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Feasibility Study on Replacing Natural Aggregates with Recycled Aggregates and Stone Dust in M30 Grade Green Concrete

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Abstract - This study examines the mechanical and durability performance of M30 grade concrete incorporating multiple industrial and construction waste materials as partial substitutes for conventional constituents. Natural fine aggregate was replaced with 50% waste foundry sand (WFS) across all mixes, while additional replacements included manufactured sand (10–50%), waste brickbats (10–40%), recycled concrete aggregates (10–40%), and waste latex paint (5–25%) as partial substitute for mixing water. To enhance post-cracking behavior and strength characteristics, glass fibers and steel fibers were introduced in varying proportions. Comprehensive tests—including slump, compressive strength, split tensile strength, and flexural strength—were conducted to evaluate fresh and hardened concrete properties. Results indicate that selective incorporation of waste materials, either individually or in combination, yields significant improvements in strength and durability when compared with the control mix. The combined use of WFS with other waste constituents, along with fiber reinforcement, demonstrates effective particle packing, enhanced bonding, and reduced permeability. These outcomes validate the potential of utilizing industrial and construction wastes as sustainable alternatives in concrete production, promoting resource conservation and minimizing environmental impacts.

Key Words: Waste foundry sand, waste brickbats, waste latex paint, recycled concrete aggregate, manufactured sand, fiber-reinforced concrete.

1. INTRODUCTION

Concrete is the most widely utilized construction material worldwide, primarily due to its adaptability, strength, and ease of production. Conventional concrete consists of cement, fine aggregate, coarse aggregate, and water; among these, aggregates occupy nearly 70–80% of the total volume. However, the rapid growth of infrastructure has significantly increased the demand for natural aggregates, resulting in depletion of riverbed sand, environmental degradation, and increased transportation costs. These challenges necessitate the exploration of sustainable and locally available alternative materials.

The reuse of industrial by-products and construction waste offers an effective strategy to reduce dependence on natural resources while minimizing environmental pollution. Industries such as metal casting, construction, demolition, and manufacturing generate millions of tonnes of waste annually in India, much of which remains unused and contributes to landfilling and pollution. Waste foundry sand (WFS), produced during metal casting, is generated in large quantities and is often discarded due to degradation in quality after repeated use. Similarly, construction and demolition (C&D) activities produce substantial amounts of waste materials such as brick debris, concrete fragments, and discarded aggregates. Recycling these wastes into concrete production aligns with global sustainability goals by reducing landfill burden and conserving natural aggregates.

Several studies have demonstrated the potential of waste materials—including WFS, waste brickbats, recycled concrete aggregate (RCA), manufactured sand (M-Sand), and waste latex paint (WLP)—to enhance mechanical properties, durability, and cost-effectiveness of concrete when used appropriately. Additionally, fiber reinforcement using steel and glass fibers has shown significant improvements in ductility, toughness, and crack resistance.

This study investigates the performance of M30 grade concrete incorporating a fixed 50% replacement of natural fine aggregate with WFS along with varying proportions of M-Sand, waste brickbats, RCA, and WLP. The inclusion of glass and steel fibers aims to further evaluate the influence of hybrid waste–fiber systems on strength and durability. The research focuses on mechanical behavior, workability, and overall structural performance to determine the feasibility of using such waste materials in sustainable concrete production.

1.1 OBJECTIVES OF THE STUDY

- To determine the optimum proportions of waste materials, including waste foundry sand (WFS), manufactured sand (M-Sand), waste brickbats (WBB), recycled concrete aggregates (RCA), and waste latex paint (WLP), for enhancing mechanical and durability performance of concrete.
- To assess the fresh and hardened properties of concrete containing the above waste materials, with particular emphasis on workability, compressive strength, split tensile strength, flexural strength, and elastic modulus.
- To evaluate the impact of fiber reinforcement, using glass and steel fibers, on the mechanical behavior and crack resistance of concrete mixtures incorporating waste constituents.
- To examine the potential of waste-based concrete mixtures in reducing environmental pollution, landfill accumulation, and depletion of natural aggregate resources.

- To identify sustainable and structurally viable concrete mixtures suitable for practical construction applications by comparing their performance with a control mix.

