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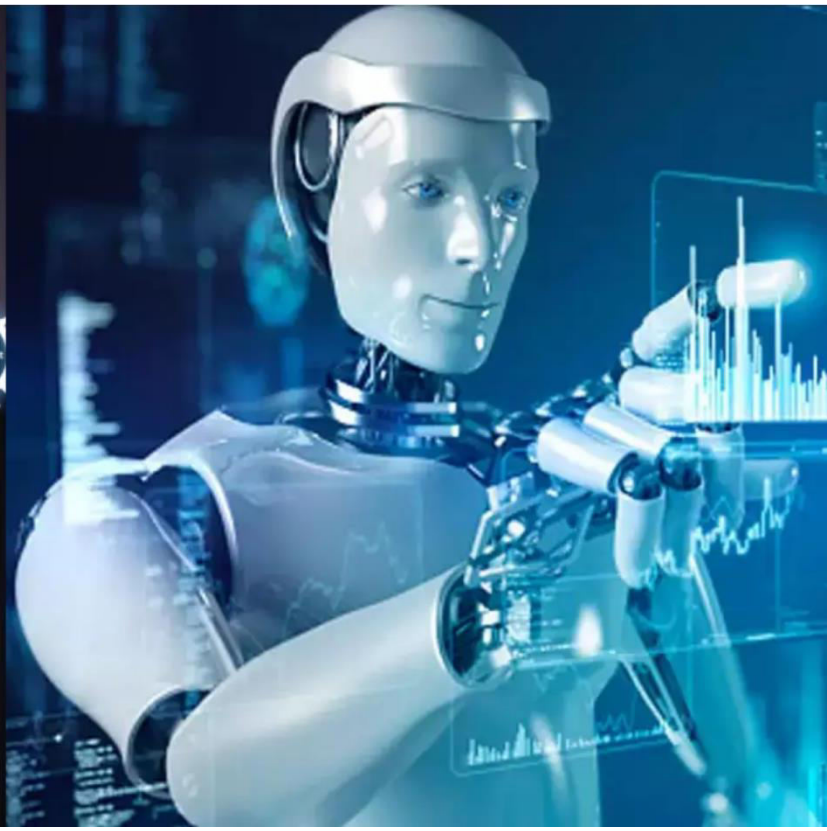

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Performance Evaluation and Cost Optimization of Sustainable Concrete Cover Blocks using Waste Glass Powder and Marble Waste Powder as Partial Cement Replacements

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ABSTRACT: This study examines the material-efficiency and preliminary economic implications of replacing ordinary Portland cement with a combined marble waste powder (MWP) and waste glass powder (WGP) fraction in concrete cover-block production. A M40 reference mixture containing 426 kg/m³ of cement was used as the basis for a transparent cement-substitution calculation. The study documents a control mixture and combined replacement levels of 5–25%; detailed economic tabulations are available for 15%, 20%, and 25%. At an cement price of ₹9/kg and zero acquisition cost for waste powders at source, the corresponding gross cement-expenditure reductions are ₹575.10, ₹766.80, and ₹958.50 per cubic metre. Dimensional records for three nominal 40 mm diameter and 10 mm thick samples indicate diameter deviations within ±0.2 mm and thickness deviations within ±0.1 mm. The calculations establish a potential for reducing purchased cement, but do not establish net production savings or verified carbon reductions because powder preparation, transport, energy, yield, and emissions factors were not measured. A cost-break-even model is presented to clarify conditions under which waste substitution could remain economically beneficial.

KEYWORDS: concrete cover block; marble waste powder; waste glass powder; cement substitution; cost optimization; dimensional accuracy; circular materials

I. INTRODUCTION

Unlike a mechanical-strength study, the present analysis examines resource substitution and the financial boundary conditions for producing cover blocks with recovered powders. Its economic estimates are scenario-based and do not represent observed manufacturing costs[1,2]. Concrete cover blocks maintain the intended separation between reinforcement and the formwork surface. Their production offers a small but repeatable opportunity to investigate alternative cementitious constituents. Marble-processing residues and ground waste glass are potential secondary raw materials, yet their incorporation must be evaluated in terms of performance, process feasibility and cost rather than waste diversion alone[3]. In theinvestigation, mixtures were prepared with paired MWP and WGP additions. This paper isolates the resource-use and preliminary economic implications of those mix proportions, while the companion strength-focused study addresses compressive performance.

