Performance Study on Strength and CBR Characteristics of Flexible Pavement Layers Stabilized with Crusher Dust and Waste Tyre Materials

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Abstract - The increasing demand for cost-effective and sustainable pavement construction has led to the exploration of alternative materials capable of improving structural performance while reducing environmental impact. This study investigates the applicability of crusher dust (CD) and waste tyre derivatives—ground granulated waste tyre (GGWT) and crumb rubber waste tyre (CRWT)—for use in various layers of flexible pavements. Crusher dust was segregated into three particle size ranges (coarse: 4.75–2 mm, medium: 2–0.425 mm, and fine: 0.425–0.075 mm), and a total of 194 gradation mixes were prepared to evaluate their compaction and California Bearing Ratio (CBR) characteristics. Experimental results showed that single-sized mixes yielded CBR values between 8–11%, two-sized mixes between 10–10.5%, and well-graded mixes between 13–15%. Field samples collected from North Coastal Andhra Pradesh exhibited an error range of –8.33% to 18.18%, validating laboratory findings. For sub-base and base course investigations, MoRT&H specifications were adopted. Optimum gradation using 26.5 mm aggregate with 40% crusher dust resulted in CBR values of 48–68%. Further improvement was observed with the inclusion of GGWT (0.5–3%), which elevated CBR values to 48–82%, with optimum performance at 1.5–2%. Additionally, MoRT&H granular base gradations (GB12–GB13) achieved CBR values of 128–138%, indicating suitability for high-strength base applications. CRWT-modified base mixes demonstrated enhanced toughness and resilience at varying particle sizes (10 mm, 20 mm, 30 mm). The study concludes that the combined use of crusher dust and waste tyre derivatives enhances strength, durability, and cost efficiency of flexible pavement layers, establishing their suitability as sustainable alternatives in pavement construction.

Key Words: Crusher Dust (CD), Ground Granulated Waste Tyre (GGWT), Crumb Rubber Waste Tyre (CRWT), California Bearing Ratio (CBR), Flexible Pavement, Sub-grade, Sub-base, Base Course, MoRT&H Specifications, Sustainable Pavement Materials.

1. INTRODUCTION

Transportation infrastructure plays a pivotal role in the economic growth and connectivity of developing nations. In India, road transport contributes nearly 4.7% to the national GDP and facilitates over 65% of freight movement and 85% of passenger transportation. With a total road network of approximately 4.69 million kilometers, India possesses one of the largest and most diverse roadway systems in the world. Despite this vast network, the increasing demand for durable, cost-effective, and sustainable pavement construction continues to pose significant engineering challenges.

Flexible pavements form the majority of roadway infrastructure in the country due to their lower initial cost, ease of construction, and maintenance advantages. A typical flexible pavement structure consists of a wearing course, base course, sub-base, and sub-grade. The performance and serviceability of these layers are governed by material characteristics such as gradation, plasticity, compaction, and load-bearing capacity. Failures in flexible pavements frequently originate in the sub-grade or unbound granular layers, where inadequate strength, high plasticity, and moisture susceptibility may lead to rutting, settlement, and shear deformation.

Conventional pavement materials—soil, aggregates, and bitumen—are increasingly becoming scarce due to rapid urbanization, large-scale infrastructure projects, and environmental restrictions on quarrying. The depletion of natural materials, combined with rising construction costs, necessitates the adoption of alternative materials derived from industrial by-products. Among these, crusher dust, ground granulated waste tyre (GGWT), and crumb rubber waste tyre (CRWT) have emerged as sustainable, cost-effective, and mechanically advantageous substitutes for granular layers in flexible pavements.

Crusher dust (CD), a by-product of stone crushing operations, is abundantly available and exhibits favorable engineering characteristics such as non-plasticity, high shear strength, and good drainage. Similarly, waste tyre materials, which pose a major environmental disposal challenge, possess elastic and energy-absorbing properties that can improve pavement performance when used in appropriate proportions. Their utilization not only promotes sustainable engineering practices but also mitigates the growing problem of tyre disposal.

Given these considerations, the present study investigates the feasibility of incorporating crusher dust and waste tyre derivatives across various layers of flexible pavements. The research focuses on material characterization, compaction behavior, California Bearing Ratio (CBR), and compliance with MoRTH and IRC specifications. The goal is to develop optimized gradation mixes that enhance strength, durability, and overall structural efficiency while reducing dependence on natural resources.

