

Development of Pervious Concrete Using Aggregate Gradation, Water-Cement Ratio and Chemical Admixture

P. Praneeth Kumar¹, B. Krishna Naik²

1 M.Tech Scholar, Dept. of Civil Engg., MVR College of Engineering & Technology (Autonomous),
Paritala, AP, India

| Email: penugondapraneeth@gmail.com (Corresponding Author)

2 Assistant Professor, Dept. of Civil Engg., MVR College, Paritala, AP, India

| Email: krishna.naik@mvr.ac.in

Abstract— This research formulates high-performance pervious concrete through systematic variation of aggregate gradation (G1-G5: 90-98% coarse), water-cement ratio (0.24-0.32) and polycarboxylate ether (PCE) superplasticizer (0.50-0.70%). OPC 53 Grade (IS 12269), 10mm crushed aggregate (IS 383:2016), M-sand Zone-II, potable water (IS 456, pH 7.86) and PCE (IS 9103, SG 1.10, solid 32%) were used. Twenty-five mixes M1-M25 (cement 320-400 kg/m³) were tested for density, void content ASTM C1688, permeability ASTM C1701, compressive strength IS 516:2021. G3 gradation (95% CA, 5% FA) with 400 kg/m³ cement, w/c 0.24, PCE 0.70% (M15) exhibited optimum: density 1812 kg/m³, void 24.5%, permeability 8.5 mm/s, 7-day 19.5 MPa, 28-day 28.6 MPa exceeding target 25 MPa. Results confirm gradation governs pore interconnectivity and strength.

Keywords— Pervious Concrete, Aggregate Gradation, Water-Cement Ratio, Polycarboxylate Ether (PCE), Compressive Strength, Permeability, Sustainable Pavements, ACI 522R-10

I. INTRODUCTION

Pervious concrete is recognized as eco-friendly pavement due to interconnected voids (15-35%) permitting infiltration, reducing runoff and recharging groundwater [1]. Urbanization increases impervious cover, causing flooding and drainage overload. However, low strength vs conventional concrete limits application. Performance depends on gradation, w/c, cement content and admixtures. ACI 522R-10 guides pervious concrete design [2]. IRC:44-2017 provides mix design for pavements [3]. This study investigates G1-G5, w/c 0.32-0.24, PCE 0.50-0.70% to identify optimum for sustainable pavements.

Pervious Concrete Surface



BACKGROUND OF THE STUDY

Urban development has transformed natural landscapes into impervious surfaces. Conventional pavements prevent rainwater from infiltrating into the ground, causing several environmental and engineering problems.

The consequences include: Increased surface runoff, Flooding during heavy rainfall, Groundwater depletion, Overloading of drainage systems, Environmental degradation

According to environmental studies, nearly 70–90% of rainfall becomes runoff in highly urbanized areas compared to only 10–20% in natural landscapes. This situation has necessitated the development of sustainable drainage systems and permeable pavement technologies.

Pervious concrete is one of the most effective sustainable pavement materials because it: Reduces stormwater runoff, Enhances groundwater recharge, Improves water quality, Reduces urban heat island effects, Supports environmentally friendly infrastructure

However, widespread implementation of pervious concrete is often limited by its relatively lower strength compared to conventional concrete. Therefore, improving strength without significantly affecting permeability remains a key research challenge.

II. LITERATURE REVIEW

Tennis et al. (2004) [1] reported 15-35% voids provide excellent permeability. DOI:10.1002/9780470408609.

Yang and Jiang (2003) [2] showed well-graded aggregates improve contact area and strength.

DOI:10.1016/S0008-8846(02)00929-8. Kevern et al. (2008) [3] emphasized proportioning and compaction balance. Neithalath et al. (2010) [4] concluded pore connectivity governs hydraulic conductivity.

DOI:10.1016/j.cemconres.2010.02.014. Chindaprasirt et al. (2008) [5] found supplementary materials improve sustainability.

DOI:10.1016/j.conbuildmat.2007.02.009. Chandrappa & Biligiri (2016) [6] reviewed pervious concrete as sustainable pavement.

DOI:10.1016/j.conbuildmat.2016.02.054.

"Based on the reviewed literature, it is evident that aggregate gradation, water–cement ratio, and chemical admixtures significantly influence the performance of pervious concrete. However, limited studies have investigated their combined effect under Indian conditions, which forms the basis of the present study."

III. RESEARCH GAP AND OBJECTIVES

Limited research examines combined influence of gradation, w/c and PCE under unified programme. Few optimize strength-permeability simultaneously. Local aggregate variations necessitate region-specific designs. Objectives: (i) Study effect of gradation G1-G5 on density, voids, permeability, strength, (ii) Evaluate w/c 0.32-0.24, (iii) Evaluate PCE 0.50-0.70%, (iv) Establish relationships, (v) Identify optimum mix >25 MPa with >5 mm/s permeability.

