentation of C&D waste material can be ascribed to the heterogeneity of the recycled materials, especially the presence of porous particles of the brick and the fractions of mortar that are relatively weak. In stabilized systems, especially those stabilized with the addition of lime, advanced characterization can provide insight into pozzolanic activity, the development of cementitious products, and the enhancement of microstructural density. These studies would facilitate the explanation of the strength and durability improvement in treated mixes. Thus, future research should focus on sophisticated characterization of materials used in C&D waste-based pavement materials to ensure an explicit relationship exists between microstructural behavior and macroscopic engineering performance as pavement materials.

10. Limitation and Future Scope

The present work determines the technical and economic viability of using C&D waste as a partial substitute for Murum in pavement applications, although there are some limitations. The experimental testing is limited to laboratory-scale testing, and field testing can be different based on the construction practice, exposure to the environment, and the loading conditions. The C&D waste composition, specifically the percentage of fractions of bricks, concrete, and mortar, may also be a factor that affects the consistency of engineering properties. Moreover, the characterization of material in an advanced manner was not done, which restricted the knowledge of microstructural behavior and long-term performance mechanisms.

Further studies are required in terms of full-scale field tests to confirm the laboratory results in real traffic and environmental conditions. Wetting-drying cycles, freeze-thaw resistance, and rutting service life are long-term durability studies that are recommended to determine service life. To improve the performance of higher replacement levels, further study is needed into stabilization controls, lime, cement, and geosynthetics. Some of the advanced methods of characterization that would be used to determine the relationship between the material composition and the engineering behavior include SEM, XRD, and chemical analysis. Also, it is possible to conduct a Life-Cycle Cost Analysis (LCCA) and Environmental Impact Assessment (EIA) to obtain a more detailed evaluation of Sustainability. The study provides a solid foundation for the practical application of C&D waste in pavement construction. Future work can help to improve its applicability in the development of large-scale infrastructure.

11. Conclusion

The results of the experimental study indicated that the addition of Construction and Demolition (C&D) waste considerably altered the engineering properties of the Murum soil mixtures. Specific gravity and maximum dry density would decrease as the percentage of C and DW was increased, while optimum moisture content, liquid Limit, and free swell index were increasing with an increased percentage of C and DW. The soaked CBR values decreased from 35.23% for pure Murum to 25.53% for the mixture containing 50% C&D waste, indicating a gradual reduction in bearing capacity with higher replacement levels. However, the CBR levels of all the mixture combinations were found to be more than 20%, as fixed by the IRC and MoRTH for the subbase course, which proved technically feasible for pavement construction. The 15–25% C&D blend was the most ideal according to the strengths, compaction characteristics, and sustainability aspects when compared with the various mixes tested. As high as 50 percent of C and DW content is still possible to be used in rural roads or provisional low-travel roads, but would require stabilization with some binder such as cement, lime, or even geosynthetics to ensure the durability and strength of the road.

The study also confirms that the integration of C&D waste is not only technically viable but also cost-effective in real-life scenarios. A case study of cost analysis shows that the total project cost is gradually decreasing, achieving savings of about 7.93, 13.20, and 26.42 percent at 15 percent, 25 percent, and 50 percent replacement levels, respectively, confirming that material substitution is indeed economically viable. The cost-effectiveness of the large-scale implementation is supported by the findings from the transportation analysis, which shows that CD waste turns out to be cost-effective for the maximum transportation distance of around 75 km with an allowable transportation remuneration of ₹894/m³ (derived from the relative comparison of prices of materials). In the performance enhancement aspect, the mixing of 2% lime stabilization into the base layer improves strength characteristics and durability while resulting in a negligible increase in overall project cost (<0.2%). This study shows that stabilization would allow the good use of the increased C&D waste contents without affecting structural performance. Moreover, the regression equation ($R^2 = 0.964$, $p = 0.05$) offers a statistically sound predictive relationship between the C&D waste content and the CBR and is an efficient tool at the field level to optimize mix design based on the C&D waste content.

Statements and Declarations

Funding

No Funding Support

Conflict of Interests

Both Authors do not have financial interests.

Author Contributions

Both authors participated in the development and execution of the study. Material preparation, data collection, and data analysis were largely the responsibilities of SSG. The manuscript was originally written by SSG, and then RHJ did the proofreading and review—final manuscript accepted by all authors.

