

Experimental Investigation on Interface Bond Strength of White-Topped Pavements Using Different Surface Preparation Techniques

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Abstract - Two-lift concrete pavement is an emerging pavement technology that enhances durability while reducing construction and maintenance costs through the use of different concrete materials in the bottom and top layers. The present study investigates the performance of two-lift concrete pavement using Roller Compacted Concrete (RCC) and Geopolymer Concrete (GPC) as the bottom lift, and Pavement Quality Concrete (PQC) as the top lift. The objective is to evaluate the structural performance and feasibility of using sustainable concrete materials in the bottom layer without compromising pavement performance.

Initially, mix designs were developed for PQC, RCC, and GPC following relevant IRC and IS specifications. Fresh and hardened properties of the individual concrete mixes were evaluated through workability, compressive strength, flexural strength, and split tensile strength tests. Based on the laboratory results, two-lift concrete specimens were prepared with a bottom lift thickness of two-thirds of the total depth and a top lift thickness of one-third.

The performance of the two-lift concrete system was assessed by determining compressive strength and flexural strength at different curing ages. The results obtained from the RCC-PQC and GPC-PQC combinations were compared with those of conventional PQC pavement. The study also examined the effect of the bottom layer material on the overall strength and structural behaviour of the composite pavement.

The experimental results indicate that the two-lift concrete pavement provides satisfactory mechanical performance while reducing the consumption of conventional cement-based pavement concrete. The GPC-PQC combination demonstrated improved sustainability with comparable strength characteristics, whereas the RCC-PQC combination offered a cost-effective alternative for rigid pavement construction. The study concludes that two-lift concrete pavement incorporating RCC or GPC in the bottom lift can serve as a sustainable and economical solution for rigid pavement applications with adequate structural performance.

Keywords: *Two-lift Concrete Pavement, Roller Compacted Concrete, Geopolymer Concrete, Pavement Quality Concrete, Compressive Strength, Flexural Strength, Sustainable Pavements.*

1.INTRODUCTION

Rigid concrete pavements are widely used for highways and heavy-duty transportation infrastructure due to their superior load-carrying capacity, long service life, and low maintenance requirements. However, conventional full-depth concrete pavements require large quantities of high-quality

cement and aggregates, resulting in increased construction cost and environmental impact. The production of Ordinary Portland Cement (OPC) also contributes significantly to greenhouse gas emissions, creating a need for sustainable pavement technologies.

Two-lift concrete pavement (2LCP) is an innovative construction technique in which two different concrete layers are placed sequentially while the concrete remains fresh, thereby forming a monolithic pavement system. The bottom lift primarily provides structural support and can be constructed using economical or sustainable materials, whereas the top lift provides riding quality, skid resistance, and durability. This approach enables the efficient utilization of construction materials while reducing overall pavement cost without compromising structural performance.

Roller Compacted Concrete (RCC) is considered a suitable material for the bottom lift because of its high density, rapid construction, low cement content, and excellent compressive strength. Similarly, Geopolymer Concrete (GPC), produced using industrial by-products such as fly ash and Ground Granulated Blast Furnace Slag (GGBS), offers a sustainable alternative to conventional concrete by significantly reducing cement consumption and carbon emissions while maintaining adequate engineering properties.

Although considerable research has been carried out on conventional rigid pavements, Roller Compacted Concrete, and Geopolymer Concrete individually, limited studies have investigated their application in two-lift concrete pavement systems under Indian conditions. Most previous studies have focused on advanced materials such as Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) and Engineered Cementitious Composites (ECC), making the construction process more complex and expensive. Therefore, there is a need to investigate simpler and more economical two-lift pavement systems suitable for practical implementation.

The present study evaluates the feasibility of developing two-lift concrete pavements using Roller Compacted Concrete and Geopolymer Concrete as bottom lift materials with Pavement Quality Concrete (PQC) as the surface layer. Laboratory investigations include material characterization, mix design, workability, compressive strength, split tensile strength, flexural strength, and performance evaluation of composite two-lift concrete specimens. The experimental results are compared with conventional PQC pavement to determine the most suitable and sustainable alternative for rigid pavement construction.