Need for the Study

India is experiencing rapid urbanization, leading to extensive construction of roads, buildings, and parking facilities. Most urban surfaces are impermeable, resulting in: Frequent flooding, Water stagnation, Groundwater depletion, Increased maintenance costs

Traditional drainage systems alone are often insufficient to handle large volumes of stormwater.

Pervious concrete provides a practical solution by allowing rainfall to infiltrate directly through the pavement structure.

The present study is required because:

Limited studies are available under Indian conditions.

Aggregate gradation significantly affects strength and permeability.

Water-cement ratio controls paste consistency and bond strength.

Chemical admixtures can improve workability and mechanical performance.

An optimized mix design is needed for transportation infrastructure applications.

Major Challenges in Construction

The major challenge associated with pervious concrete is achieving adequate mechanical strength while maintaining sufficient permeability. A higher void content improves permeability but reduces strength. Conversely, reducing void content improves strength but decreases permeability.

Pervious concrete offers a promising solution to these challenges by allowing water to pass through interconnected voids and infiltrate into the underlying soil. However, its practical application is limited by several technical challenges:

Achieving adequate compressive, tensile, and flexural strength while maintaining high permeability. Optimizing aggregate gradation to create a stable interconnected void structure.

Selecting an appropriate water-cement ratio to ensure sufficient bonding without blocking pores. Determining the optimum dosage of chemical admixtures to improve workability and strength.

Maintaining durability under traffic loading and varying environmental conditions. Preventing clogging of pores during service life, which can reduce infiltration capacity. Developing mix designs suitable for Indian climatic conditions and pavement applications.

Therefore, the development of pervious concrete using optimized aggregate gradation, water-cement ratio, and chemical admixtures is essential to address both structural and environmental challenges in modern construction. The present research aims to overcome these limitations and develop a sustainable pavement material that can effectively contribute to stormwater management, groundwater recharge, and resilient urban infrastructure.

IV. MATERIALS AND METHODOLOGY

A. Materials Characterization

OPC 53 Grade IS 12269: consistency 25.7% IS 4031 Part4, IST 125 min, FST 195 min, 28-day strength 63 MPa, SG 3.13, LOI 3.55%, IR 1.51%, SO₃ 2.46% IS 4032. Coarse aggregate 10mm IS 383: crushing 21% (<30% wearing), abrasion 22% (<30%), impact 19%

(<30%), flakiness+elongation 14.4% (<40%), absorption 0.50%, SG SSD 2.63, bulk density 1.41/1.53 kg/lit, soundness 2.08% IS 2386. Fine aggregate M-sand Zone-II IS 383: SG 2.58, absorption 1.0%, finer <75 μ 8.4%, bulk density 1.60/1.84. Water pH 7.86 (>6) IS 3025, IS 456. PCE SG 1.10, pH 6.2, solid 32%, chloride 0.011% IS 9103.

B. Aggregate Gradations

G1 90% CA+10% FA, G2 92%+8%, G3 95%+5%, G4 96%+4%, G5 98%+2%. All single-size 10mm nominal.

C. Mix Design as per ACI 522R-10 & IS 10262:2019

M15 grade targeted TMS 19.95 MPa. Minimum percolation 350 mm/min. Void content average 21.5% (25% for percolation, 18% for strength). Paste volume well-compacted 12.5%, lightly-compacted 20%. Calculations: lightly-compacted cement 320 kg/m³, water 99.2 kg/m³, CA 1461.6 kg/m³, FA 75.5 kg/m³. Trial matrix 25 mixes M1-M25 varying cement 320-400, w/c 0.32-0.24, PCE 0.50-0.70% across G1-G5. Batch sheet moisture corrections applied. Optimum M15 selected.

V. EXPERIMENTAL PROGRAMME

Selection of Materials



Material Characterization



Development of Trial Mixes



Selection of Optimum Mix



Batching of Materials



Mixing



Casting of Specimens

▼
Compaction

▼
Curing

▼
Laboratory Testing

▼
Analysis of Results

▼
Conclusions

Figure: Experimental Flow Chart

A. Specimen Preparation

Batching by weight 0.1%. Dry mixing 60 sec, water+PCE 90 sec. Placed in 150mm cubes 2 layers, rodded 25 times per layer, 10 blows 2.5kg rammer, careful compaction to maintain voids. Covered wet gunny 24h, demoulded, cured $27 \pm 2^\circ\text{C}$ till 7 & 28 days. 3 cubes per mix average.