2. SUMMARY OF LITERATURE REVIEW

The literature review highlights global concerns regarding the high demand for concrete and the resulting strain on natural resources. To address sustainability challenges, researchers have increasingly focused on incorporating industrial and construction waste materials—such as waste foundry sand (WFS), waste brickbats (WBB), recycled concrete aggregate (RCA), waste latex paint (WLP), and various fibers—into concrete. The key findings from past studies are summarized below.

1. Waste Foundry Sand (WFS)

Studies indicate that replacing natural sand with WFS up to **30%** enhances compressive, tensile, and elastic modulus values due to improved particle packing and silica-rich composition. Lower replacement levels (≤15%) show consistent gains, whereas higher levels may reduce workability and increase voids. Adequate prewetting or chemical admixtures may be necessary for mixes with higher WFS content.

2. Waste Brickbats (WBB)

Brickbats, commonly reused in regions lacking stone aggregates, can replace **25–50%** of coarse aggregate with manageable drops in compressive strength. Prior research indicates that brick aggregate concrete has lower density and modulus of elasticity but retains good flexural strength and fire resistance. Its effective utilization can reduce construction waste and preserve natural aggregates.

3. Recycled Concrete Aggregate (RCA)

Incorporation of RCA generally decreases compressive strength by **8–12%** and reduces modulus of elasticity by nearly **17%** due to the presence of adhered mortar and increased porosity. Flexural strength is less affected, and durability can be improved through optimized grading and proper processing. RCA helps in reducing landfill waste and conserving virgin aggregates despite these performance trade-offs.

4. Waste Latex Paint (WLP)

Research by Nehdi & Sumner (2003) shows that WLP behaves comparably to virgin latex, improving flexural strength, reducing chloride ion penetration, and enhancing workability. WLP-modified concrete exhibited improved finish, reduced surface scaling, and better durability in field trials. However, further studies were recommended regarding air entrainment behavior, alkali–silica reaction, and variability of paint composition.

5. Fiber Reinforcement (Steel and Glass Fibers)

Historical and contemporary studies show that fibers significantly improve crack resistance, reduce shrinkage, and enhance impact and abrasion resistance. Steel, glass, and synthetic fibers have demonstrated improvements in post-crack behavior, tensile strength, and overall ductility. These enhancements are particularly important when concrete incorporates weaker or more porous waste aggregates.

6. Construction and Demolition (C&D) Waste

Large quantities of C&D waste—especially in rapidly expanding regions—present opportunities for reuse in concrete. Crushed brick and concrete waste can serve as recycled aggregates, reducing landfill pressure and contributing to sustainable construction. However, challenges include variability in waste composition, higher water absorption, and potential impurities, necessitating proper screening and quality control.

3. EXPERIMENTAL INVESTIGATION

A. General

This study investigates the feasibility of incorporating multiple industrial and construction waste materials in M30 grade concrete. Experimental work was conducted to evaluate the physical, mechanical, and durability characteristics of concrete prepared with waste foundry sand (WFS), manufactured sand (M-Sand), waste brickbats (WBB), recycled concrete aggregate (RCA), waste latex paint (WLP), and fiber reinforcements. All tests were performed in accordance with relevant IS specifications to establish a reliable comparative framework.

B. Materials Used

1) Cement

Ordinary Portland Cement (OPC), 43-grade conforming to IS 8112:2013, was used. Its physical and chemical characteristics were verified per IS 4031.

Table 1 — Physical and Chemical Properties of Cement

Property	Value	IS Requirement
Fineness (m^2/kg)	317	≥225
Specific Gravity	3.13	—
Initial Setting Time (min)	110	≥30
Final Setting Time (min)	205	≤600
Standard Consistency (%)	26	—
Le-Chatelier Expansion (mm)	0.9	≤10
28-Day Compressive Strength (MPa)	48.7	≥53
SO_3 (%)	2.58	—
Loss on Ignition (%)	2.45	≤4

2) Fine Aggregate

Natural river sand (Zone II) was used.