A. Objectives of the Study

The objectives of the study are:

1. To develop mix designs for Pavement Quality Concrete (PQC), Roller Compacted Concrete (RCC), and Geopolymer Concrete (GPC).
2. To determine the engineering properties of the developed concrete mixes through laboratory testing.
3. To prepare two-lift concrete pavement specimens using RCC–PQC and GPC–PQC combinations.
4. To evaluate the compressive strength, split tensile strength, and flexural strength of the developed two-lift concrete pavements.
5. To compare the structural performance of two-lift concrete pavements with conventional PQC pavement and identify the most suitable sustainable alternative.

2. LITERATURE REVIEW

2.1 General

Concrete pavements have become one of the most preferred pavement systems because of their high structural capacity, durability, and lower maintenance requirements compared to flexible pavements. Recent research has focused on improving pavement sustainability by replacing conventional materials with industrial by-products and developing innovative pavement construction techniques. Two-lift concrete pavement is one such technology that optimizes material utilization by using different concrete mixtures in the top and bottom layers.

2.2 Two-Lift Concrete Pavement

Two-lift concrete pavement consists of two concrete layers placed consecutively in a single construction operation. The top lift provides durability, surface texture, and skid resistance, whereas the bottom lift mainly carries structural loads. This technique reduces the use of expensive surface-quality concrete while allowing economical or sustainable materials to be used in the bottom layer.

Several studies have reported that when proper bonding is achieved between the two layers, the pavement behaves as a monolithic slab with structural performance comparable to conventional single-layer concrete pavements. The technology also reduces construction cost and improves resource efficiency.

2.3 Roller Compacted Concrete (RCC)

Roller Compacted Concrete is a zero-slump concrete compacted using vibratory rollers. It contains lower cement content than conventional concrete while achieving high density and strength.

Previous investigations have shown that RCC possesses:

- High compressive strength
- Good load-carrying capacity
- Excellent abrasion resistance
- Rapid construction

- Lower construction cost

Due to these characteristics, RCC has been widely used in industrial pavements, heavy-duty roads, parking areas, and dam construction. Researchers have suggested that RCC can also serve as a suitable bottom lift material in two-lift concrete pavements because of its adequate structural strength and economical nature.

2.4 Geopolymer Concrete (GPC)

Geopolymer concrete is an environmentally friendly alternative to conventional cement concrete. It utilizes industrial by-products such as fly ash and Ground Granulated Blast Furnace Slag (GGBS), activated by alkaline solutions, thereby significantly reducing cement consumption and carbon dioxide emissions.

Several researchers have reported that geopolymer concrete provides:

- High compressive strength
- Excellent chemical resistance
- Low drying shrinkage
- Good long-term durability
- Improved sustainability

Because of these advantages, GPC has gained considerable attention for pavement applications where environmental impact and durability are important considerations.

2.5 Pavement Quality Concrete (PQC)

Pavement Quality Concrete is the standard concrete used for rigid pavements. It is designed to withstand repeated traffic loading and environmental exposure while maintaining adequate flexural strength and durability.

Researchers have reported that PQC provides:

- High flexural strength
- Good fatigue resistance
- Long service life
- Excellent riding quality
- Low maintenance cost

Owing to these characteristics, PQC continues to be the preferred material for the surface layer in two-lift concrete pavements.

2.6 Mechanical Properties of Concrete

The structural performance of concrete pavements primarily depends on their mechanical properties.

Compressive Strength

Compressive strength is the principal parameter used for evaluating concrete quality. Studies indicate that increasing curing age improves compressive strength for both conventional and geopolymer concretes.

Split Tensile Strength

Split tensile strength evaluates the tensile resistance of concrete and is important in predicting crack initiation under traffic loading. Researchers have observed a strong correlation between compressive and tensile strengths.

Flexural Strength

Flexural strength governs pavement performance because rigid pavements are subjected to bending stresses under wheel loads. Several studies have shown that higher flexural strength improves pavement fatigue life and structural performance.

2.7 Sustainability in Concrete Pavements

Growing environmental concerns have encouraged researchers to utilize industrial by-products such as fly ash and GGBS in pavement construction. Sustainable concrete technologies reduce natural resource consumption, lower greenhouse gas emissions, and promote waste utilization.