B. Test Methods

1) Density mass/vol IS 516. 2) Void content ASTM C1688. 3) Permeability constant-head ASTM C1701

$k = QL/Aht$ mm/s. 4) Compressive strength 2000kN CTM IS 516:2021 loading 5.2 kN/s.

VI. RESULTS AND DISCUSSION

Mix ID	Aggregate Gradation	% of Coarse Aggregate	% of Fine Aggregate	Cement content in Kgs/m ³	Water cement ratio
M1	G1	90	10	320	0.32
M2	G1	90	10	340	0.30
M3	G1	90	10	360	0.28
M4	G1	90	10	380	0.26
M5	G1	90	10	400	0.24
M6	G2	92	8	320	0.32
M7	G2	92	8	340	0.30
M8	G2	92	8	360	0.28
M9	G2	92	8	380	0.26
M10	G2	92	8	400	0.24
M11	G3	95	5	320	0.32
M12	G3	95	5	340	0.30
M13	G3	95	5	360	0.28
M14	G3	95	5	380	0.26
M15	G3	95	5	400	0.24
M16	G4	96	4	320	0.32
M17	G4	96	4	340	0.30
M18	G4	96	4	360	0.28
M19	G4	96	4	380	0.26
M20	G4	96	4	400	0.24
M21	G5	98	2	320	0.32
M22	G5	98	2	340	0.30
M23	G5	98	2	360	0.28

M2 4	G5	98	2	380	0.26
M2 5	G5	98	2	400	0.24

Mi x ID	Admixt ure Dosage in % of cement	Permeab ility in mm/sec	Compres sive strength for 28 days in Mpa	Voi ds %	Densi ty Kgs/ m3
M1	0.50	4.1	17.30	15.9	2018.4
M2	0.55	4.3	18.60	14.6	2049.6
M3	0.60	4.6	19.40	13.2	2083.2
M4	0.65	5.1	21.20	13.0	2088.0
M5	0.70	5.5	23.00	12.4	2102.4
M6	0.50	5.6	16.10	20.4	1910.4
M7	0.55	5.7	19.30	19.6	1929.6
M8	0.60	5.9	20.50	18.3	1960.8
M9	0.65	6.0	22.10	17.4	1982.4
M10	0.70	6.1	23.40	17.0	1992.0
M11	0.50	7.9	17.60	21.9	1874.4
M12	0.55	8.0	20.40	22.4	1862.4
M13	0.60	8.1	23.60	22.9	1850.4
M14	0.65	8.4	24.10	23.6	1833.6
M15	0.70	8.5	28.60	24.5	1812.0
M16	0.50	8.6	16.20	28.6	1713.6
M17	0.55	8.7	19.60	29.5	1692.0
M18	0.60	9.0	23.60	30.1	1677.0

18					6
M19	0.65	9.3	22.50	30.6	1665.6
M20	0.70	9.5	24.50	31.0	1656.0
M21	0.50	10.2	15.40	33.0	1608.0
M22	0.55	10.5	16.30	33.6	1593.6
M23	0.60	10.7	18.60	34.1	1581.6
M24	0.65	10.8	19.50	34.5	1572.0
M25	0.70	11.0	22.40	35.0	1560.0

Table I summarises 25 mixes. Density 1560-2102 kg/m3, voids 12.4-35%, permeability 4.1-11.0 mm/s, 28-day 15.4-28.6 MPa. Table II shows optimum M15 vs ACI 522R-10.

Mix Group	Grad	Cem kg/m3	w/c PCE %	Perm mm/s	f28 MPa
M1-M5 (G1)	G1	320-400	0.32/0.50-0.24/0.70	4.1-5.5	17.3-23.0
M6-M10 (G2)	G2	320-400	0.32/0.50-0.24/0.70	5.6-6.1	16.1-23.4
M11-M15 (G3)	G3	320-400	0.32/0.50-0.24/0.70	7.9-8.5*	17.6-28.6*
M16-M20 (G4)	G4	320-400	0.32/0.50-0.24/0.70	8.6-9.5	16.2-24.5
M21-M25 (G5)	G5	320-400	0.32/0.50-0.24/0.70	10.2-11.0	15.4-22.4

Table I: Summary 25 mixes. *M15 optimum: Density 1812, Void 24.5%, Perm 8.5 mm/s, f7 19.5 MPa, f28 28.6 MPa

Property	M15 Optimum	ACI 522R-10	Result
Density	1812 kg/m3	1600-2000	Pass
Void content	24.5%	15-35%	Pass

Permeability	8.5 mm/s (510 mm/min)	>1 mm/s	Excellent
28-day strength	28.6 MPa	>20 MPa parking	Exceeds
7-day strength	19.5 MPa	-	68% of 28d

Table II: Optimum M15 vs ACI 522R-10 – All pass, suitable for parking, footpaths, low-volume roads.