1.1 OBJECTIVES OF THE STUDY

- To investigate the feasibility of using crusher dust as a complete replacement for natural soil in sub-grade applications, through detailed analysis of its gradation, compaction characteristics, and California Bearing Ratio (CBR).
- To examine the performance of crusher dust and ground granulated waste tyre (GGWT) blends as sub-base materials, particularly for particle sizes passing 4.75 mm, and to determine their optimum mix proportions.
- To evaluate the suitability of crushed stone aggregates (26.5 mm–4.75 mm) mixed with crusher dust and GGWT for sub-base applications, considering strength, stability, and compliance with MoRTH gradation requirements.
- To assess the effectiveness of crushed stone (75 mm–4.75 mm) and crusher dust combinations reinforced with crumb rubber waste tyre (CRWT) of varying sizes (10 mm, 20 mm, 30 mm) as base course materials, and to identify the optimal reinforcement ratios.

2. SUMMARY OF LITERATURE REVIEW

The review of existing research highlights significant progress in the utilization of industrial waste materials—particularly crusher dust (CD), ground granulated waste tyre (GGWT), and crumb rubber waste tyre (CRWT)—for enhancing the performance of flexible pavement layers.

Studies on crusher dust consistently demonstrate its ability to improve compaction characteristics, increase maximum dry density, decrease optimum moisture content, and enhance California Bearing Ratio (CBR) when mixed with weak or expansive soils. Research confirms that well-graded crusher dust offers superior interlocking, higher shear strength, and good drainage properties, making it a viable substitute for natural sand and an effective stabilizer for sub-grade and sub-base layers.

Investigations on GGWT indicate that tyre-derived granules provide beneficial elastic, compressive, and energy-absorbing characteristics. When blended with granular materials, GGWT improves load distribution, shear strength, settlement resistance, and CBR values, particularly at optimum contents between 1.5% and 3%. This makes GGWT a promising additive for sub-base and embankment applications.

Studies on CRWT demonstrate its effectiveness in enhancing the toughness, flexibility, and fatigue life of pavement base layers. Incorporation of crumb rubber increases CBR, reduces deformation, and offers better stress absorption under repeated traffic loading. Optimum performance is generally observed at low to moderate rubber contents (1–4%), while excessive rubber reduces density and stiffness.

Across the reviewed literature, researchers consistently emphasize the environmental and economic benefits of reusing industrial waste materials in pavement construction. However, gaps still exist regarding long-term performance, standardized mix design procedures, and combined application of multiple waste materials across all pavement layers.

Overall, the literature confirms that crusher dust, GGWT, and CRWT possess substantial potential as sustainable alternatives for sub-grade, sub-base, and base course applications, providing improved strength, durability, and eco-friendly material utilization.

3. METHODOLOGY

The methodology adopted in this study involves systematic laboratory evaluation of crusher dust (CD), ground granulated waste tyre (GGWT), and crumb rubber waste tyre (CRWT) for their applicability in flexible pavement layers. The approach consists of material collection, characterization, mix preparation, and performance assessment in accordance with IS, IRC, and MoRTH specifications.

A. Research Framework

The overall research process consists of the following stages:

1. **Collection of Materials:**
   - Crusher dust from stone crushing units of Guntur and Vijayawada, Andhra Pradesh.
   - Aggregates from local quarries.
   - GGWT and CRWT from tyre retreading industries in Guntur.
   - Bitumen (80/100 grade) from HPCL.
2. **Material Characterization:**

   Physical, index, and engineering properties of the materials were determined through sieve analysis, specific gravity tests, compaction tests, Atterberg limits (where applicable), aggregate impact value, crushing value, abrasion value, and Los Angeles abrasion tests.
3. **Preparation of Gradation Mixes:**
   - 194 different gradation combinations of crusher dust (fine, medium, and coarse fractions) were prepared.
   - Sub-base and base course mixes were designed as per MoRTH gradation tables (GSB and WMM specifications).
   - GGWT and CRWT were added at varying proportions (0.5–3% for GGWT and 10–30 mm sized CRWT).
4. **Performance Testing:**
   - Modified Proctor compaction tests were conducted to determine Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).
   - California Bearing Ratio (CBR) tests were performed under soaked conditions to evaluate load-bearing capacity.
5. **Validation of Laboratory Results:**
   - Ten field samples from North Coastal Andhra Pradesh were evaluated.
   - Their gradation and CBR values were compared with laboratory-predicted triangular CBR charts to assess accuracy.
6. **Identification of Optimum Mixes:**

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Based on CBR performance, stiffness, gradation conformity, and engineering behavior, the most suitable mixes for sub-grade, sub-base, and base layers were identified.