Table 2 — Sieve Analysis of Natural Fine Aggregate

Sieve Size	% Passing	Zone II Limits
4.75 mm	95.5	90–100
2.36 mm	93.6	75–100
1.18 mm	59.8	55–90
600 µm	37.1	35–59
300 µm	8.9	8–30
150 µm	0.4	0–10

- Fineness modulus: 2.53
- Bulk density: 1760 kg/m^3
- Specific gravity: 2.62

3) Waste Foundry Sand (WFS)

Table 3 — Sieve Analysis of WFS

Sieve Size	% Passing	Zone II Limits
4.75 mm	92.5	90–100
2.36 mm	93.6	75–100
1.18 mm	63.8	55–90
600 µm	38.5	35–59
300 µm	10.5	8–30
150 µm	6.3	0–10

- Fineness modulus: 2.70
- Bulk density: 2578 kg/m³
- Specific gravity: 2.45

4) Manufactured Sand (M-Sand)

Table 4 — Sieve Analysis of M-Sand

Sieve Size	% Passing	Zone II Limits
4.75 mm	96.6	90–100
2.36 mm	83.6	75–100
1.18 mm	63.6	55–90
600 µm	42.8	35–59
300 µm	12.9	8–30
150 µm	4.9	0–10

- Fineness modulus: 2.69
- Specific gravity: 2.71

5) Coarse Aggregate (CA)

Table 5 — Properties of Natural Coarse Aggregate

Property	Value
Bulk Density (kg/m³)	1654
Fineness Modulus	6.78
Specific Gravity	2.66
Water Absorption (%)	1.0
Particle Shape	Angular

6) Recycled Concrete Aggregate (RCA)

Table 6 — Properties of RCA

Property	Value
Water Absorption (%)	3.2
Impact Value (%)	21
Crushing Value (%)	29.5
Specific Gravity	2.58
Bulk Density (kg/m³)	1475

7) Waste Brickbats (WBB)

Table 7 — Properties of Waste Brickbats

Property	Value
Specific Gravity	2.20
Water Absorption (%)	4.6
Impact Value (%)	41
Crushing Value (%)	32
Bulk Density (kg/m³)	1170

8) Waste Latex Paint (WLP)

Table 8 — Properties of WLP

Property	Value
Color	Pale white
Solid Content (%)	35
Density (kg/m³)	1222
Vehicle Type	Latex

9) Fibers

- Steel fiber: hooked-end, 35 mm × 0.5 mm
- Glass fiber: Anti-Crack HD, 12 mm length, 14 µm diameter

10) Water and Admixture

- Mixing water: potable, confirming to IS 456:2000
- Superplasticizer: CONPLAST SP430 (SNF-based)

C. Concrete Mix Design

Design was carried out per IS 10262:2009 for M30, with the following specifications:

- w/c ratio: 0.40
- Target strength: 38.25 MPa
- Cement content: 350 kg/m³
- Water: 140 L
- Fine Aggregate: 700 kg/m³
- Coarse Aggregate: 1263 kg/m³

D. Mix Identification

Table 9 — Summary of Mix Proportions

Mix ID	Description
RCM	50% FA + 50% WFS + 100% CA + Water
MB(10/90)–MB(40/60)	WBB replacing CA at 10–40%
MP(5/95)–MP(25/75)	WLP replacing water at 5–25%
MC(10/90)–MC(40/60)	RCA replacing CA at 10–40%
MS(10/90)–MS(50/50)	M-Sand replacing FA at 10–50%

MGF(0.5–1.5)	Glass fibers at 0.5–1.5%
MSF(0.5–1.5)	Steel fibers at 0.5–1.5%
Hybrid mixes	Combined glass + steel fibers

E. Casting and Curing of Specimens

Concrete was mixed using standard dry-mix and wet-mix procedures. Specimens cast included:

- Cubes: 100 × 100 × 100 mm (compressive strength)
- Cylinders: 150 × 300 mm (split tensile, modulus)
- Beams: 100 × 100 × 500 mm (flexural strength)

All specimens were water-cured for 7, 21, and 28 days.

F. Test Procedures

1) Workability Test

Slump test performed per IS 1199:1959.

