

Investigations on the Replacement of Fine and Coarse Aggregates with Ceramic Tile Waste in M40 and M70 Concretes

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Abstract- Industrial ceramic tile waste represents a persistent construction-related solid waste stream with potential for use as aggregate in concrete. This study evaluates crushed ceramic tile waste as partial replacement of natural fine aggregate and combined fine/coarse aggregates in standard-grade M40 and high-strength M70 concretes. Concrete mixtures were proportioned using the ACI method and evaluated through workability, density, compressive strength, split tensile strength, flexural strength, stress-strain response, modulus of elasticity, rebound hammer, ultrasonic pulse velocity (UPV), sorptivity, and chemical durability. Replacement trials covered 0-100% ceramic waste; selected mixtures were subsequently examined in detail. For M40 concrete, the 50% fine-aggregate replacement mixture achieved a 28-day compressive strength of 55.36 MPa, while the selected combined-replacement mixture achieved 52.10 MPa. For M70 concrete, the control, 50% fine-aggregate replacement, and combined-replacement mixtures recorded 28-day compressive strengths of 71.03, 67.36, and 63.12 MPa, respectively. UPV values for the investigated mixes were generally above 4.2 km/s, indicating good concrete quality. Sorptivity decreased with time, whereas exposure to 5% H₂SO₄ and 5% HCl produced pronounced mass and compressive-strength losses. The results demonstrate that ceramic tile waste can be incorporated as aggregate while maintaining useful mechanical performance at selected replacement levels, although higher replacement levels and aggressive acidic environments adversely affect performance.

Keywords: Ceramic tile waste; recycled aggregate; M40 concrete; M70 concrete; mechanical properties; UPV; sorptivity; durability.

I. INTRODUCTION

Concrete production consumes large quantities of natural fine and coarse aggregates, while ceramic manufacturing and construction activities generate substantial quantities of brittle tile waste. Reusing ceramic waste as aggregate provides a route for reducing landfill disposal and conserving natural aggregate resources. Ceramic tile particles possess relatively low density, hard surfaces and chemical resistance, but their glazed surfaces and interfacial characteristics can alter workability, bonding and mechanical response.

Previous studies have reported the feasibility of ceramic waste as coarse aggregate, fine aggregate and cementitious powder, with performance depending strongly on particle form, replacement level and concrete grade. The source project identifies an information gap concerning systematic

replacement of natural aggregates with ceramic tile waste in both M40 and M70 concretes, together with evaluation of mechanical properties, non-destructive quality indicators, sorptivity and resistance to aggressive solutions within a single experimental programme.

Research objective and novelty

The objective is to quantify the influence of ceramic tile waste on fresh and hardened properties of M40 and M70 concretes and to identify practical replacement levels for further performance evaluation. The study combines strength testing, stress-strain/modulus assessment, rebound hammer and UPV measurements, sorptivity, and durability exposure to 5% MgSO₄, H₂SO₄, HCl and NaCl. The scientific contribution lies in comparing standard- and high-strength concretes under the same ceramic-waste framework and linking destructive, non-destructive and durability indicators.

II. MATERIALS AND METHODS

Constituent materials

53-grade Ordinary Portland Cement, Zone-II natural river sand, crushed granite coarse aggregate, potable water, FOSROC SP-430 superplasticizer, silica fume and crushed ceramic tile waste were used. The ceramic waste was processed for use as fine and coarse aggregate fractions. The reported specific gravities of natural coarse aggregate, natural fine aggregate and ceramic waste were 2.77, 2.67 and 2.33, respectively.

Table 1. Physical properties of natural aggregates and ceramic waste.

Property	Coarse aggregate	Fine aggregate	Ceramic waste
Specific gravity	2.77	2.67	2.33
Void ratio	0.43	0.72	0.66
Porosity (%)	47.50	49.0	40.1
Bulk density (g/cc)	1.454	1.292	1.33
Fineness modulus	7.18	2.63	6.98
Water absorption (%)	0.46	1.00	0.36



Fig. 1. Representative ceramic tile waste used as aggregate.

Mix design and selected mixtures

The ACI method was used for the control mixtures. The reported control proportions by weight were 1:1.4:1.77:0.38 (cement:fine aggregate:coarse

aggregate:w/c) for M40 and 1:0.77:1.5:0.26 for M70. Replacement trials included ceramic tile waste at 0%, 25%, 50%, 75% and 100%, after which representative mixtures were selected for detailed mechanical and durability testing.

