

Experimental Investigation on the Mechanical and Durability Properties of M40 and M70 Cement-Based Composite Using Waste Glass as Partial Replacement of Coarse Aggregate

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Abstract- The increasing consumption of natural aggregates in concrete production and the accumulation of non-biodegradable discarded glass have created a need for sustainable alternative construction materials. This experimental investigation evaluates the feasibility of utilizing discarded glass as a partial replacement for conventional coarse-grained aggregate in standard-grade M40 and high-strength M70 concrete. Waste glass was incorporated at substitution proportions of 25%, 50%, 75%, and 100%, and selected mixes were also modified with microsilica to improve their performance. The study examined fresh properties such as ease of placement and wet density, as well as hardened properties including compression strength, splitting tensile strength, bending strength, impact resistance, elastic modulus, and dry density. Additionally, the quality and durability-related characteristics of this concrete were assessed through rebound hammer, ultrasonic pulse velocity and sorptivity tests.

Keywords— waste glass; M40 concrete; M70 concrete; coarse aggregate replacement; silica fume; mechanical properties; durability; sorptivity; ultrasonic pulse velocity.

I. INTRODUCTION

The depletion of natural aggregate resources and the accumulation of non-biodegradable waste glass motivate the development of concrete mixtures that reuse discarded glass as aggregate. The present investigation evaluates toughened waste glass as a partial replacement for conventional coarse aggregate in M40 and M70 concrete. Replacement levels extend from 25% to 100%, with selected high-replacement mixtures modified using silica fume. The study covers fresh-state behaviour, density, compressive, splitting tensile and flexural strengths, impact resistance, stress-strain response, elastic modulus, rebound hammer response, ultrasonic pulse velocity (UPV) and sorptivity. The experimental programme therefore links resource recovery with structural and durability-related performance.

1. Objectives and research scope

The objectives were to quantify workability and density; evaluate mechanical properties and elastic response; assess concrete quality using rebound

hammer and UPV; and determine sorptivity for M40 and M70 concretes containing 25%, 50%, 75% and 100% waste-glass replacement of coarse aggregate. The source programme used thirteen mixtures and 273 specimens.

II. MATERIALS AND EXPERIMENTAL PROGRAMME

The constituent materials were OPC 53-grade cement, Zone-II fine aggregate, crushed granite coarse aggregate, potable water, toughened waste glass, SP-430 superplasticizer and silica fume. Waste glass had a reported specific gravity of 2.56, bulk density of 1.41 g/cc and fineness modulus of 7.42. The control mix proportions were 1:1.4:1.77:0.38 for M40 and 1:0.77:1.5:0.26 for M70 (cement:sand:coarse aggregate:w/c). Standard cubes, cylinders, prisms and discs were cast and water cured before testing.



Fig. 1. Waste glass used as coarse aggregate



Fig. 5. Flexural test setup



Fig. 2. Cast concrete specimens



Fig. 6. Impact-test disc after cracking



Fig. 3. Compression testing of cube specimen



Fig. 7. Sorptivity specimens during water exposure



Fig. 4. Splitting tensile test setup



Fig. 8. Elastic modulus / cylinder test setup



Fig. 9. Rebound hammer used for non-destructive testing

Specific gravity	Specific gravity bottle (IS 4031-Part II)	3.15
Initial setting time	Vicat apparatus (IS 4031-Part V)	45 min
Final setting time	Vicat apparatus (IS 4031-Part V)	175 min
Fineness	Sieve test (IS 4031-Part IV)	6%

III. RESULTS AND DISCUSSION

All numerical results reported in the project source are retained below. Tables 1-20 correspond to the source report Tables 4.1-4.20. Graphs were regenerated directly from the embedded chart data so that curves and bar/line comparisons remain clear and publication-ready. Apparent inconsistencies in the source dataset are preserved rather than silently corrected.