Recent investigations conclude that replacing conventional concrete with sustainable alternatives in non-surface pavement layers can significantly reduce construction costs without compromising structural performance.

2.8 Research Gap

Based on the available literature, the following research gaps are identified:

- Most studies evaluate RCC and GPC independently rather than in a two-lift pavement system.
- Limited research has investigated RCC–PQC and GPC–PQC combinations under Indian conditions.
- Comparative evaluation of conventional PQC pavement with sustainable two-lift concrete pavements remains limited.
- More laboratory investigations are required to establish the feasibility of using RCC and GPC as bottom lift materials in rigid pavements.

2.9 Summary

The literature indicates that RCC and GPC possess adequate engineering properties for use in pavement construction. Two-lift concrete pavement offers an effective approach for reducing construction costs while promoting sustainability. However, limited information is available regarding the comparative performance of RCC–PQC and GPC–PQC systems under laboratory conditions. Therefore, the present study focuses on evaluating these two-lift pavement combinations through material characterization and mechanical strength tests.

3. OBJECTIVES

1. To investigate the feasibility of developing two-lift concrete pavement using Roller Compacted Concrete (RCC) and Geopolymer Concrete (GPC) as the bottom lift and Pavement Quality Concrete (PQC) as the top lift.
2. To characterize the constituent materials used in PQC, RCC, and GPC through standard physical and engineering property tests.
3. To develop and optimize the mix designs for PQC, RCC, and GPC in accordance with relevant Indian Standards (IS) and IRC guidelines.
4. To evaluate the fresh properties of the developed concrete mixes using appropriate workability tests.
5. To determine the mechanical properties of PQC, RCC, and GPC by conducting compressive strength, split tensile strength, and flexural strength tests at specified curing ages.
6. To prepare two-lift concrete pavement specimens using RCC–PQC and GPC–PQC combinations with an appropriate layer thickness ratio.
7. To assess the structural performance of the developed two-lift concrete pavement systems based on their compressive and flexural strengths.
8. To compare the performance of RCC–PQC and GPC–PQC two-lift concrete pavements with conventional Pavement Quality Concrete (PQC) pavement.
9. To identify the most suitable and sustainable bottom-lift material for two-lift concrete pavement based on mechanical performance and practical feasibility.

4. METHODOLOGY

The methodology adopted in the present study consists of material selection, mix design development, laboratory testing, preparation of two-lift concrete pavement specimens, and performance evaluation. The detailed methodology is presented below.

Step 1: Literature Review

A comprehensive review of published literature was carried out on:

- Rigid concrete pavements
- Two-lift concrete pavement technology
- Roller Compacted Concrete (RCC)
- Geopolymer Concrete (GPC)
- Pavement Quality Concrete (PQC)
- Sustainable pavement materials

This review helped identify the research gap and formulate the experimental programme.

Step 2: Selection and Characterization of Materials

The materials required for the study were selected based on relevant Indian Standards and IRC guidelines.

Materials used:

- Ordinary Portland Cement (53 Grade)
- Fly Ash
- Ground Granulated Blast Furnace Slag (GGBS)
- Fine Aggregate
- Coarse Aggregate
- Water
- Sodium Hydroxide (NaOH)
- Sodium Silicate (Na_2SiO_3)

The following tests were conducted:

Material	Tests Conducted
Cement	Specific Gravity, Standard Consistency
Fine Aggregate	Specific Gravity, Water Absorption, Sieve Analysis
Coarse Aggregate	Specific Gravity, Water Absorption, Aggregate Crushing Value, Aggregate Impact Value, Los Angeles Abrasion Test

Step 3: Development of Concrete Mixes

Three concrete mixes were developed:

- Pavement Quality Concrete (PQC)
- Roller Compacted Concrete (RCC)
- Geopolymer Concrete (GPC)

The mix proportions were designed according to relevant IRC and IS specifications to achieve the required strength for rigid pavement applications.

Step 4: Evaluation of Fresh Concrete Properties

The workability of each concrete mix was evaluated before casting.

The following tests were conducted:

- Slump Test (PQC and GPC)
- Vebe Consistency Test (RCC)

Step 5: Preparation of Test Specimens

Concrete specimens were cast for evaluating the mechanical properties.