The primary research question is whether the reduction in purchased cement can create a meaningful economic margin after accounting for the unmeasured costs of processing and handling the two waste powders. A secondary question concerns the dimensional repeatability indicated by the limited measurements recorded in the study[4].

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II. MATERIALS AND METHODOLOGY

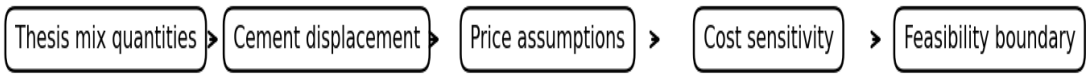

Figure.1. Analytical workflow for estimating resource substitution and economic feasibility [5]

Figure 1 illustrates the systematic methodology adopted to evaluate the economic feasibility and resource efficiency of concrete cover blocks incorporating Marble Waste Powder (MWP) and Waste Glass Powder (WGP) as partial cement replacements. The analytical process begins with the reference M40 concrete mix design, followed by the selection of different cement replacement percentages. The corresponding reductions in cement consumption are calculated to determine potential material savings. Subsequently, the economic assessment considers cement costs, waste-powder processing expenses, and transportation-related factors through cost-sensitivity analysis. The framework also incorporates dimensional quality assessment to examine the suitability of the developed cover blocks. Finally, the results are compared to identify economically favorable replacement levels and assess their potential contribution to sustainable construction practices[6].

2.1 Concrete mixture

TheM40 reference design specifies cement at 426 kg/m³, fine aggregate at 757 kg/m³, coarse aggregate at 1116 kg/m³, water at 153 L/m³, admixture at 4.7 kg/m³, and a nominal water cement ratio of 0.36. These values are reproduced and rather than independently redesigned mix proportions.

Table.1. M40 reference mix quantities

Constituent	Quantity
Cement	426 kg/m³
Fine aggregate	757 kg/m³
Coarse aggregate	1116 kg/m³
Water	153 L/m³
Admixture	4.7 kg/m³
Water–cement ratio	0.36

2.2 Replacement strategy

The experimental scheme increases the combined MWP–WGP substitution in five-percentage-point increments. Themix table explicitly identifies equal contributions from MWP and WGP through 20% total replacement. The 25% mixture appears in the strength and cost reporting, but its individual MWP and WGP fractions are specified in the composition 12.5%.

Table.2. Cement replacement design in the study

Mix	Cement (%)	MWP (%)	WGP (%)	Total (%)
M0	100	0	0	0
M1	95	2.5	2.5	5
M2	90	5	5	10
M3	85	7.5	7.5	15
M4	80	10	10	20
M5	75	12.5	12.5	25

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2.3 Cost-assessment framework

The study assumes a cement purchase rate of ₹9/kg, with MWP and WGP supplied at zero material-acquisition cost at their source. These are scenario assumptions, not surveyed market prices. Gross cement saving S (₹/m³) is calculated as $S = C \times r \times P$, where $C = 426$ kg/m³, r is the combined cement replacement fraction, and P = ₹9/kg. Remaining cement expenditure is $(1 - r) \times C \times P$. For net saving, the incremental collection, grinding, sieving, drying, transport, admixture, labour and quality-control costs must be deducted from S[7,8,9].

A break-even condition follows directly: net saving remains positive only if the combined additional cost of preparing and using the replacement powders is lower than the gross cement saving. The analysis does not assume that waste material has zero delivered or processing cost.

2.4 Dimensional inspection

This study focused on diameter and thickness measurements for three nominally circular specimens. Deviations are computed relative to 40.0 mm diameter and 10.0 mm thickness. The small sample is used descriptively; no statistical process capability, acceptance rate or formal dimensional compliance claim can be inferred without a specified tolerance standard and a larger sampling plan.

2.5 Environmental assessment boundaries

Cement displacement is as a mass-based proxy for potential resource conservation. It is not equated to a measured reduction in embodied carbon. A defensible life-cycle comparison would require verified cement emission factors, powder collection and processing energy, transport distances, production yields, and any changes in durability or service life. No life-cycle inventory was provided in the study.