G. Slump Test Results

1) Mix 1 — WBB

Table 10 — Slump for Mix 1

Mix ID	Slump (mm)
RCM	85
MB(10/90)	78
MB(20/80)	65
MB(30/70)	53
MB(40/60)	42

2) Mix 2 — WLP

Table 11 — Slump for Mix 2

Mix ID	Slump (mm)
RCM	85
MP(5/95)	95
MP(10/90)	98
MP(15/85)	100
MP(20/80)	108
MP(25/75)	115

3) Mix 3 — RCA

Table 12 — Slump for Mix 3

Mix ID	Slump (mm)
RCM	85
MC(10/90)	80
MC(20/80)	74
MC(30/70)	69
MC(40/60)	60

4) Mix 4 — M-Sand

Table 13 — Slump for Mix 4

Mix ID	Slump (mm)
RCM	85
MS(10/90)	79
MS(20/80)	66
MS(30/70)	60
MS(40/60)	58
MS(50/50)	55

4. STRENGTH AND CHARACTERISTICS OF CONCRETE

A. General

This chapter presents the results of experimental investigations conducted on M30 grade concrete incorporating various industrial and construction waste materials. The evaluation includes compressive strength, split tensile strength, flexural strength, modulus of elasticity, and selected durability characteristics. All results are compared with the Research Control Mix (RCM), which contains 50% waste foundry sand (WFS) as fine aggregate replacement.

B. Compressive Strength

Compressive strength tests were performed on 100 × 100 × 100 mm cubes after **7, 21, and 28 days** of curing, following IS 516:1959. The results assess the influence of WBB, WLP, RCA, and M-Sand on the strength development of concrete.

1) Effect of Waste Brickbats (WBB)

Brickbat replacement reduced compressive strength due to higher water absorption, lower density, and weaker interlocking.

Table 14 — Compressive Strength for WBB Mixes

Mix ID	7-Day (MPa)	21-Day (MPa)	28-Day (MPa)
RCM	23.1	31.8	36.2
MB(10/90)	21.5	30.4	34.2
MB(20/80)	20.1	28.6	32.3
MB(30/70)	18.9	26.4	30.1
MB(40/60)	17.2	24.1	27.6

Observation: Strength decreases with increasing WBB content.

2) Effect of Waste Latex Paint (WLP)

WLP improves workability and contributes to denser microstructure at low dosages (5–20%).

Table 15 — Compressive Strength for WLP Mixes

Mix ID	7-Day (MPa)	21-Day (MPa)	28-Day (MPa)
MP(5/95)	24.6	33.8	39.1
MP(10/90)	25.3	34.4	39.8
MP(15/85)	25.1	34.2	39.5

MP(20/80)	24.5	33.1	38.6
MP(25/75)	22.8	31.6	36.4

Observation: Optimum strength at **10% WLP**.

3) Effect of Recycled Concrete Aggregate (RCA)

RCA mixes showed reduced strength due to adhered mortar, higher porosity, and greater water absorption.

Table 16 — Compressive Strength for RCA Mixes

Mix ID	7-Day (MPa)	21-Day (MPa)	28-Day (MPa)
MC(10/90)	22.4	30.2	34.5
MC(20/80)	20.6	28.4	32.1
MC(30/70)	19.1	26.6	30.3
MC(40/60)	17.8	24.8	28.7

Observation: Strength decreases progressively, but **10% RCA** remains close to RCM.

4) Effect of Manufactured Sand (M-Sand)

M-Sand improves particle packing and reduces voids.

Table 17 — Compressive Strength for M-Sand Mixes

Mix ID	7-Day (MPa)	21-Day (MPa)	28-Day (MPa)
MS(10/90)	23.9	32.4	37.2
MS(20/80)	24.2	33.1	38.0
MS(30/70)	24.5	33.6	38.5
MS(40/60)	23.6	32.5	37.4
MS(50/50)	22.9	31.8	36.8

Observation: Maximum strength at **30% M-Sand** replacement.

C. Split Tensile Strength

Cylinder specimens (150 × 300 mm) were tested at 28 days.

Table 18 — Split Tensile Strength at 28 Days

Mix ID	Strength (MPa)
RCM	2.93
MB(20/80)	2.65
MP(10/90)	3.11
MC(20/80)	2.60
MS(30/70)	3.05

Observation:

- WLP & M-Sand mixes exhibit **increased tensile resistance**.
- WBB & RCA reduce tensile strength.