Table 2. Ingredient contents of principal M40 mixtures (kg/m³).

Mix	Cement	SF	Fine agg.	Fine ceramic	Coarse agg.	Coarse ceramic	Water
A-0	526.32	0	739.53	0	930.56	0	200
A-1	505.27	21.05	739.53	0	930.56	0	200
A-2	505.27	21.05	739.53	0	893.33	37.22	200
A-3	505.27	21.05	709.95	29.58	893.33	37.22	200

Table 3. Ingredient contents of principal M70 mixtures (kg/m³).

Mix	Cement	SF	Fine agg.	Fine ceramic	Coarse agg.	Coarse ceramic	SP (ml)	Water
B-0	695.96	0	532.77	0	1046.88	0	7655.56	180.95
B-1	668.12	27.84	532.77	0	1046.88	0	7655.56	180.95
B-2	668.12	27.84	532.77	0	1005.00	41.88	7655.56	180.95
B-3	668.12	27.84	511.46	21.31	1005.00	41.88	7655.56	180.95

Specimen preparation and curing

Concrete was mixed in a 50-L pan mixer. Dry constituents were mixed for approximately two minutes, followed by addition of water and superplasticizer and further mixing for about three minutes. Specimens included 100 mm and 150 mm cubes, 150 x 300 mm cylinders and 100 x 100 x 500 mm prisms. A total of 264 specimens was reported for the full programme. After 24 h under ambient laboratory conditions, specimens were demoulded and water-cured at approximately 27 +/- 2 degC.

Compression specimens were tested after 7 and 28 days.



Fig. 2. Representative specimen preparation and moulding arrangement.

Test methods

Workability was evaluated by slump. Hardened properties comprised cube compressive strength, cylinder split tensile strength, prism flexural strength and modulus of elasticity. Rebound hammer and UPV tests were used for non-destructive assessment. Sorptivity was determined from water uptake at 30-210 min. Durability was evaluated by immersing 28-day specimens in 5% MgSO₄, H₂SO₄, HCl and NaCl solutions for up to 90 days and measuring mass and compressive-strength changes.



Fig. 3. Rebound hammer used for non-destructive testing.

III. RESULTS AND DISCUSSION

Workability and mechanical strength

Table 4. Selected 28-day mechanical properties.

Mix	Compressive strength (MPa)	Split tensile (MPa)	Flexural strength (MPa)
A-0	53.136	3.10	5.10
A-1	55.36	4.22	5.75
A-2	52.10	4.05	5.00
B-0	71.03	3.36	6.44
B-1	67.36	6.12	7.50
B-2	63.12	5.62	7.00

The M40 mixture with 50% ceramic tile waste as fine aggregate recorded the highest reported 28-day compressive strength among the selected M40 mixes (55.36 MPa). For M70, compressive strength declined from 71.03 MPa for the control to 67.36 MPa and 63.12 MPa for B-1 and B-2. The source attributes strength reduction at higher ceramic contents to weaker bonding and increased interfacial defects between ceramic particles and cement paste.

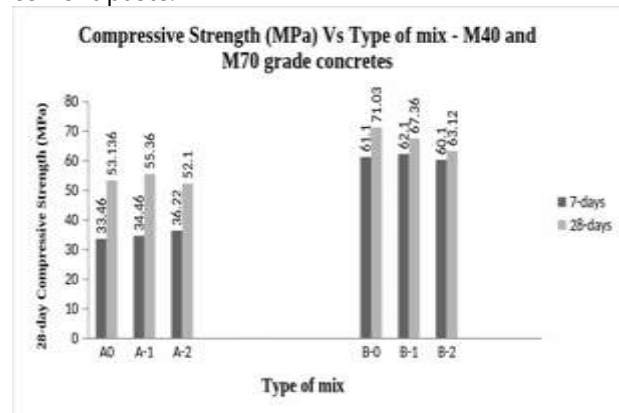


Fig.4 Variation of compressive strength with type of mix - M40 and M70 concretes.