III. RESULTS AND DISCUSSION

3.1 Cement demand and gross material savings

Table.3. Calculated cement demand and gross savings at an ₹9/kg

Replacement	Cement retained (kg/m³)	Cement displaced (kg/m³)	Cement cost (₹/m³)	Gross saving (₹/m³)
0%	426.00	0.00	3,834.00	0.00
5%	404.70	21.30	3,642.30	191.70
10%	383.40	42.60	3,450.60	383.40
15%	362.10	63.90	3,258.90	575.10
20%	340.80	85.20	3,067.20	766.80
25%	319.50	106.50	2,875.50	958.50

The calculated gross saving rises linearly with the substitution fraction because both the reference cement content and the unit price are held constant. At 15%, 20% and 25%, the displaced cement masses are 63.90, 85.20 and 106.50 kg/m³. The corresponding gross expenditure reductions are ₹575.10, ₹766.80 and ₹958.50/m³. These figures measure avoided cement purchases only; they do not represent the total cost of a finished cover block.

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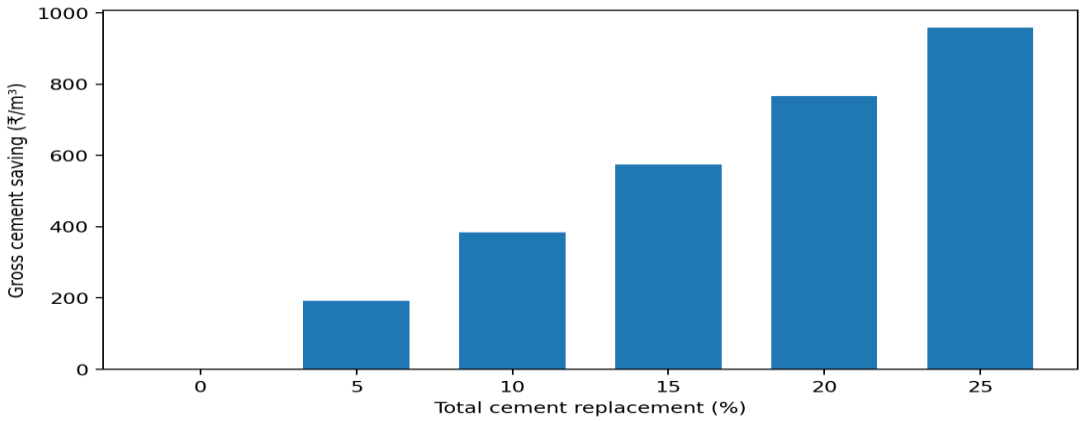

Figure.2. Calculated gross cement-purchase saving by total replacement percentage

3.2 Economic break-even interpretation

The avoided cement cost defines the maximum additional processing and delivery cost that can be incurred before the substitution loses its gross price advantage. For example, at 20% replacement the powders collectively replace 85.2 kg of cement per cubic metre, leaving a gross saving of ₹766.80. If additional costs attributable to the powders equal ₹400/m³, the illustrative net benefit becomes ₹366.80/m³; if they exceed ₹766.80/m³, the illustrative cost advantage disappears. The ₹400 example is a scenario, not an observed expense.

Table.4. Break-even thresholds for additional waste-powder costs

Replacement	Displaced cement (kg/m³)	Maximum added cost for positive net saving (₹/m³)	Equivalent threshold (₹/kg displaced cement)
15%	63.90	575.10	9.00
20%	85.20	766.80	9.00
25%	106.50	958.50	9.00

The equality of the ₹9/kg break-even threshold across replacement levels is a mathematical consequence of the fixed cement price, not evidence that the waste powders can be processed at that rate. Future production trials should record the actual delivered powder cost and rejected-block rate before recommending an economically optimal mixture.

3.3 Cover-block-level cost estimates

Thestudy separately reports cement-only savings per cover block of ₹0.0072, ₹0.0096 and ₹0.0120 for 15%, 20% and 25% replacement. These very small values depend on an implicit per-block cement mass that is not fully documented. They are retained below as estimates and should not be used for procurement or pricing decisions without verifying block geometry, density, production yield and the conversion from cubic metres to individual units.