Table 1. Physical properties of OPC 53-grade cement

Property	Test method	Result
Normal consistency	Vicat apparatus (IS 4031-Part IV)	34%

Table 2. Physical properties of aggregates and waste glass

Property	Coarse aggregate	Fine aggregate	Waste glass
Specific gravity	2.77	2.67	2.56
Void ratio	0.43	0.72	0.67
Porosity	47.50%	49%	40.27%
Bulk density	1.454	1.292	1.41
Fineness modulus	7.18	2.63	7.42
Water absorption	0.46%	1%	0.16%

Table 3. Material quantities and fresh-state properties - M40

Mix	Cement	SF	Fine agg.	Coarse agg.	Waste glass	w/c	Water	SP	Slump	Wet density
P0	526.32	0	739.53	930.56	0	0.38	200	0	65	2821
P25	526.32	0	739.53	697.92	232.64	0.38	200	0	68	2700
P50	526.32	0	739.53	465.28	0.38	200	0	73	2466	
P75	526.32	0	739.53	232.64	697.92	0.38	200	0	82	2382
P100	526.32	0	739.53	0	930.56	0.38	200	0	85	2216
P75-4	526.32	21.05	739.53	232.64	697.92	0.38	200	0	32	2357
P100-4	526.32	21.05	739.53	0	930.56	0.38	200	0	37	2201

Table 4. Material quantities and fresh-state properties - M70

Mix	Cement	SF	Fine agg.	Coarse agg.	Waste glass	w/c	Water	SP	Slump	Wet density
MC	695.96	0	695.96	1046.88	0	0.26	180.95	7.66	80	2413
M0-5	695.96	34.79	695.96	1046.88	0	0.26	180.95	7.66	0	2398
M25-5	695.96	34.79	695.96	785.16	261.72	0.26	180.95	7.66	8	2382
M50-6	695.96	41.76	695.96	523.44	0.26	180.95	7.66	5	2472	
M75-7	695.96	48.72	695.96	261.72	785.16	0.26	180.95	7.66	4	2502
M100-7	695.96	48.72	695.96	0	1046.88	0.26	180.95	7.66	12	2324

Table 5. Dry density - M40

Mix	SF (%)	Dry density (kg/m ³)
P0	0	2462
P25	0	2451
P50	0	2432
P75	0	2426
P100	0	2100
P75-4	4	2420
P100-4	4	1980

Table 6. Dry density - M70

Mix	SF (%)	Dry density (kg/m ³)
MC	0	2535
M0-5	5	2498
M25-5	5	2398
M50-6	6	2507
M75-7	7	2479
M100-7	7	2300

Table 7. Compressive strength - M40

Mix	SF (%)	7 d (MPa)	28 d (MPa)
P0	0	30.21	53.5
P25	0	32.54	54.2
P50	0	30.01	47
P75	0	28.22	40.5
P100	0	21.65	31.3
P75-4	4	30.04	46.5
P100-4	4	29.86	40.3

Table 8. Compressive strength - M70

Mix	SF (%)	7 d (MPa)	28 d (MPa)
MC	0	59.6	66.9
M0-5	5	65.12	73.23
M25-5	5	61.6	74.36
M50-6	6	52.1	62.1
M75-7	7	40.7	56.5
M100-7	7	38.2	46.2

Table 9. Split tensile strength - M40

Mix	SF (%)	28 d (MPa)
P0	0	3.28
P25	0	3.57
P50	0	2.76
P75	0	2.389
P100	0	1.975

P75-4	4	2.452
P100-4	4	2.038

Table 10. Split tensile strength - M70

Mix	SF (%)	28 d (MPa)
MC	0	3.365
M0-5	5	3.769
M25-5	5	4.299
M50-6	6	3.96
M75-7	7	3.121
M100-7	7	2.683

Table 11. Flexural strength - M40

Mix	SF (%)	28 d (MPa)
P0	0	5.133
P25	0	5.252
P50	0	5.054
P75	0	3.87
P100	0	3.317
P75-4	4	3.922
P100-4	4	3.501

Table 12. Flexural strength - M70

Mix	SF (%)	28 d (MPa)
MC	0	6.449
M0-5	5	7.923
M25-5	5	8.555
M50-6	6	8.134
M75-7	7	5.765
M100-7	7	3.804

Table 13. Impact resistance - M40

Mix	SF (%)	28 d (blows)
P0	0	115
P25	0	129
P50	0	85
P75	0	78
P100	0	70
P75-4	4	84
P100-4	4	76