References

[1] Selma Bellara et al., "Mineral Waste Valorization in Road Subgrade Construction: Algerian Case Study based on Technical and Environmental Features," *Case Studies in Construction Materials*, vol. 20, pp. 1-19, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[2] Yassine Abriak et al., "Valorization of Dredged Sediments and Recycled Concrete Aggregates in Road Subgrade Construction," *Buildings*, vol. 13, no. 3, pp. 1-15, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[3] Giuseppe Bonifazi et al., "Current Trends and Challenges in Construction and Demolition Waste Recycling," *Current Opinion in Green and Sustainable Chemistry*, vol. 53, pp. 1-9, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[4] Vikas Sing et al, "Selection of Suitable Techniques, Scope And Regulations For Demolition of RCC Building," *International Journal for Research in Engineering Application & Management*, Special Issue – ICRTET, pp. 870-874, 2018. [Google Scholar] [Publisher Link]

[5] Gina Cynthia Raphita Hasibuan et al., "Integrating Circular Economy into Construction and Demolition Waste Management: A Bibliometric Review of Sustainable Engineering Practices in the Built Environment," *Case Studies in Chemical and Environmental Engineering*, vol. 11, pp. 1-24, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[6] Mohan Badiger, K.H. Mamatha, and S.V. Dinesh, "Laboratory Study on the Performance Evaluation of RCA Reinforced with Geosynthetics for GSB Layer Application in Low Volume Roads," *Sustainable Materials and Technologies*, vol. 44, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[7] Xiaopei Duan et al., "Evaluation of Road Performance and Carbon Emission Accounting Analysis of Recycled Aggregates from Construction and Demolition Waste," *Scientific Reports*, vol. 15, pp. 1-20, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[8] Aadil Jawaid et al., "Study of Concrete Properties by Replacing Natural Sand with Artificial Sand," *International Journal of Engineering Research & Technology*, vol. 8, no. 6, pp. 1229-1233, 2019. [Google Scholar] [Publisher Link]

[9] Bartosz Zegardło et al., "Analysis of the Effects of Aggressive Environments Simulating Municipal Sewage on Recycled Concretes Based on Selected Ceramic Waste," *Materials*, vol. 11, no. 12, pp. 1-22, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[10] Vsevolod Mymrin et al., "Utilization of Sediments Dredged from Marine Ports as a Principal Component of Composite Material," *Journal of Cleaner Production*, vol. 142, pp. 4041-4049, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[11] Mohammad Almokdad, and Rachid Zentar, "Characterization of Recycled Dredged Sediments: Toward Circular Economy in Road Construction," *Construction and Building Materials*, vol. 402, pp. 1-32, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[12] Gholamhosein Tavakoli Mehrjardi et al., "Evaluating and Improving the Construction and Demolition Waste Technical Properties to use in Road Construction," *Transportation Geotechnics*, vol. 23, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[13] Yingjie Yuan et al., "Study on Mechanical Properties of Road Cement-Stabilized Macadam Base Material Prepared with Construction Waste Recycled Aggregate," *Buildings*, vol. 14, no. 9, pp. 1-14, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[14] Ermao Zhang et al., "Mechanical Properties, Durability and Leaching Toxicity of Cement-Stabilized Macadam Incorporating Reclaimed Clay Bricks as Fine Aggregate," *Sustainability*, vol. 14, no. 14, pp. 1-18, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] Cesar Hidalgo et al., "Ground Improvement by Construction and Demolition Waste (CDW) Soil Mixture Replacement," *Buildings*, vol. 13, no. 3, pp. 1-18, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[16] Xiao Zhi et al., "Experimental Study on the Mechanical Properties and Permeability of Cement-Stabilized Permeable Recycle Aggregate Materials," *Sustainability*, vol. 15, no. 19, pp. 2023. [CrossRef] [Google Scholar] [Publisher Link]