Table.5. Source- cement-only savings per cover block

Replacement	Saving (₹/block)	Interpretation
0%	0.0000	Reference
15%	0.0072	Illustrative cement-only
20%	0.0096	Illustrative cement-only
25%	0.0120	Illustrative cement-only

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3.4 Dimensional quality observations

Table.6. dimensions of three nominal circular cover-block specimens

Sample	Diameter (mm)	Thickness (mm)	Diameter deviation (mm)	Thickness deviation (mm)
1	40.0	10.0	0.0	0.0
2	39.8	9.9	−0.2	−0.1
3	40.2	10.1	+0.2	+0.1
Mean	40.0	10.0	0.0	0.0

The observed mean equals the nominal dimensions, while individual readings vary by up to 0.2 mm in diameter and 0.1 mm in thickness. This pattern suggests limited variation in the three measurements, but it does not prove repeatability across batches or demonstrate compliance with a particular cover-block standard. In addition, the study does not identify the replacement percentage corresponding to each measured specimen; a mix-wise dimensional comparison is therefore not possible.

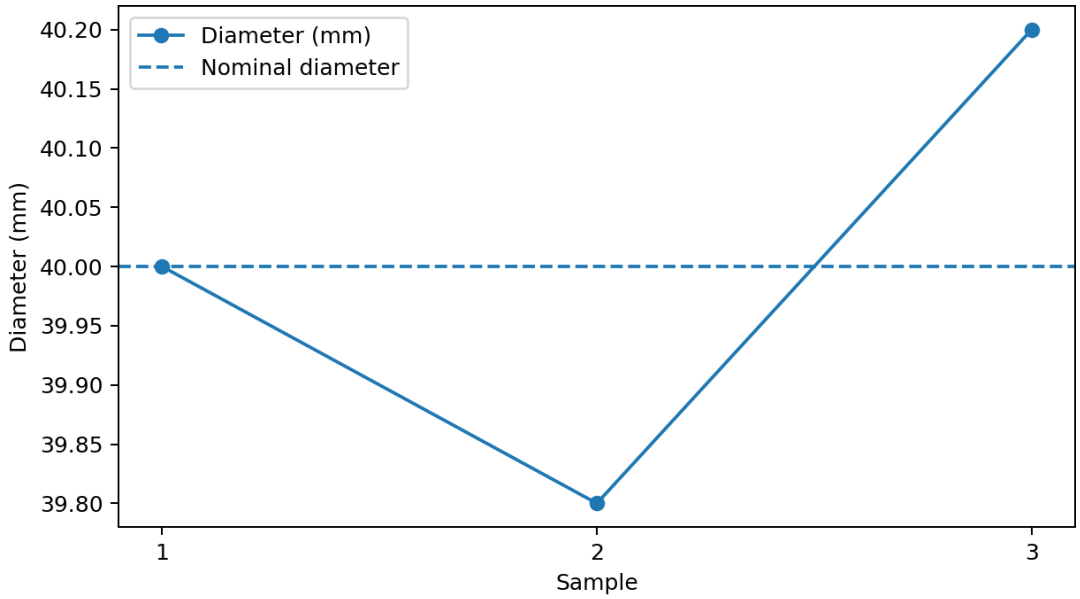

Figure.3. diameter variation among three cover-block specimens

3.5 Performance and sustainability considerations

The study also provides 7-, 14- and 28-day compressive-strength values across the replacement series, but the control is described as a 150 mm cube whereas the modified specimens are described as 40 mm diameter × 10 mm thick cover blocks. The associated failure-load units and conversion to strength are inconsistent. For that reason, this cost-focused paper does not use the strength series to rank mixtures or claim a verified optimum. The absence of comparable water-absorption measurements and service-life data also prevents a quantitative durability-based optimization.

Replacing cement with recovered powders can lower the mass of virgin cement specified per unit volume. Nevertheless, whether this translates into lower total environmental impacts depends on the energy needed to process glass and marble residues, transportation, any required changes in admixture demand, and long-term block performance. A numerical percentage reduction in greenhouse-gas emissions cannot be substantiated from the available study data.

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3.6 Decision framework for future production-scale optimization

Table.7. Production-scale optimization

Criterion	Availableevidence	Additional measurement needed
Cement use	Reference mix and replacement levels	Actual batch mass balance
Material cost	₹9/kg cement; free waste at source	Delivered and processed powder costs
Dimensional accuracy	Three specimen measurements	Mix-specific sample sizes and tolerance criteria
Mechanical performance	strength values with specimen inconsistencies	Comparable standardized tests
Durability	No complete mix-wise test series	Water absorption and exposure testing
Environmental benefit	Cement mass displaced	Life-cycle inventory and emissions factors

An economically preferable mixture should be selected only after satisfying a minimum mechanical and dimensional acceptance criterion. Within that feasible set, net cost can be minimized by combining actual unit costs with production yield and rejection rates. The present calculation supports preliminary screening of replacement levels, not a final optimum.