Table 14. Impact resistance - M70

Mix	SF (%)	28 d (blows)
MC	0	134
M0-5	5	156
M25-5	5	172

M50-6	6	140
M75-7	7	123
M100-7	7	83

Table 15. Young's modulus - M40

Mix	SF (%)	E ($\times 10^3$ N/mm ²)
P0	0	36.924 $\times 10^3$
P25	0	37.248 $\times 10^3$
P50	0	36.138 $\times 10^3$
P75	0	31.621 $\times 10^3$
P100	0	28.308 $\times 10^3$
P75-4	4	35.385 $\times 10^3$
P100-4	4	32.250 $\times 10^3$

Table 16. Young's modulus - M70

Mix	SF (%)	E ($\times 10^3$ N/mm ²)
MC	0	40.266 $\times 10^3$
M0-5	5	43.551 $\times 10^3$
M25-5	5	43.927 $\times 10^3$
M50-6	6	38.996 $\times 10^3$
M75-7	7	37.467 $\times 10^3$
M100-7	7	34.244 $\times 10^3$

Table 17. Rebound number and UPV - M40

Mix	SF (%)	Rebound	UPV (km/s)
P0	0	45	3.452
P25	0	49	3.73
P50	0	41	3.66
P75	0	38	4.18
P100	0	36	3.56
P75-4	4	38	4.02
P100-4	4	36	3.49

Table 18. Rebound number and UPV - M70

Mix	SF (%)	Rebound	UPV (km/s)
MC	0	55	3.6
M0-5	5	55	3.582
M25-5	5	56	3.53
M50-6	6	54	3.31
M75-7	7	52	3.44
M100-7	7	49	3.41

Table 19. Sorptivity - M40

Mix	SF (%)	30 min	60 min	90 min	120 min	150 min	180 min	210 min
P0	0	0.310	0.245	0.221	0.201	0.204	0.186	0.173
P25	0	0.237	0.232	0.211	0.192	0.188	0.179	0.166
P50	0	0.329	0.284	0.264	0.265	0.269	0.246	0.228
P75	0	0.347	0.297	0.264	0.256	0.229	0.216	0.200
P100	0	0.365	0.310	0.274	0.265	0.245	0.224	0.207
P75-4	4	0.237	0.232	0.210	0.220	0.201	0.186	
P100-4	4	0.329	0.284	0.274	0.237	0.220	0.209	0.193

Table 20. Sorptivity - M70

Mix	SF (%)	30 min	60 min	90 min	120 min	150 min	180 min	210 min
MC	0	0.310	0.258	0.221	0.201	0.188	0.171	0.173
M0-5	5	0.310	0.232	0.211	0.192	0.180	0.164	0.152
M25-5	5	0.183	0.155	0.137	0.128	0.147	0.134	0.124
M50-6	6	0.164	0.142	1.265	0.128	0.139	0.127	0.117
M75-7	7	2.191	1.614	1.349	1.260	1.143	1.043	0.966
M100-7	7	3.104	2.298	1.918	1.698	1.551	1.416	1.318

1. Publication-style result figures and curves

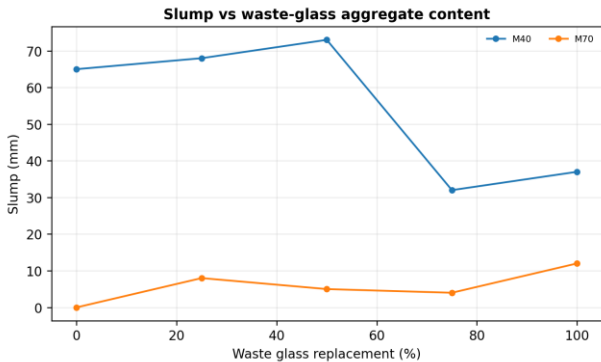


Fig. 10. Slump vs waste-glass aggregate content.