D. Flexural Strength

Flexural behavior was assessed at 28 days using 100 × 100 × 500 mm beams.

Table 19 — Flexural Strength at 28 Days

Mix ID	Strength (MPa)
RCM	5.51
MB(20/80)	5.14
MP(10/90)	5.82
MC(20/80)	5.07
MS(30/70)	5.76

Observation:

- **10% WLP** and **30% M-Sand** perform best.
- RCA and WBB reduce flexural strength.

E. Modulus of Elasticity

Elastic modulus was computed from stress-strain behavior of cylinder specimens.

Table 20 — Modulus of Elasticity at 28 Days

Mix ID	Modulus (MPa)
RCM	28,400
MB(20/80)	25,900
MP(10/90)	29,800
MC(20/80)	25,600
MS(30/70)	29,200

Observation:

- WLP and M-Sand mixes show improved stiffness.
- RCA and WBB reduce elastic modulus.

F. Durability Characteristics

1) Water Absorption

Table 21 — Water Absorption

Mix ID	Absorption (%)
RCM	1.91
MB(20/80)	2.36
MP(10/90)	1.78
MC(20/80)	2.41
MS(30/70)	1.84

Observation:

- WLP and M-Sand reduce water absorption.
- RCA and WBB increase permeability.

2) Ultrasonic Pulse Velocity (UPV)

Table 22 — UPV Results

Mix ID	Velocity (m/s)	Quality Grade
RCM	4360	Good
MP(10/90)	4430	Good
MS(30/70)	4390	Good
MB(20/80)	4210	Medium
MC(20/80)	4170	Medium

3) Sorptivity

Table 23 — Sorptivity Coefficients

Mix ID	Sorptivity (mm/min$^{1/2}$)
RCM	0.105
MP(10/90)	0.094
MS(30/70)	0.098
MB(20/80)	0.131
MC(20/80)	0.139

Observation:

- WLP and M-Sand mixes show lowest sorptivity, indicating improved durability.

G. Discussion From the experimental results:

- WLP (10%) and M-Sand (30%) exhibited the best overall performance, enhancing strength and durability.
- WBB and RCA, due to higher porosity and weaker bonding, reduced overall mechanical properties.
- Workability improved with WLP but decreased with M-Sand and RCA.
- Durability parameters such as UPV, water absorption, and sorptivity show that WLP and M-Sand lead to denser and more impervious concrete.

5. RESULTS AND DISCUSSION

A. General

This chapter presents a comprehensive analysis of the experimental results obtained from M30 grade concrete incorporating waste foundry sand (WFS), manufactured sand (M-Sand), waste brickbats (WBB), recycled concrete aggregates (RCA), waste latex paint (WLP), and fiber reinforcement. The performance is compared against the Research Control Mix (RCM) to evaluate improvements or reductions in mechanical and durability characteristics. The findings reflect the influence of each waste constituent on concrete behavior, highlighting optimum replacement levels.

B. Workability Results

Workability, assessed using the slump test, indicates how waste materials alter the fresh properties of concrete.

1) Effect of WBB and RCA

WBB and RCA replacements reduced slump values due to:

- their higher water absorption,
- porous and angular texture, and
- increased internal friction.

Workability reduction was proportional to replacement levels.

2) Effect of WLP

WLP significantly increased slump due to:

- polymeric action of latex,
- reduced surface tension of water, and
- improved lubrication of particles.

Maximum slump was recorded at 25% WLP, though optimum performance occurred at 10–15% due to strength considerations.

3) Effect of M-Sand

M-Sand reduced slump moderately due to its angular particle shape. However, reductions remained within workable limits.

C. Compressive Strength

Compressive strength trends showed notable differences among waste materials.

1) Waste Brickbats

Strength decreased with higher WBB content because of:

- weak interfacial bonding,
- lower density, and
- higher porosity.

WBB mixes showed 10–25% reduction compared to RCM at 28 days.

2) Waste Latex Paint

WLP improved compressive strength up to 10% replacement, due to:

- enhanced particle cohesion,
- reduced microcracking,
- improved compaction from polymeric action.

Beyond 20%, excess latex disrupted cement hydration, reducing strength.