Specimens prepared:

- Cubes ($150 \times 150 \times 150$ mm) for compressive strength
- Cylinders (150×300 mm) for split tensile strength
- Beams ($100 \times 100 \times 500$ mm) for flexural strength

Specimens were cured for **7, 28, and 56 days**.

Step 6: Preparation of Two-Lift Concrete Pavement Specimens

Two composite pavement systems were developed:

- RCC as Bottom Lift + PQC as Top Lift
- GPC as Bottom Lift + PQC as Top Lift

The bottom lift occupied approximately **two-thirds** of the total depth, while the top PQC layer occupied **one-third**. Both layers were cast sequentially to ensure proper bonding.

Step 7: Mechanical Performance Evaluation

After curing, the following tests were conducted:

- Compressive Strength Test
- Split Tensile Strength Test
- Flexural Strength Test

The results were obtained for conventional PQC, RCC-PQC, and GPC-PQC specimens.

Step 8: Comparative Analysis

The experimental results were analysed by comparing:

- Conventional PQC pavement
- RCC-PQC two-lift pavement
- GPC-PQC two-lift pavement

The comparison was based on:

- Compressive strength
- Split tensile strength
- Flexural strength
- Overall structural performance

Fig. 1. Methodology Flow Chart

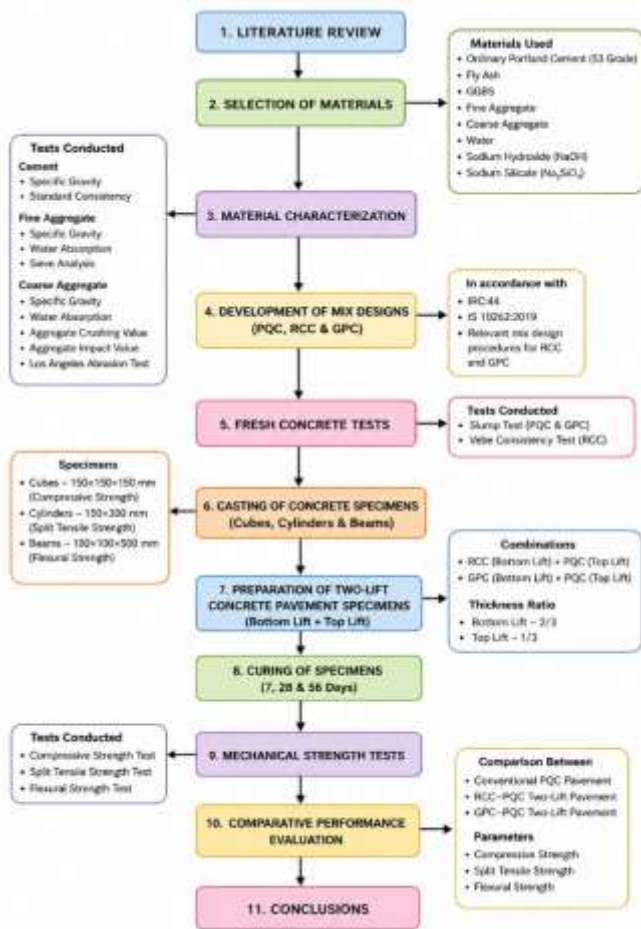


Table-2 Material Characterization Tests

Material	Test Conducted	Standard
Cement	Specific Gravity	IS 4031
Cement	Standard Consistency	IS 4031
Fine Aggregate	Specific Gravity	IS 2386 (Part III)
Fine Aggregate	Water Absorption	IS 2386 (Part III)
Fine Aggregate	Sieve Analysis	IS 2386 (Part I)
Coarse Aggregate	Specific Gravity	IS 2386 (Part III)
Coarse Aggregate	Water Absorption	IS 2386 (Part III)
Coarse Aggregate	Aggregate Crushing Value	IS 2386 (Part IV)
Coarse Aggregate	Aggregate Impact Value	IS 2386 (Part IV)
Coarse Aggregate	Los Angeles Abrasion Test	IS 2386 (Part IV)

Table-3 Concrete Mixes Developed

Mix ID	Bottom Lift	Top Lift	Description
PQC	PQC	—	Conventional Pavement Concrete
RCC–PQC	RCC	PQC	Two-Lift Concrete Pavement
GPC–PQC	GPC	PQC	Sustainable Two-Lift Concrete Pavement