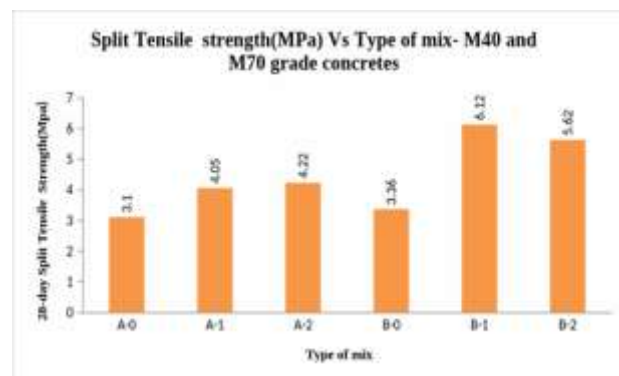


Fig. 5 Variation of Split Tensile Strength with type of mix - M40 & M70 Concretes.

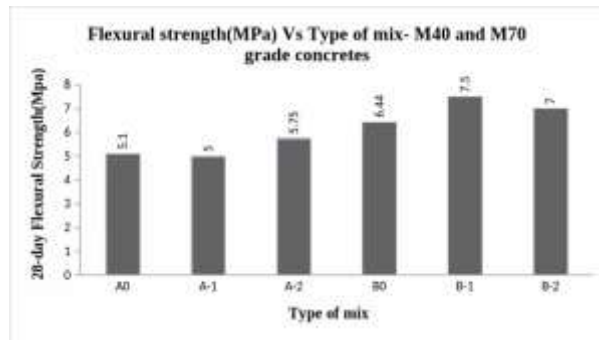


Fig. 6 Variation of Flexural Strength with type of mix - M40 & M70 concretes.

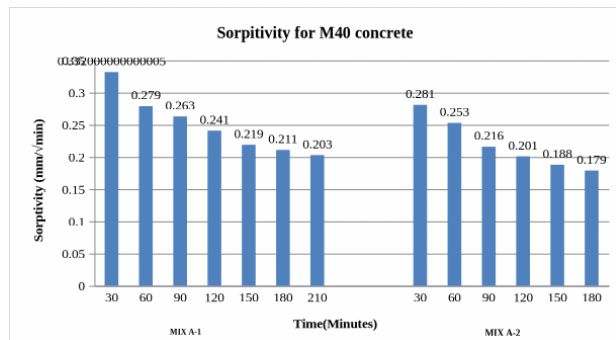


Fig. 9 Variation of Sorptivity with time using Ceramic tile waste - M40 concrete.

Stress-strain response and modulus of elasticity

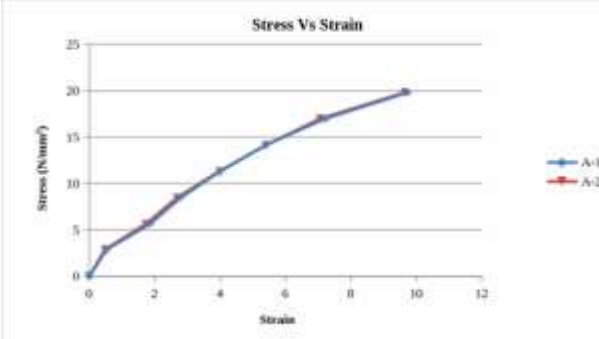


Fig. 7 Stress - Strain behavior of M40 Concrete

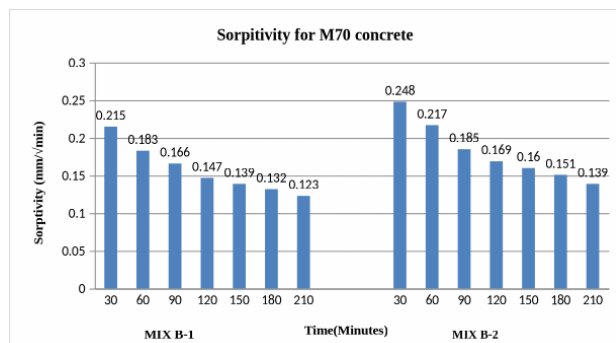


Fig. 10 Variation of Sorptivity with time using Ceramic tile waste - M70 concrete.