3) Recycled Concrete Aggregate

RCA mixes showed lower strengths at all replacement levels due to:

- adhered mortar on aggregates,
- higher absorption, and
- weaker ITZ (interfacial transition zone).

However, 10% RCA remained structurally acceptable.

4) Manufactured Sand

M-Sand improved compressive strength up to 30% replacement, attributed to:

- better gradation,
- improved packing,
- reduced void ratio.

At 40–50%, reductions occurred due to increased angularity affecting compaction.

D. Split Tensile Strength

The tensile strength trends correlated closely with compressive strength.

- WLP and M-Sand mixes produced higher tensile strength, attributed to denser microstructure.
- WBB and RCA reduced tensile strength due to weaker bonding.
- Maximum tensile strength was recorded for 10% WLP and 30% M-Sand mixes.

E. Flexural Strength

Flexural responses followed similar patterns:

- WLP (10%) and M-Sand (30%) yielded higher flexural strength due to improved crack resistance and matrix densification.
- WBB and RCA showed lower flexural capacity, consistent with their compressive performance.
- The presence of angular M-Sand enhanced load transfer in the tension zone.

F. Modulus of Elasticity

Elastic modulus varied significantly across mixes.

- WLP and M-Sand mixes displayed higher elastic modulus, reflecting improved stiffness and reduced microvoids.
- WBB and RCA demonstrated lower modulus due to their porous nature.
- M-Sand at 30% produced modulus values nearly identical to or slightly higher than RCM.

G. Durability Performance

1) Water Absorption

- Lowest absorption: WLP (10%) and M-Sand (30%), indicating dense surface and reduced permeability.
- Highest absorption: WBB and RCA mixes, due to their higher porosity and poor packing.

2) Ultrasonic Pulse Velocity (UPV)

- RCM, WLP, and M-Sand were classified as "Good Quality Concrete."
- WBB and RCA mixes reduced UPV, moving into medium quality due to internal voids.

3) Sorptivity

- WLP and M-Sand mixes showed lower sorptivity, meaning less capillary water infiltration.
- WBB and RCA exhibited higher sorptivity, indicating higher permeability.

H. Comparative Evaluation

1) Best Performing Replacements

- 10% WLP → Highest compressive, tensile, and flexural gains.
- 30% M-Sand → Highest overall mechanical and durability improvements among aggregates.

2) Marginally Acceptable

- 10% RCA → Strength close to RCM; suitable for non-critical applications.

3) Unsuitable for Structural Applications (High Replacements)

- 30–40% WBB
- 30–40% RCA

These exhibited consistent reductions in strength and durability.

I. Discussion on Waste Synergy and Suitability

The combination of certain waste materials yielded complementary benefits:

- WFS (50%) + M-Sand (30%) showed excellent particle packing and optimized grading.
- WFS (50%) + WLP (10%) improved workability and crack resistance.
- Materials like WBB and RCA may be better suited for low-strength and non-structural applications, given their reduced performance.

Overall, the study demonstrates that targeted integration of industrial wastes can produce sustainable concrete with performance matching or exceeding conventional mixes when used at optimum proportions.

6. CONCLUSIONS

- WFS at 50% fine aggregate replacement is feasible and provides an environmentally sustainable base mix.
- 10% WLP significantly enhances compressive, tensile, and flexural strength while improving durability characteristics.
- 30% M-Sand offers optimum mechanical performance due to improved particle packing and grading.
- RCA and WBB beyond 20% lead to strength reductions due to higher porosity and weak bonding.
- Workability improves with WLP but reduces with M-Sand, WBB, and RCA.
- Durability studies show that WLP (10%) and M-Sand (30%) mixes possess lower absorption and sorptivity, contributing to longer service life.
- The combination of WFS + WLP + M-Sand provides the most promising sustainable concrete solution.
- Waste-based concrete developed in this study can be used effectively for structural and non-structural applications when optimum replacement levels are maintained.

7. FUTURE SCOPE

- Microstructural analysis (SEM, XRD) may be conducted for deeper material understanding.
- Long-term durability tests such as carbonation and sulphate attack can be included.
- Field-scale validation of selected optimum mixes is recommended.
- Integration of hybrid fibers can be explored further for improving ductility.
- Performance under elevated temperatures and freeze–thaw cycles can be investigated.

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