3.7 Sensitivity of savings to waste-powder preparation cost

To distinguish theoretical cement-purchase savings from achievable net savings, a scenario analysis was calculated using an combined processing and transport cost of ₹0, ₹2, ₹4, or ₹6 per kilogram of substituted powder. These values are hypothetical scenarios, not measured costs. Net material saving = displaced cement mass × (₹9/kg − waste-powder preparation cost).

Table.8. Scenario-based net material savings (₹/m³), excluding other production costs

Replacement	₹0/kg	₹2/kg	₹4/kg	₹6/kg
5%	₹191.70	₹149.10	₹106.50	₹63.90
10%	₹383.40	₹298.20	₹213.00	₹127.80
15%	₹575.10	₹447.30	₹319.50	₹191.70
20%	₹766.80	₹596.40	₹426.00	₹255.60
25%	₹958.50	₹745.50	₹532.50	₹319.50

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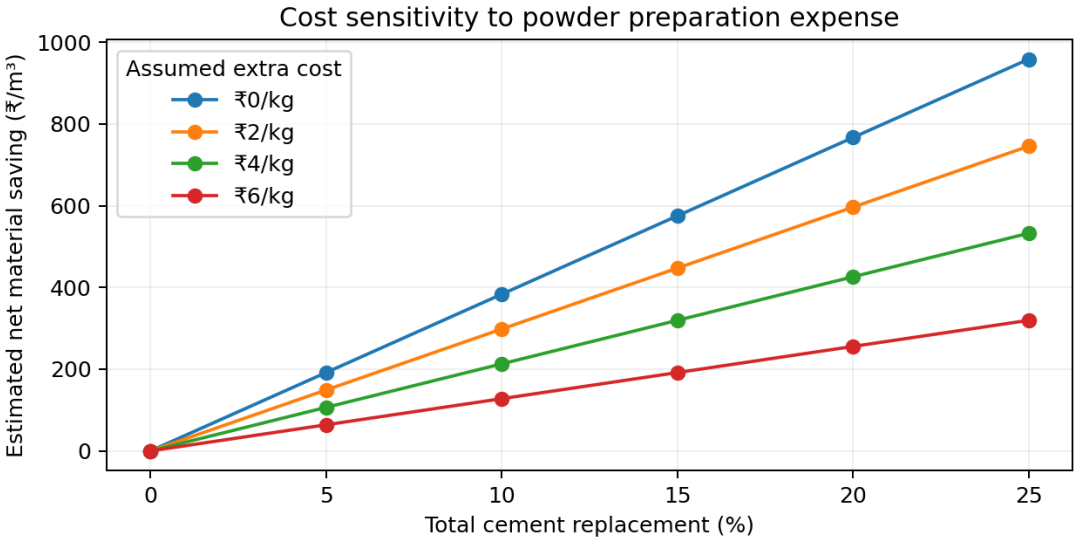

Figure.4. Sensitivity of calculated material savings to waste-powder preparation cost

IV. CONCLUSIONS

1. At a fixed cement content of 426 kg/m³ and cement price of ₹9/kg, total replacement levels of 15%, 20% and 25% correspond to gross cement-purchase savings of ₹575.10, ₹766.80 and ₹958.50 per cubic metre, respectively.
2. The estimated saving is proportional to cement displacement and should not be interpreted as a verified reduction in the overall production cost of concrete cover blocks. Processing, transport, handling and quality-control expenditures remain unmeasured.
3. Three specimens averaged 40.0 mm in diameter and 10.0 mm in thickness; observed deviations were within ±0.2 mm and ±0.1 mm, respectively. These observations are descriptive and insufficient for formal dimensional compliance assessment.
4. The available evidence supports the potential for reducing purchased cement and redirecting mineral and glass residues into construction materials. Quantified embodied-carbon reduction, durability performance and economic optimality require additional primary measurements.
5. A defensible future optimum should be based on matched strength testing, mix-wise dimensional inspection, measured waste-powder preparation costs and an explicit environmental system boundary.

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