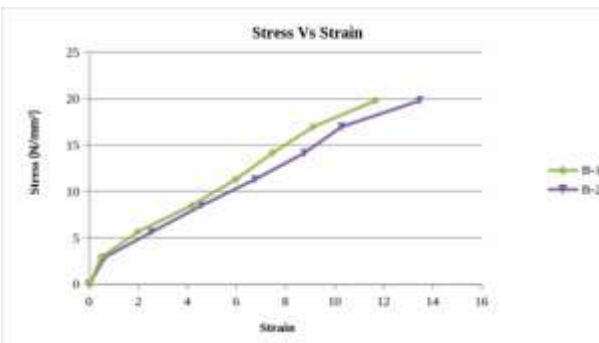


Fig. 8 Stress - Strain behavior of M70 Concrete

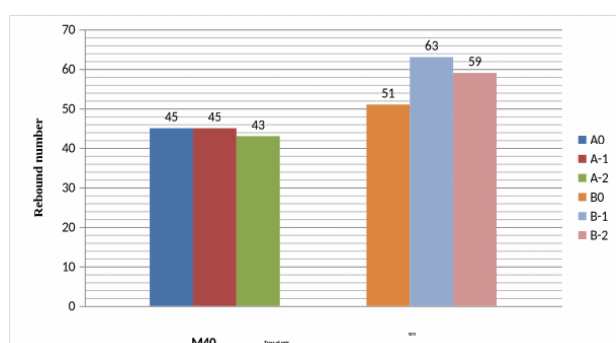


Fig. 11 Variation of Rebound Number with type of mix.

Sorptivity and non-destructive evaluation

Sorptivity decreased with elapsed absorption time for both grades and selected replacement conditions. The project concludes that the 50% fine-aggregate replacement condition produced the optimum sorptivity response in both M40 and M70. Rebound number was also reported as optimum at 50% fine-aggregate replacement. UPV values for the investigated mixes were generally above 4.2 km/s and were interpreted as indicating good concrete quality.

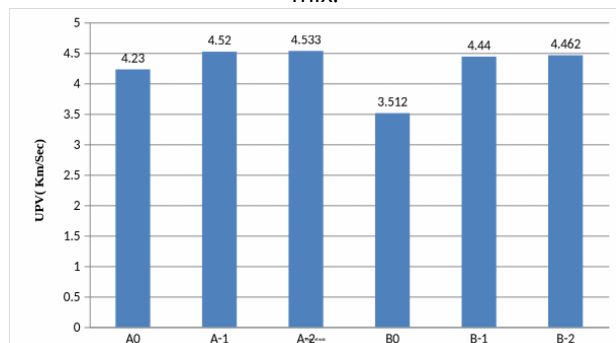


Fig. 12 Variation of UPV with the type of mix

Durability under chemical exposure

Chemical durability was assessed using 5% MgSO_4 , H_2SO_4 , HCl and NaCl solutions for 30, 60 and 90 days. Sulphate exposure produced measurable mass and compressive-strength losses. Acid exposure was more severe: after 90 days in 5% H_2SO_4 , reported compressive-strength losses were 7.51% and 14.97% for A-1 and A-2 and 20.71% and 16.349% for B-1 and B-2. After 90 days in 5% HCl , the corresponding losses were 22.32%, 9.98%, 12.08% and 9.537%. NaCl exposure produced both gains and losses, associated in the source discussion with salt deposition and chloride-related interactions.