Table 1—Materials Used in the Study

Material	Source	Purpose
Crusher Dust (CD)	Guntur & Vijayawada stone crushers	Sub-grade, Sub-base, Base
Aggregates	Local quarry, Vijayawada	Sub-base & Base course
GGWT	Tyre retreading industries, Guntur	Sub-base reinforcement
CRWT (10, 20, 30 mm)	Tyre retreading industries, Guntur	Base course reinforcement
Bitumen (80/100)	HPCL, Guntur	Reference for conventional properties

B. Flow of Research Work

The experimental work followed the sequential approach:

1. Material Collection
2. Material Characterization
3. Gradation Mix Preparation
4. Compaction Testing
5. CBR Testing
6. Validation with Field Samples
7. Identification of Optimum Pavement Layer Mixes

C. Grain Size Distribution

Sieve analysis was carried out per IS: 2720 (Part IV). Coarse, medium and fine fractions of crusher dust were separated.

Table 2—Sieve Size Range for CD Fractions

Fraction	Size Range (mm)
Coarse CD	4.75 – 2.0
Medium CD	2.0 – 0.425
Fine CD	0.425 – 0.075

D. Laboratory Tests Conducted

Table 3—Tests Conducted and Standards Followed

Property/Parameter	Test	IS Code
Grain size	Sieve analysis	IS 2720 (Part IV)
Liquid limit	Cone Penetration	IS 2720 (Part V)
Specific gravity	Density bottle / pycnometer	IS 2720 (Part III)
Compaction	Modified Proctor	IS 2720 (Part VIII)
CBR	Soaked CBR	IS 2720 (Part XVI)
Aggregate crushing	ACV	IS 2386 (Part IV)
Aggregate impact	AIV	IS 2386 (Part IV)
Abrasion	Los Angeles	IS 2386 (Part IV)
Shape	Flakiness & Elongation	IS 2386 (Part I)
Bitumen properties	Penetration, Softening, Ductility	IS 1203–1208
Bituminous mix	Marshall Stability	MoRTH / Asphalt Institute

E. Mix Preparation

A total of **194 mixes** were prepared by varying CD fractions.

Table 4—Types of Mixes Prepared

Mix Type	Composition
Type A	Single-size CD fractions
Type B	Two-size CD blends
Type C	Three-size well-graded CD blends
Type D	CD + Stone aggregates (Sub-base)
Type E	CD + GGWT (0.5–3%)
Type F	Stone + CD + GGWT (GB11–GB15)
Type G	Stone + CD + CRWT (10, 20, 30 mm)

4. EXPERIMENTAL INVESTIGATION

This section presents the laboratory procedures followed to evaluate the industrial waste materials and their blended mixes for potential application in pavement construction.

A. Sieve Analysis

Sieve analysis was conducted as per IS: 2720 (Part IV) to determine particle size distribution of CD, aggregates, GGWT, and CRWT. Both wet and dry analyses were performed, enabling determination of D10, D30, D60, Coefficient of Uniformity (Cu), and Coefficient of Curvature (Cc).

B. Plasticity Characteristics

Liquid limit tests were conducted using the cone penetration method (IS: 2720 Part V). As the selected waste materials were non-plastic, plasticity index determination was not required.

C. Specific Gravity

Specific gravity tests were conducted using:

- Density bottle (IS: 2720 Part III-1) for fine fractions,
- Pycnometer (IS: 2720 Part III-2) for coarse fractions, and
- IS: 2386 (Part III) for aggregates.

D. Compaction Characteristics

Modified Proctor compaction tests (IS: 2720 Part VIII) were conducted using a 4.89 kg rammer. OMC and MDD were obtained for all materials and their mixes. These parameters were essential for preparing specimens for CBR testing.

E. California Bearing Ratio (CBR) Test

CBR tests (IS: 2720 Part XVI) were performed on specimens compacted at OMC and MDD and soaked for 4 days. Load–penetration curves were generated, and CBR values at 2.5 mm and 5.0 mm penetrations were calculated. Based on test response, the higher of the two values was adopted.

F. Aggregate Engineering Tests

Several tests were conducted to assess suitability of aggregates in base and sub-base layers:

1. Aggregate Impact Value (AIV) – IS: 2386 Part IV
2. Aggregate Crushing Value (ACV) – IS: 2386 Part IV
3. Los Angeles Abrasion Value (LAAV) – IS: 2386 Part IV
4. Flakiness & Elongation Index – IS: 2386 Part I

These tests ensured conformity to MoRTH requirements.

G. Bitumen Tests

For comparison with conventional materials, bitumen properties were evaluated using:

- Specific gravity (IS: 1202),
- Penetration (IS: 1203),
- Softening point (IS: 1205),
- Ductility (IS: 1208).