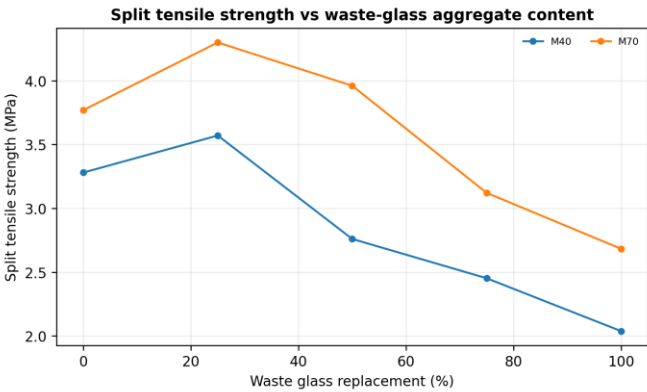


Fig. 13. Split tensile strength vs waste-glass aggregate content.

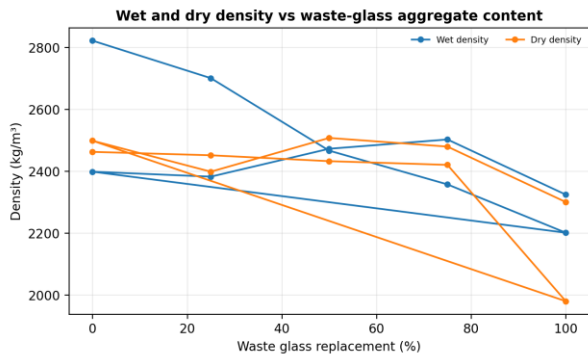


Fig. 11. Wet and dry density vs waste-glass aggregate content.

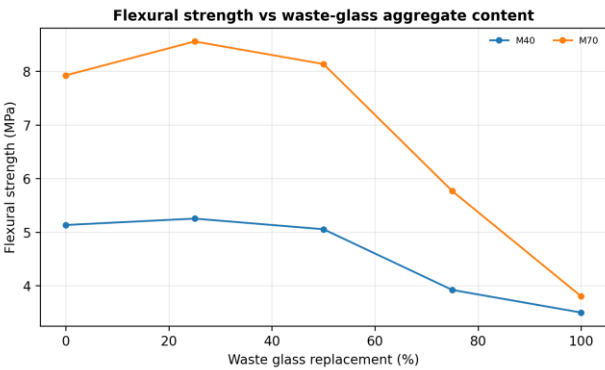


Fig. 14. Flexural strength vs waste-glass aggregate content.

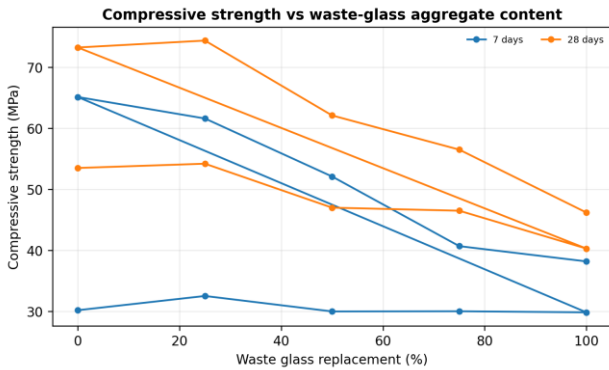


Fig. 12. Compressive strength vs waste-glass aggregate content.

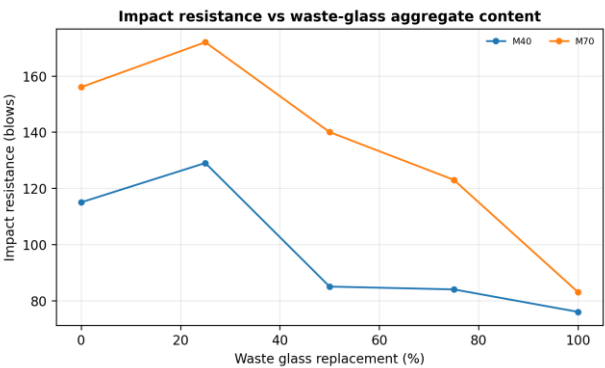


Fig. 15. Impact resistance vs waste-glass aggregate content.