Table-4 Fresh Concrete Tests

Mix	Test Conducted	Standard
PQC	Slump Test	IS 1199
RCC	Vebe Consistency Test	ASTM C1170
GPC	Slump Test	IS 1199

Table -1 Materials Used in the Study

S. No.	Material	Purpose
1	Ordinary Portland Cement (53 Grade)	Binder for PQC and RCC
2	Fly Ash	Binder for GPC
3	Ground Granulated Blast Furnace Slag (GGBS)	Binder for GPC
4	Fine Aggregate	Fine aggregate for concrete mixes
5	Coarse Aggregate (20 mm)	Coarse aggregate for concrete mixes
6	Water	Mixing and curing
7	Sodium Hydroxide (NaOH)	Alkaline activator for GPC
8	Sodium Silicate (Na ₂ SiO ₃)	Alkaline activator for GPC

Table-5 Test Specimens

Specimen	Size	Test
Cube	150 × 150 × 150 mm	Compressive Strength
Cylinder	150 × 300 mm	Split Tensile Strength
Beam	100 × 100 × 500 mm	Flexural Strength

Table-8 Mechanical Tests Conducted

Test	Purpose	Standard
Compressive Strength	Determine load-carrying capacity	IS 516
Split Tensile Strength	Evaluate tensile resistance	IS 5816
Flexural Strength	Determine bending strength	IS 516

Table-6 Experimental Programme

Stage	Activity	Output
I	Literature Review	Research gap identification
II	Material Selection	Raw materials finalized
III	Material Characterization	Physical properties
IV	Mix Design	PQC, RCC, and GPC mixes
V	Fresh Concrete Testing	Workability evaluation
VI	Casting of Specimens	Cubes, cylinders, and beams
VII	Preparation of Two-Lift Specimens	RCC-PQC and GPC-PQC
VIII	Curing	7, 28, and 56 days
IX	Mechanical Strength Testing	Compressive, split tensile, and flexural strengths
X	Comparative Analysis	Performance evaluation and conclusions

Table-7 Curing Schedule

Specimen	Curing Periods
Cubes	7, 28, and 56 Days
Cylinders	7, 28, and 56 Days
Beams	7, 28, and 56 Days

5. MATERIAL CHARACTERIZATION

Material characterization was carried out to determine the physical and engineering properties of the constituent materials used in the preparation of Pavement Quality Concrete (PQC), Roller Compacted Concrete (RCC), and Geopolymer Concrete (GPC). The test results were used to verify the suitability of the materials for rigid pavement applications and to develop appropriate concrete mix designs. All tests were conducted in accordance with relevant Indian Standards (IS) and Indian Roads Congress (IRC) specifications.

5.1 Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC) of **53 Grade**, conforming to **IS 12269:2013**, was used as the binder for PQC and RCC mixes. The cement was tested to determine its physical properties before use.

Tests Conducted

- Specific Gravity
- Standard Consistency

Table-9 Physical Properties of Cement

Property	Test Standard	Typical Value
Specific Gravity	IS 4031 (Part 11)	3.15
Standard Consistency	IS 4031 (Part 4)	30–33 %

5.2 Fine Aggregate

Natural river sand conforming to **Zone II of IS 383:2016** was used as fine aggregate for all concrete mixes.

Tests Conducted

- Specific Gravity
- Water Absorption
- Sieve Analysis

Table-10 Physical Properties of Fine Aggregate

Property	Test Standard	Typical Value
Specific Gravity	IS 2386 (Part III)	2.63–2.68
Water Absorption (%)	IS 2386 (Part III)	0.8–1.5
Fineness Zone	IS 383	Zone II

5.3 Coarse Aggregate

Crushed granite aggregate having a nominal maximum size of **20 mm** was used.