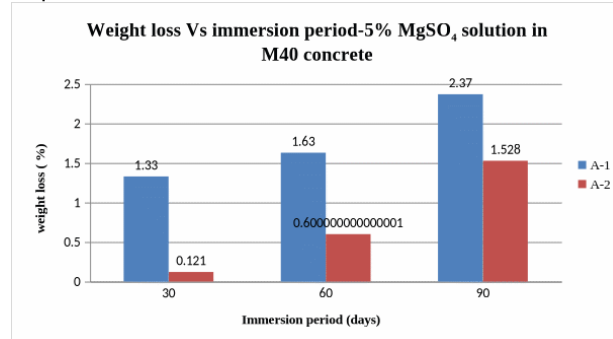


Fig. 13 Variation of weight loss with immersion period

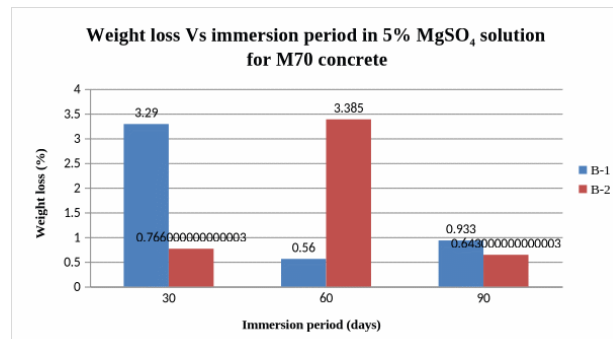


Fig. 14 Variation of weight loss with immersion period

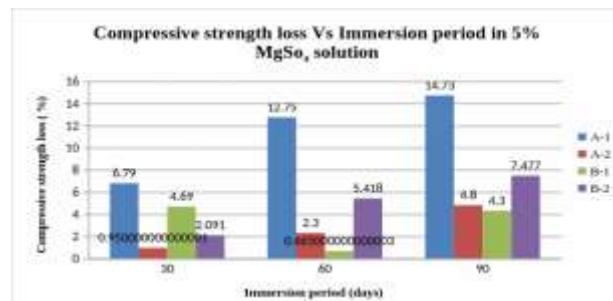


Fig. 15 Variation of compressive strength loss with immersion period

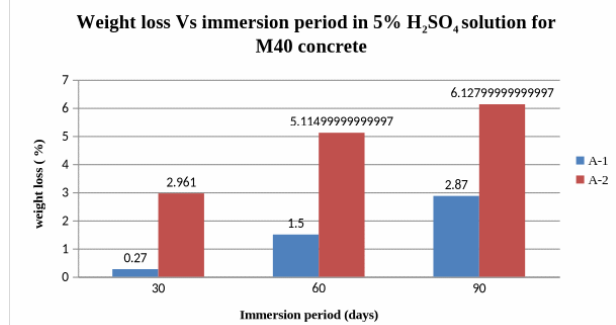


Fig. 16 Variation of weight loss with immersion period

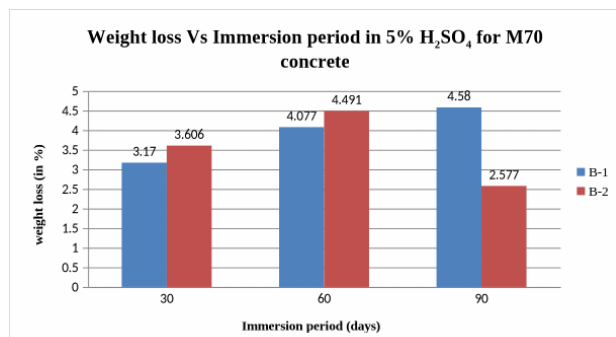


Fig.17 Variation of weight loss with immersion period

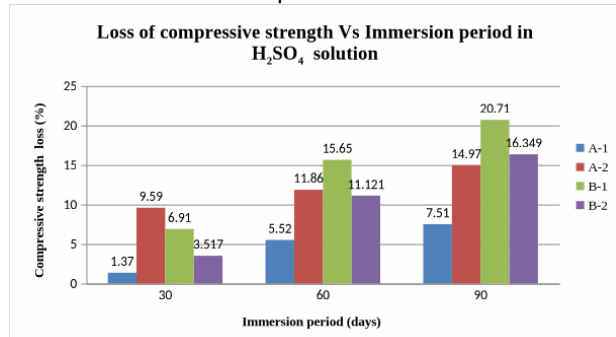


Fig. 18 Variation of compressive strength loss with immersion period

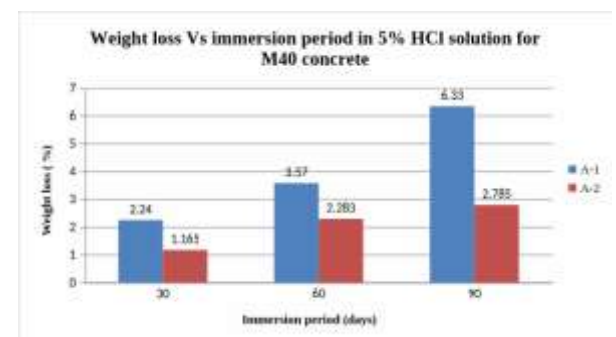


Fig. 19 Variation of weight loss with immersion period

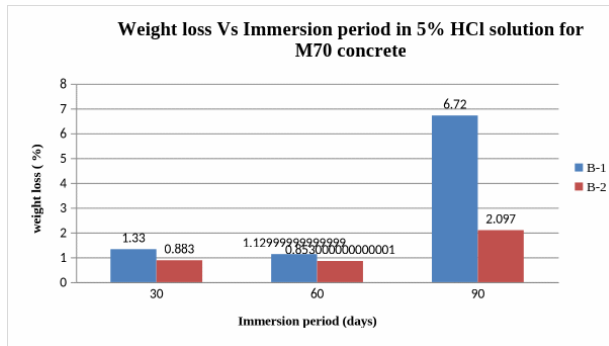


Fig. 20 Variation of weight loss with immersion period

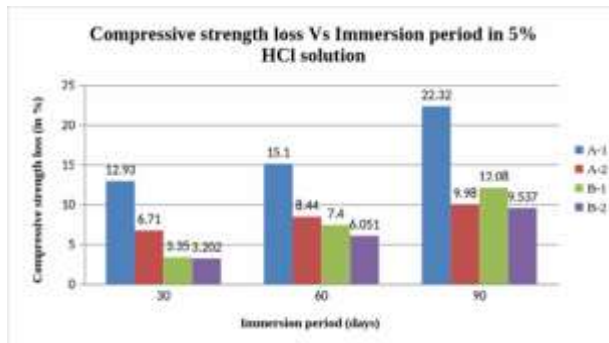


Fig. 21 Variation of compressive strength loss with immersion period

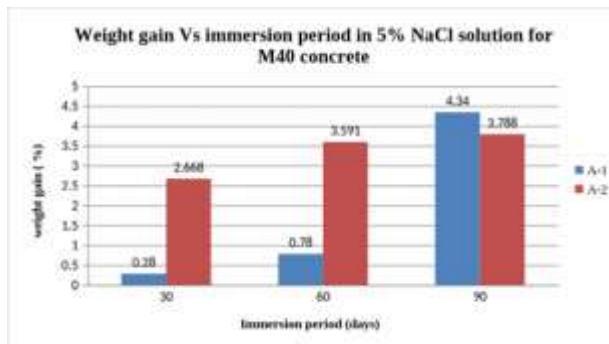


Fig. 22 Variation of weight gain with immersion period

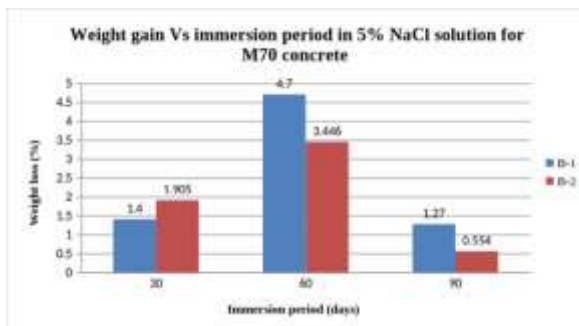


Fig. 23 Variation of weight loss with immersion period

The combined results indicate that ceramic tile waste can provide acceptable mechanical performance when replacement is controlled, but performance is grade- and property-dependent. M40 benefited from the selected 50% fine-aggregate replacement in several strength indicators, whereas M70 showed lower compressive strength in the selected ceramic-waste mixes.

IV. CONCLUSIONS

- Workability increased with ceramic waste content in the reported M40 mixtures, while the M70 response was influenced by silica fume and admixture content.