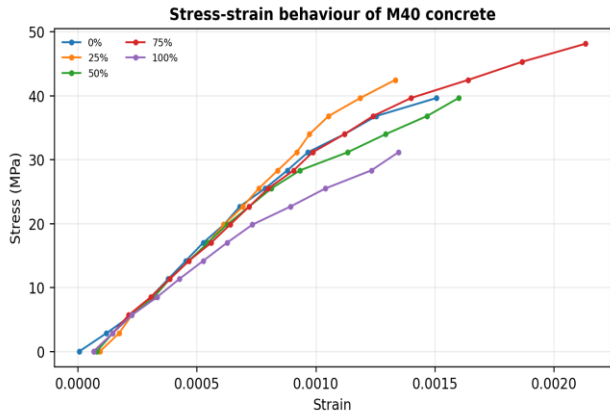


Fig. 16. Stress-strain behaviour of M40 concrete.

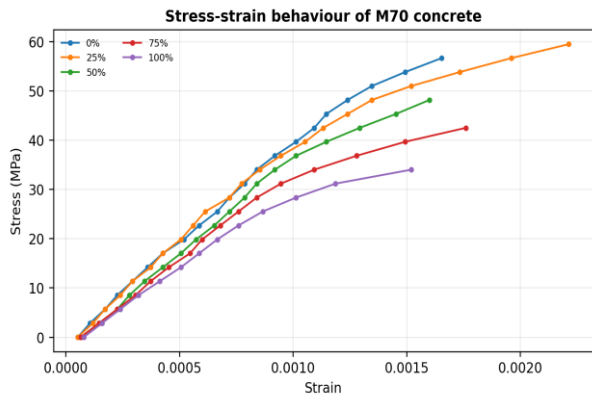


Fig. 17. Stress-strain behaviour of M70 concrete.

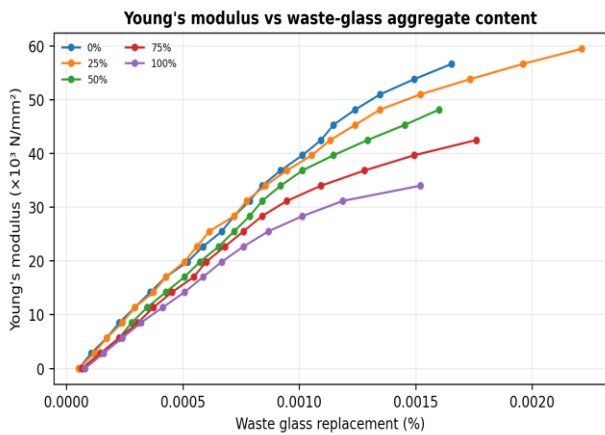


Fig. 18. Young's modulus vs waste-glass aggregate content.

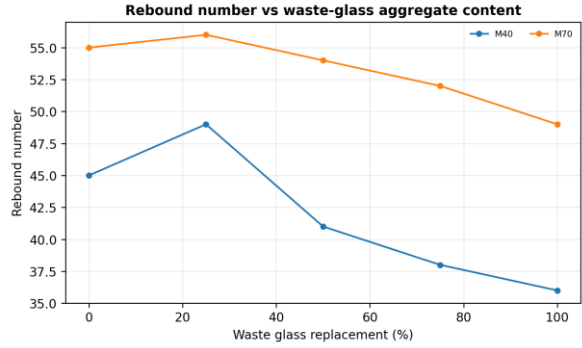


Fig. 19. Rebound number vs waste-glass aggregate content.

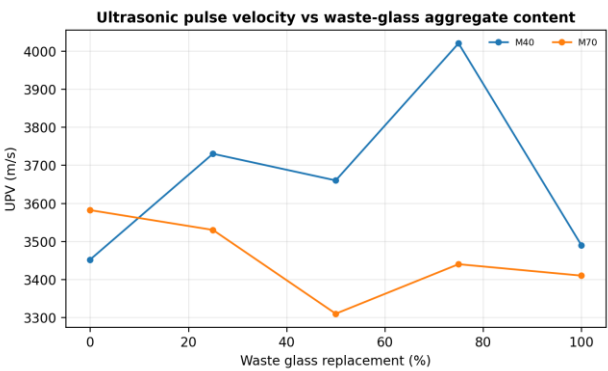


Fig. 20. Ultrasonic pulse velocity vs waste-glass aggregate content.