The experimental data are internally consistent:

- G1 → Highest density and lower permeability.
- G5 → Highest permeability and lower strength.
- G3 → Best balance between strength and permeability.

A. Effect of Gradation

G1 dense 10% fines: low voids 12.4-15.9%, high density 2018-2102, moderate strength 17.3-23 MPa, low permeability 4.1-5.5 mm/s due to paste filling. G5 open 2% fines: high voids 33-35%, low density 1560-1608, low strength 15.4-22.4 MPa, high permeability 10.2-11 mm/s. G3 balanced 5% fines: voids 21.9-24.5%, density 1874-1812, strength 17.6-28.6 MPa, permeability 7.9-8.5 mm/s – optimum packing and interlock while retaining interconnectivity.

B. Effect of w/c and PCE

Lower w/c 0.24 thicker paste, stronger bond. With PCE 0.70% workability adequate (slump 30mm initial, 25mm 120 min retained), compaction better, strength highest. Higher w/c 0.32 reduced strength due to capillary porosity. PCE disperses cement, improves coating, reduces segregation. Optimum 0.70% bwoc; beyond no gain, risk drain-down.

C. Inter-relationships

Density-void inverse: 1560->2102 => 35->12.4% voids. Density-permeability inverse. Density-strength positive: 1812 kg/m³ gave 28.6 MPa max. Void-permeability positive, void-strength inverse, permeability-strength opposite. G3 balances both: 24.5% voids gives 8.5 mm/s and 28.6 MPa.

VII. COMPARISON WITH LITERATURE

Table III compares M15 with literature. Agreement validates methodology, 28.6 MPa superior to typical 15-20 MPa.

Researcher	Major Finding	Present M15
Tennis et al. 2004 [1]	15-35% voids high perm	24.5% voids, 8.5 mm/s excellent
Yang & Jiang 2003 [2]	Well-graded improves strength	G3 95/5 achieved 28.6 MPa max
Kevern et al. 2008 [3]	Gradation governs strength-perm	Similar trend, G3 optimum
Neithalath 2010 [4]	Pore connectivity controls k	Continuous network 8.5 mm/s

Table III: Comparison – 28.6 MPa superior to typical 15-20 MPa reported.

VIII. PRACTICAL APPLICATIONS

M15 suitable for: (i) Parking areas (28.6 MPa >20 MPa required), (ii) Residential streets, (iii) Footpaths & walkways, (iv) Bicycle tracks, (v) Parks, (vi) Low-volume roads, (vii) Open yards, (viii) Bus bays, (ix) Institutional campuses, (x) Industrial pavements. Benefits: reduces runoff 70-80%, promotes recharge, minimizes drainage burden, mitigates heat island.

IX. LIMITATIONS & FUTURE SCOPE

Limitations: Only 5 gradations, single cement OPC 53, no SCMs, no durability – abrasion IS 9284, freeze-thaw ASTM C666, sulfate ASTM C1012, no clogging, no field traffic, no flexural IS 516, split tensile IS 5816. Future: Fibre-reinforced pervious concrete, SCMs fly ash/GGBS/silica fume/metakaolin, nano-materials, durability, abrasion, fatigue, LCCA, carbon footprint ISO 14040, field monitoring at MVR campus, AI/ML optimization ANN/GEP.

X. CONCLUSIONS

1. Gradation significantly influences density, voids, permeability, strength – G3 optimum.
2. G3 (95% CA, 5% FA) best among G1-G5 with balanced packing and interconnectivity.

3. w/c 0.24 + PCE 0.70% optimum workability and mechanical properties, slump retention 2hr.
4. Optimum M15: Density 1812 kg/m³, Void 24.5%, Permeability 8.5 mm/s (510 mm/min), f₇ 19.5 MPa, f₂₈ 28.6 MPa >25 MPa target.
5. All ACI 522R-10 criteria satisfied – suitable for parking, footpaths, low-volume roads.
6. Sustainable alternative promoting recharge, reducing urban flooding, supporting SDGs 6,11,13.

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DECLARATIONS

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AUTHOR BIOGRAPHY

P. Praneeth Kumar – M.Tech Transportation Engineering scholar at MVR College, B.Tech Civil. Research interests: sustainable pavements, pervious concrete, SCMs. B. Krishna Naik – M.Tech, Assistant Professor at MVR College with 8 years experience in concrete technology, transportation engineering. Guided 12 M.Tech projects. Member ISTE.