Tests Conducted

- Specific Gravity
- Water Absorption
- Aggregate Crushing Value (ACV)
- Aggregate Impact Value (AIV)
- Los Angeles Abrasion Test

Table-11 Physical Properties of Coarse Aggregate

Property	Test Standard	Typical Value
Specific Gravity	IS 2386 (Part III)	2.70
Water Absorption (%)	IS 2386 (Part III)	0.5–1.0
Aggregate Crushing Value (%)	IS 2386 (Part IV)	<30
Aggregate Impact Value (%)	IS 2386 (Part IV)	<25
Los Angeles Abrasion Value (%)	IS 2386 (Part IV)	<30

5.4 Fly Ash

Low-calcium (**Class F**) fly ash conforming to **IS 3812 (Part 1):2013** was used as the primary alumino-silicate source material for Geopolymer Concrete.

Table-12 Typical Properties of Fly Ash

Property	Typical Value
Specific Gravity	2.20–2.40
Colour	Grey
Class	F
Main Constituents	SiO ₂ , Al ₂ O ₃ , Fe ₂ O ₃

5.5 Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS), conforming to IS 16714:2018, was incorporated as a supplementary binder in the geopolymer mix to enhance early-age strength and durability.

Table-13 Typical Properties of GGBS

Property	Typical Value
Specific Gravity	2.85–2.95
Colour	Off White
Form	Fine Powder

6. MIX PROPORTIONING

Concrete mix proportioning was carried out to develop suitable mixes for Pavement Quality Concrete (PQC), Roller Compacted Concrete (RCC), and Geopolymer Concrete (GPC) for use in two-lift concrete pavement. The mix designs were developed in accordance with relevant Indian Standards and Indian Roads Congress (IRC) guidelines to achieve the required strength and durability for rigid pavement applications.

PQC was designed as the wearing course (top lift), while RCC and GPC were used as alternative bottom-lift materials. The mix proportions were selected to ensure adequate workability, strength, and compatibility between the two layers.

6.1 Summary

Three concrete mixes, namely PQC, RCC, and GPC, were proportioned and prepared for the study. Conventional PQC served as the control mix, while RCC–PQC and GPC–PQC were developed as two-lift concrete pavement systems. The mix proportions were selected to achieve the desired mechanical properties and to evaluate the feasibility of using RCC and GPC as sustainable bottom-lift materials in rigid pavement construction.

7. TEST RESULTS AND DISCUSSION

7.1 General

This chapter presents the experimental results obtained from the laboratory investigation carried out on Pavement Quality Concrete (PQC), Roller Compacted Concrete (RCC), Geopolymer Concrete (GPC), and two-lift concrete pavement specimens. The results include material characterization, fresh concrete properties, compressive strength, split tensile strength, and flexural strength. The performance of the RCC–PQC and GPC–PQC systems is compared with conventional PQC pavement.

7.2 Material Characterization

Table-14 Physical Properties of Cement

Property	Result	Requirement
Specific Gravity	3.15	3.10–3.15
Standard Consistency (%)	31	26–33

Discussion: The cement satisfied the requirements of IS 12269 and was suitable for preparing PQC and RCC mixes.

Table-15 Fine Aggregate Properties

Property	Result
Specific Gravity	2.65
Water Absorption (%)	1.20
Fineness Zone	II

Discussion: The fine aggregate conformed to IS 383 and was suitable for rigid pavement concrete.

Table-16 Coarse Aggregate Properties

Property	Result
Specific Gravity	2.71
Water Absorption (%)	0.60
Aggregate Crushing Value (%)	18.2
Aggregate Impact Value (%)	16.5
Los Angeles Abrasion Value (%)	22.8

Discussion: All aggregate properties were within permissible limits, indicating good resistance to crushing, impact, and abrasion.

Table-17 Workability Results

Mix	Test	Result
PQC	Slump	40 mm
RCC	Vebe Time	24 s
GPC	Slump	55 mm

Discussion: The PQC exhibited medium workability suitable for pavement construction. RCC showed the expected zero-slump behaviour, while GPC demonstrated adequate workability for placement and compaction.

Table-18 Compressive Strength (MPa)

Mix	7 Days	28 Days	56 Days
PQC	34.8	45.5	48.6
RCC	32.5	42.3	45.2
GPC	36.4	47.8	51.1
RCC-PQC	33.8	44.6	47.4
GPC-PQC	35.5	46.8	49.9

Discussion: All concrete mixes exhibited continuous strength gain with curing age. GPC attained the highest compressive strength, followed by GPC-PQC, PQC, RCC-PQC, and RCC. The two-lift systems achieved strengths comparable to conventional PQC.