H. Marshall Stability Test

Marshall Stability and Flow values were determined as per Asphalt Institute MS-2 and MoRTH guidelines. Compacting temperature, mixing temperature, and bitumen content were controlled to obtain consistent specimens.

I. Preparation of Sub-base Mixes

Gradation mixes for GSB layers were prepared:

- Crusher dust blended with aggregates,
- Crusher dust blended with GGWT,
- Crusher dust + aggregate + GGWT combinations.

Compaction and CBR tests were used to determine optimum gradation.

J. Preparation of Base Course Mixes

Water Bound Macadam (WMM) and Wet Mix Macadam (WMM) mixes were prepared using:

- Stone aggregates (75–4.75 mm),
- Crusher dust (4.75–0.075 mm),
- CRWT sized 10 mm, 20 mm, and 30 mm.

Performance was evaluated based on OMC, MDD, and CBR.

K. Identification of Optimum Mixes

The following performance parameters guided selection:

- Increased CBR values,
- Improved compaction results,
- Conformity to MoRTH gradations,
- Improved load resistance and reduced plastic deformation.

Table 5—Representative Compaction Results for CD Mixes

Mix Type	OMC (%)	MDD (g/cc)
Single-size	9.8 – 10.4	1.92 – 1.98
Two-size	9.2 – 9.6	1.96 – 2.00
Three-size graded	8.4 – 9.0	2.02 – 2.10

Table 6—CBR Values for CD Mix Categories

CD Mix Type	CBR (%)
Single-size	8 – 11
Two-size	10 – 10.5
Three-size (well-graded)	13 – 15

Table 7—Effect of GGWT on Sub-base CBR

GGWT (%)	CBR (%)
0	48–68
0.5	54–70
1.0	60–76
1.5 – 2.0	Peak 72–82
3.0	Slight decrease

Table 8—Performance of CRWT Modified Base Mixes

CRWT Size (mm)	CRWT %	CBR (%)	Observation
10 mm	1–3	120–138	Improved stiffness
20 mm	1–3	118–134	Good interlock
30 mm	1–3	115–130	Highest flexibility

Table 9—Field Sample Validation Summary

Sample ID	Observed CBR (%)	Predicted CBR (%)	Error (%)
L1–L10	7–14	Based on triangular CBR chart	–8.33 to 18.18

5. RESULTS AND DISCUSSION

This section presents the experimental findings from the 194 laboratory-prepared gradation mixes of Crusher Dust (CD), along with the performance of Ground Granulated Waste Tyre (GGWT)–modified sub-base mixes and Crumb Rubber Waste Tyre (CRWT)–reinforced base course mixes. Results are discussed in terms of compaction behavior, strength characteristics, gradation influence, and comparison with MoRTH standards.

A. Results from Crusher Dust Gradation Mixes

1. Compaction Behavior

The compaction results showed a clear trend:

- Single-sized mixes exhibited comparatively lower Maximum Dry Density (MDD) values (1.92–1.98 g/cc).
- Two-sized blends showed moderate improvement (1.96–2.00 g/cc).
- Well-graded three-size mixes produced the highest densities (2.02–2.10 g/cc).

Interpretation: A well-graded aggregate structure provides better particle packing and reduced air voids, which enhances the dry density. This aligns with conventional granular mechanics, confirming that gradation uniformity strongly governs compaction efficiency.

2. California Bearing Ratio (CBR) Performance

A significant increase in CBR was observed with improvements in gradation quality:

Table 10— A significant increase in CBR was observed with improvements in gradation quality

Mix Type	CBR (%)	IEEE Interpretation
Single-sized	8–11%	Weak interlock, high void ratio
Two-sized	10–10.5%	Slight improvement due to partial packing
Three-sized	13–15%	Peak CBR from dense gradation

Discussion: The CBR values correlate strongly with MDD. Increased density enhances shear resistance and particle interlock, leading to higher penetration resistance during CBR testing.

Graph Trend Interpretation: All CBR-vs-gradation graphs in the thesis show a consistent upward trend from poorly-graded mixes to well-graded mixes, peaking in mixes with optimized fine-to-coarse ratios.

B. Sub-base Layer Results (CD + Aggregates + GGWT)

1. Influence of GGWT on Strength

GGWT was added at 0.5%, 1.0%, 1.5%, 2.0%, and 3.0%. The results indicate:

- 0.5–1.0% GGWT → Gradual improvement in CBR.
- 1.5–2.0% GGWT → Maximum CBR (72–82%), representing a major improvement.
- 3.0% GGWT → Slight decline due to excessive rubber interfering with densification.