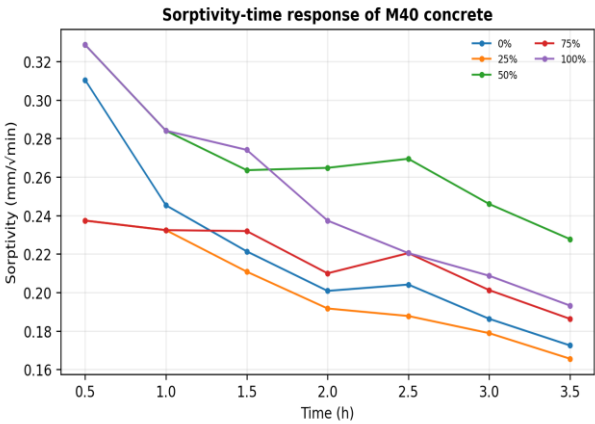


Fig. 21. Sorptivity-time response of M40 concrete.

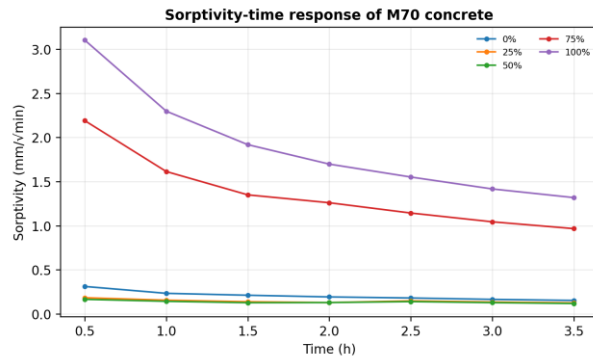


Fig. 22. Sorptivity-time response of M70 concrete.

2. Integrated interpretation of results

Workability generally increased with waste-glass content in M40 concrete because of the smooth glass surface and low water absorption, while silica-fume-modified mixtures showed lower slump. Wet and dry densities generally decreased as glass replaced denser natural coarse aggregate. The M40 mechanical response was most favorable at 25% waste-glass replacement: the reported 28-day compressive strength was 54.2 MPa, split tensile strength 3.57 MPa, flexural strength 5.252 MPa and impact resistance 129 blows. At higher replacement levels, most mechanical properties declined.

For M70 concrete, the source data show the strongest overall mechanical response near 25% waste-glass replacement with silica fume: 28-day compressive strength reached 74.36 MPa, split tensile strength 4.299 MPa, flexural strength 8.555 MPa and impact resistance 172 blows. The elastic modulus was also highest at this condition (43.927×10^3 N/mm²). Stress-strain curves for both grades are nonlinear and indicate increasing deformation as waste-glass content rises beyond the favorable replacement range.

Non-destructive test results show M40 UPV values ranging from 3.452 to 4.18 km/s and M70 values from 3.31 to 3.60 km/s. Rebound numbers were highest at 25% replacement for both grades in the reported series. Sorptivity was comparatively low around the 25% replacement level; however, the source M70 sorptivity dataset contains very large values at 75% and 100% replacement, and these values are reproduced exactly as reported.

IV. CONCLUSIONS

Workability increased with increasing waste-glass aggregate content in the reported mixtures because of the smooth glass surface, whereas silica fume reduced ease of placement.

Concrete density generally decreased as waste glass replaced natural coarse aggregate because waste glass has a lower density than conventional aggregate.

M40 concrete showed its most favorable combined mechanical performance at approximately 25% replacement of natural coarse aggregate by waste glass.

M70 concrete showed its most favorable combined mechanical performance at approximately 25% waste glass with 5% silica fume in the reported experimental programme.

Rebound number was most favorable near 25% waste-glass replacement, while UPV classifications ranged from medium to good depending on grade and replacement level.

Sorptivity was lowest around 25% waste-glass replacement in both grades according to the source interpretation, indicating comparatively lower capillary permeability at this level.

The combined evidence supports partial use of discarded toughened glass as coarse aggregate, with performance becoming less favorable at high replacement levels.

Scope for Further Research

Future work may evaluate different maximum waste-glass particle sizes, combinations of recycled aggregate and waste glass, long-term durability, alkali-silica reaction mitigation, chloride transport, microstructural characterization, and statistically replicated stress-strain testing.

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