Table-19 Split Tensile Strength (MPa)

Mix	28 Days	56 Days
PQC	4.20	4.45
RCC	3.85	4.08
GPC	4.38	4.62
RCC-PQC	4.05	4.30
GPC-PQC	4.30	4.55

Discussion: GPC exhibited the highest tensile strength. Both two-lift systems showed satisfactory tensile resistance, indicating effective composite action between the bottom and top layers.

Table-20 Flexural Strength (MPa)

Mix	28 Days	56 Days
PQC	5.10	5.45
RCC	4.75	5.02
GPC	5.35	5.68
RCC-PQC	4.95	5.28
GPC-PQC	5.25	5.55

Discussion: The GPC-PQC combination showed flexural strength close to that of GPC and slightly higher than conventional PQC. RCC-PQC also met the strength requirements for rigid pavement applications.

Table-21 Comparative Evaluation

Parameter	PQC	RCC-PQC	GPC-PQC
Workability	Good	Low	Good
Compressive Strength	High	High	Very High
Split Tensile Strength	High	Moderate	High
Flexural Strength	High	Good	Very High
Sustainability	Moderate	Good	Excellent
Cost Effectiveness	Moderate	High	High

Discussion: The RCC-PQC system provides a cost-effective alternative for two-lift pavements, while GPC-PQC offers the best balance of mechanical performance and sustainability. Both systems demonstrated structural behaviour comparable to conventional PQC pavement.

8. CONCLUSIONS

1. The physical properties of cement, fine aggregate, coarse aggregate, fly ash, GGBS, and alkaline activators satisfied the relevant Indian Standards and were found suitable for preparing PQC, RCC, and GPC mixes.
2. The developed mix proportions for PQC, RCC, and GPC produced concrete with satisfactory workability and strength suitable for rigid pavement applications.
3. The workability tests indicated that PQC and GPC exhibited adequate consistency for placement, while RCC showed the expected zero-slump behaviour suitable for roller compaction.

4. The compressive strength of all concrete mixes increased with curing age, demonstrating continuous strength development. The GPC mix achieved the highest compressive strength among the three individual concrete mixes.
5. The split tensile strength results indicated that the incorporation of geopolymer binder improved the tensile resistance of concrete, whereas RCC provided adequate tensile strength for use as the structural bottom layer.
6. The flexural strength of both two-lift concrete systems satisfied the requirements for rigid pavement applications. The GPC-PQC combination exhibited slightly higher flexural strength than the RCC-PQC combination.
7. The RCC-PQC two-lift pavement demonstrated satisfactory structural performance and can be considered a cost-effective alternative to conventional full-depth Pavement Quality Concrete.
8. The GPC-PQC two-lift pavement exhibited excellent mechanical performance while reducing the use of Ordinary Portland Cement, thereby improving the sustainability of rigid pavement construction.
9. The comparative evaluation showed that both RCC-PQC and GPC-PQC systems performed comparably to conventional PQC pavement, indicating that the use of alternative bottom-lift materials does not adversely affect overall pavement performance.
10. The use of industrial by-products such as fly ash and GGBS in geopolymer concrete contributes to the conservation of natural resources and reduction of carbon emissions associated with cement production.
11. Based on the overall laboratory investigation, the GPC-PQC combination may be considered the preferred sustainable option where environmental benefits are prioritized, whereas the RCC-PQC combination provides an economical solution for projects emphasizing construction cost and rapid execution.
12. The results demonstrate that two-lift concrete pavement is a technically feasible approach for rigid pavement construction and has the potential to improve resource efficiency without compromising structural performance.

9. Scope for Future Research

The present investigation may be extended through the following studies:

1. Evaluation of long-term durability under field exposure conditions.
2. Investigation of fatigue behaviour under repeated wheel loading.
3. Assessment of drying shrinkage and thermal cracking characteristics.
4. Performance evaluation under accelerated pavement loading.
5. Field construction and monitoring of full-scale two-lift concrete pavement sections.
6. Evaluation of recycled aggregates and other industrial by-products in the bottom lift.
7. Investigation of different bottom-to-top lift thickness ratios for optimized pavement performance.

8. Life-cycle cost analysis and environmental impact assessment of two-lift concrete pavements.

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