

# Technical and environmental assessment of cement mortars incorporating recycled bottle glass powder as a supplementary cementitious material

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## 1. Introduction

Reducing the climate impact of cement-based materials is a strategic priority for the construction sector. Cement production is carbon-intensive, largely because of clinker manufacture, and the use of supplementary cementitious materials (SCMs) is widely recognised as a practical route to lower embodied emissions whilst maintaining performance (Habert et al., 2020). In parallel, circular-economy approaches encourage the valorisation of waste streams as resources within construction products.

Post-consumer container glass is an abundant waste stream with potential for use in cementitious systems after comminution. When sufficiently finely ground, glass powder can show pozzolanic reactivity and may contribute to strength development; however, the net effect depends on replacement level, fineness and curing age, and high replacement levels can lead to marked strength penalties due to clinker dilution (Jani and Hogland, 2014).

Although recycled glass powder has been studied previously, evidence remains fragmented regarding the combined technical–environmental trade-off in mortars across broad substitution ranges and multiple curing ages. This work provides an integrated assessment of (i) relatively high cement replacement levels (10–40% by mass) at constant w/c, (ii) mechanical performance at 7, 14 and 28 days in both compression and flexure under controlled curing, and (iii) a comparative cradle-to-gate GWP analysis considering materials only (no transport), modelled consistently for 1 m<sup>3</sup> of mortar using established LCA tools and standards (EN 15804+A2; IPCC 2021 GTP100), enabling a clear quantification of carbon savings versus performance.

## 2. Materials and Methods

Portland cement CEM I 42.5 R-SR was used. The aggregate was a limestone natural sand (0/3) with density 2.447 g/cm<sup>3</sup> and water absorption 2.6%. The SCM consisted of recycled bottle glass, crushed using a jaw crusher and subsequently milled with a laboratory pulveriser to obtain a powder intended to replace cement. Potable water was used for mixing and no admixtures were added.



Figure 1. Crushed glass in the two crushing phases

Five mixes were produced: a reference mortar (M0) and four mortars with cement replacement by recycled glass powder at 10%, 20%, 30% and 40% by mass (M10–M40). The water-to-cement ratio was maintained at w/c = 0.60. Mix proportions are given in Table 1.

Table 1. Mix proportions (kg/m<sup>3</sup>).

Material	M0	M10	M20	M30	M40
CEM I	972.41	875.17	777.93	680.69	583.45
Recycled Glass	0.00	97.24	194.48	291.72	388.96
Natural Sand	3758.59	3758.59	3758.59	3758.59	3758.59
Total Water	679.48	679.48	679.48	679.48	679.48

Mixing followed a staged protocol: sand was pre-mixed with its saturation water for 2 min at low speed (V1; 140 rpm) and rested for 10 min (mixer off). Cement was added gradually whilst mixing continued at V1 for 30 s. Effective mixing water was then added and mixing continued for 2 min at V1. After a 1 min mixing resumed for

1 min at high speed (V2; 285 rpm). Mortar was cast into 40 × 40 × 160 mm prisms and cured at 20 ± 2 °C and 65 ± 5% RH until testing.

Flexural and compressive strength were measured at 7, 14 and 28 days according to UNE-EN 1015-11. A simplified GWP assessment (materials only; no transport) was performed for a functional unit of 1 m<sup>3</sup> of mortar to enable internal comparison between mixes. Inventory data were sourced from ecoinvent 3.10 and modelling was performed in SimaPro 9.6.0.1, applying EN 15804+A2 and IPCC 2021 GTP100.

### 3. Results and discussion

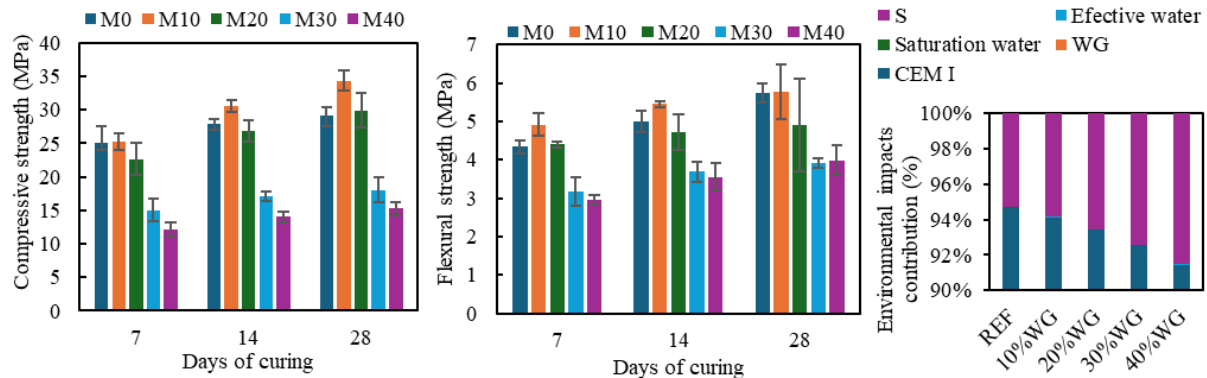


Figure 2. Summarises compressive strength, flexural strength and materials-only GWP for all mixes.

Regarding compressive strength at 7 days, M0 and M10 were comparable (25.12 and 25.29 MPa), whilst M20 decreased to 22.62 MPa and higher replacement levels showed pronounced reductions (15.03 MPa for M30; 12.13 MPa for M40). At 28 days, M10 reached 34.35 MPa versus 29.11 MPa for M0 ( $\approx +18\%$ ), and M20 achieved 29.94 MPa (comparable to M0). In contrast, M30 and M40 remained substantially lower (18.05 and 15.28 MPa). This pattern aligns with published observations that moderate glass powder contents can maintain or improve later-age strength depending on fineness and curing, whereas higher replacements tend to be dominated by dilution effects (Matos and Sousa-Coutinho, 2012). Flexural strengths follow the same trends as compressive strengths.

The GWP decreased monotonically with increasing glass content: 497.96 (M0), 450.82 (M10), 403.67 (M20), 356.53 (M30) and 309.39 kg CO<sub>2</sub>-eq (M40) per 1 m<sup>3</sup>, corresponding to reductions of  $\sim 9.5\%$ , 18.9%, 28.4% and 37.9% relative to M0. This confirms the clear embodied-carbon advantage of reducing cement content, consistent with broader decarbonisation strategies for cement and concrete (Habert et al., 2020). The combined results highlight a practical trade-off: carbon savings increase with replacement, but mechanical performance imposes an upper bound on feasible substitution.

### 4. Conclusions

Recycled bottle glass powder can function as an SCM in cement mortars to reduce materials-only embodied carbon whilst maintaining acceptable strength at moderate replacement levels. A 10% replacement provided the most favourable overall balance, improving compressive strength at 14 and 28 days and maintaining flexural strength equivalent to the reference at 28 days. A 20% replacement achieved compressive strength comparable to the reference at 28 days but reduced flexural strength. Higher replacements (30–40%) delivered larger GWP reductions (up to  $\sim 38\%$ ) but incurred substantial strength penalties. For the studied system and curing regime, 10–20% replacement appears to provide the most practical compromise between technical performance and environmental benefit.

### 5. References

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