Discussion of Trend:

The graphs in your thesis show the following characteristics:

- The CBR curve initially rises steeply from 0 to ~1.5% GGWT.
- It reaches a plateau around 1.5–2%.
- It drops slightly past 2%, indicating the formation of elastic zones inside the compacted mass.

Engineering Explanation:

GGWT particles improve strength by:

- Filling microvoids, increasing density,
- Providing energy absorption,
- Enhancing load transfer between CD and aggregates.

Excessive GGWT (>2%) acts like soft inclusions, reducing stiffness.

C. Base Course Results (CD + Aggregates + CRWT)

Three sizes of CRWT (10, 20, 30 mm) were tested:

Table 11— CBR Performance

CRWT Size	Peak CBR (%)	Interpretation
10 mm	120–138%	Highest strength; best interlock
20 mm	118–134%	Slightly lower but stable
30 mm	115–130%	Highest flexibility, lower stiffness

Discussion:

- Smaller CRWT (10 mm) particles fit better into the aggregate skeleton, decreasing voids and improving confinement.
- Larger rubber particles (20–30 mm) increase flexibility but reduce stiffness, resulting in slightly lower CBR.

Graph Interpretation:

Your CRWT strength graphs show:

- A clear positive trend as CRWT is added from 0 to 2%.
- A slight reduction at 3% CRWT due to excess elasticity.
- 10 mm CRWT consistently produces the steepest rise.

D. Field Sample Validation

Ten field samples from North Coastal Andhra Pradesh were compared with the CD-based CBR prediction chart.

- Observed CBR: 7–14%
- Predicted CBR: Within allowable error range
- Error: –8.33% to 18.18%

Discussion: The triangular CBR prediction model developed in the thesis was found accurate within ±18%, confirming its

usefulness for field applications.
This supports the reliability and generalizability of the laboratory gradation–CBR relationships.

E. Comparative Discussion

Table 12 - Sub-grade vs. Sub-base vs. Base

Layer	Material	CBR Improvement	Discussion
Sub-grade	CD	8–15%	Suitable as soil replacement
Sub-base	CD + GGWT	48–82%	Strongest improvement from waste tyre granules
Base	CD + CRWT	115–138%	Ideal for high-strength WMM layers

Sustainability Perspective

Use of CD, GGWT, and CRWT:

- Reduces dependence on quarried aggregates,
- Provides engineering value to waste materials,
- Enhances pavement durability,
- Lowers construction cost.

6. CONCLUSIONS

This study evaluated the engineering behavior of Crusher Dust (CD), Ground Granulated Waste Tyre (GGWT), and Crumb Rubber Waste Tyre (CRWT) for application in various layers of flexible pavement systems. Based on extensive laboratory investigations involving 194 CD gradation mixes, sub-base blends, and base course reinforcement combinations, the following conclusions are drawn:

1. Crusher Dust (CD) is a viable alternative to natural soil for sub-grade applications. Well-graded CD mixes demonstrated significantly higher compaction density (2.02–2.10 g/cc) and CBR values (13–15%) compared to single- or two-sized mixes. Improved gradation enhances interlocking and shear resistance, making CD suitable for replacing weak or unstable sub-grade soils.
2. Optimal gradation is the key determinant of strength.
Three-size dense graded CD mixes achieved up to 40–60% higher CBR than poorly graded mixes, confirming the strong correlation between particle packing and bearing capacity.
3. GGWT substantially enhances sub-base performance. The addition of 1.5–2.0% GGWT resulted in the highest CBR values (72–82%), exceeding that of conventional granular sub-base materials. Rubber granules improve energy absorption, reduce voids, and enhance load transfer. However, contents beyond 2% slightly reduce strength due to increased elasticity.
4. CRWT effectively reinforces base course materials.
CRWT-modified mixes showed very high CBR values (115–138%), suitable for Water Bound Macadam (WMM) and Wet Mix Macadam (WMM) layers.
    - 10 mm CRWT exhibited the best performance due to improved void filling and densification.
    - Larger rubber particles increased flexibility but reduced stiffness.
5. Field validation confirms the reliability of the CD–CBR model. The predicted CBR values for 10 field samples showed acceptable accuracy within an error range of –8.33% to 18.18%, demonstrating that the laboratory-derived gradation–CBR relationships are suitable for real-world conditions in coastal Andhra Pradesh soils.
6. Use of CD, GGWT, and CRWT promotes sustainable pavement construction. These industrial waste materials reduce the burden on natural aggregates, lower construction costs, and contribute to environmentally responsible engineering practices.

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