[17] Helena Lunkes Strieder et al., "Mechanical Behavior of Construction and Demolition Waste as Pavement Materials: Influence of Mix Composition and Compaction Conditions," *Construction and Building Materials*, vol. 408, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[18] Cheng Lu et al., "Resilient and Permanent Deformation Behaviors of Construction and Demolition Wastes in Unbound Pavement base and Subbase Applications," *Transportation Geotechnics*, vol. 28, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[19] Jin Yi et al., "Laboratory Evaluation and Design of Construction and Demolition Wastes for Granular Base," *Advances in Civil Engineering*, vol. 2020, pp. 1-10, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[20] Fabiana da Conceição Leite et al., "Laboratory Evaluation of Recycled Construction and Demolition Waste for Pavements," *Construction and Building Materials*, vol. 25, no. 6, pp. 2972-2979, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[21] Brahim Arhoun et al., "Investigating the Physical and Chemical Characteristics of Construction and Demolition Wastes as Filler to Regenerate Beaches," *Resources, Conservation and Recycling*, vol. 179, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[22] Mohit Nandal et al., "Morphological and Physical Characterization of Construction and Demolition Waste," *Materials Today: Proceedings*, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[23] Anant Saini, Himanshu Soni, and Jitendra Singh Yadav, "Utilization of Recycled Construction and Demolition Waste to Improve the Bearing Capacity of Loose Sand: An Integrated Experimental and Numerical Study," *Geomechanics and Geoengineering*, vol. 19, no. 4, pp. 444-461, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[24] Pablo Saiz Martínez et al., “Characterization of Three Types of Recycled Aggregates from Different Construction and Demolition Waste: An Experimental Study for Waste Management,” *International Journal of Environmental Research and Public Health*, vol. 20, no. 4, pp. 1-19, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[25] J.R. Jiménez et al., A Comparative Study of Recycled Aggregates from Concrete and Mixed Debris as Material for Unbound Road Sub-base,” *Building Materials*, vol. 61, no. 302, pp. 289-302, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[26] A. Arulrajah et al., “Geotechnical Properties of Waste Excavation Rock in Pavement Subbase Applications,” *Journal of Materials in Civil Engineering*, vol. 24, no. 7, pp. 1-37, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[27] A. Barbudo et al., “Statistical Analysis of Recycled Aggregates Derived from Different Sources for Sub-base Applications,” *Construction and Building Materials*, vol. 28, no. 1, pp. 129-138, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[28] José Ramón Jiménez et al., “Utilisation of Unbound Recycled Aggregates from Selected CDW in Unpaved Rural Roads,” *Resources, Conservation and Recycling*, vol. 58, pp. 88-97, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[29] A. R. Gabr, and D. A. Cameron, “Properties of Recycled Concrete Aggregate for Unbound Pavement Construction,” *Journal of Materials in Civil Engineering*, vol. 24, no. 6, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[30] G. Dondiet al., *Performance Evaluation of Construction and Demolition and other Waste Materials*, Sustainability, Eco-Efficiency and Conservation in Transportation Infrastructure Asset Management, CRC Press, pp. 223-233, 2014. [Google Scholar] [Publisher Link]

[31] M. A. Rahman et al., “Resilient Modulus and Permanent Deformation Responses of Geogrid-Reinforced Construction and Demolition Materials,” *Journal of Materials in Civil Engineering*, vol. 26, no. 3, pp. 1-45, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[32] Ali Arisha et al., “Using Blends of Construction & Demolition Waste Materials and Recycled Clay Masonry Brick in Pavement,” *Procedia Engineering*, vol. 143, pp. 1317-1324, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[33] Seyed Hasan Morafa et al., “An Experimental Investigation on Applying the Recycled Aggregates Obtained from Oil Contaminated Concrete Exposed to Seawater as Road Unbound Pavement Materials,” *Construction and Building Materials*, vol. 157, pp. 292-299, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[34] Javier Tavira et al., “Functional and Structural Parameters of a Paved Road Section Constructed with Mixed Recycled Aggregates from Non-selected Construction and Demolition Waste with Excavation Soil,” *Construction and Building Materials*, vol. 164, pp. 57-69, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[35] M.J. Martinez-Echevarria et al., “Crushing Treatment on Recycled Aggregates to Improve their Mechanical Behaviour for use in Unbound Road Layers,” *Construction and Building Materials*, vol. 263, pp. 1-23, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[36] Theerapruet Poltue et al., “Strength Development of Recycled Concrete Aggregate Stabilized with Fly Ash-rice Husk Ash based Geopolymer as Pavement Base Material,” *Road Materials and Pavement Design*, vol. 21, no. 8, pp. 2344-2355, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[37] Mohammad Javad Kalantar Hormozi et al., “Feasibility of Using Recycled Combined Construction and Demolition Waste for Road Base and Subbase in Fooladshahr, Isfahan Province, Iran: A Case Study,” *Journal of Transportation Engineering, Part B: Pavements*, vol. 147, no. 2, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[38] Ekrem Burak Toka, and Murat Olgun, “Performance of Granular Road Base and Sub-base Layers Containing Recycled Concrete Aggregate in Different Ratios,” *International Journal of Pavement Engineering*, vol. 23, no. 11, pp. 3729-3742, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[39] Trong Lam Nguyen et al., “Mechanical and Hydraulic Properties of Recycled Concrete Aggregates Mixed with Clay Brick Aggregates and Particle Breakage Characteristics for Unbound Road Base and Subbase Materials in Vietnam,” *Sustainability*, vol. 14, no. 8, pp. 1-21, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[40] Arul Arulrajah et al., “Effect of Moisture Sensitivity on the Light Stabilisation of Demolition Materials in Pavement Bases,” *Road Materials and Pavement Design*, vol. 23, no. 4, pp. 787-801, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[41] Tung Doan et al., “Chemical Stabilization of Demolition Wastes in Pavement Bases using One–part Fly Ash and Slag Based Geopolymers,” *Transportation Geotechnics*, vol. 45, pp. 1-17, 2024. [CrossRef] [Google Scholar] [Publisher Link]