- Concrete density decreased as ceramic tile waste content increased because the waste ceramic had lower density than conventional aggregate.
- For the selected M40 mixes, 50% fine-aggregate replacement achieved a 28-day compressive strength of 55.36 MPa, compared with 53.136 MPa for the control.
- For M70, the selected ceramic-waste mixtures recorded 67.36 MPa (B-1) and 63.12 MPa (B-2), below the 71.03 MPa control.
- Sorptivity decreased with time, and the 50% fine-aggregate replacement condition was reported as the optimum sorptivity case for both concrete grades.
- UPV measurements generally exceeded 4.2 km/s, corresponding to good concrete quality under the classification used in the study.
- Exposure to 5% H₂SO₄ and 5% HCl caused substantial mass and compressive-strength losses, whereas NaCl exposure produced mixed mass/strength changes.
- Controlled use of ceramic tile waste can reduce natural aggregate demand and provide a practical disposal route, but replacement level and exposure environment must be considered.

V. LIMITATIONS AND FUTURE RESEARCH

The study is limited to the reported M40 and M70 mixtures, selected ceramic tile source, replacement configurations and 90-day chemical exposures. Further work should examine carbonation, chloride

penetration, longer-term durability, alternative ceramic sources, non-glazed ceramic fractions, recycled coarse aggregates and additional concrete strength classes.

12. ASTM C1585. Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes.

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