Accelerated Corrosion Analysis of Recycled Aggregate Concrete with Pumice: A Detailed Study on Durability and Performance

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Abstract. The study evaluates the durability performance of recycled aggregate concrete (RAC) incorporating pumice as a partial replacement for natural coarse aggregate, with emphasis on accelerated corrosion and acid resistance. Pumice replaced coarse aggregate at 15%, 25%, and 35% by weight. Durability was assessed through impressed current accelerated corrosion tests and immersion in 5% HCl solution for 28 days. The results indicate that pumice content significantly influences the mechanical and durability properties of RAC. The 15% replacement level exhibited the best overall performance, recording the lowest mass loss (3.8%), minimum compressive strength reduction (12%), least dimensional change (0.22%), and lowest durability loss (15%) compared with the control mix. The 25% replacement showed moderate performance, while 35% replacement resulted in increased mass loss (4.5%), higher strength reduction (17%), and maximum durability loss (20%). Accelerated corrosion tests revealed that the optimum pumice content delayed corrosion initiation and propagation by improving the interfacial bond and refining the concrete microstructure, thereby restricting chloride ion penetration. Overall, replacing 15% of natural coarse aggregate with pumice provides an effective balance between strength, durability, and sustainability, making it a suitable lightweight aggregate for enhancing RAC under aggressive environmental conditions.

Keywords: Accelerated Corrosion, Acid Resistance, Durability, Pumice Aggregate, Recycled Aggregate Concrete, Sustainable Construction.

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1 Introduction

The rising need for durable construction materials has further promoted the usage of supplementary cementitious materials and recycled aggregates to concrete producers. Recycled aggregate concrete, the usage of construction and demolition debris instead of aggregates, is a green material and reduces wastage and conservation. Although it leads to higher pore and reduced durability of natural aggregate concrete (NAC) in harsh environments, the question of its usage and behavior long-term remains [1]. By using SCM, like pumice (Figure 1), researchers claim that RAC durability was substantially enhanced and permeability, chloride ion penetration reduced [2, 3, 4], hence, corrosion is minimized.

Due to their porosity, it is known that Pumice, as it can also reduce concrete weight while also enhancing its thermal insulating properties, thus suitable for non-structural and structural uses. With addition of SCM like pumice, fly ash, metakaolin and silica fume, micro structure was improved, and permeability, ASR, carbonation and chloride ingress reduced [5,6,7]. Recently reported researches concluded that, by utilizing the improved mix designs using recycled aggregate and SCM, strength and durability properties of concrete can be further boosted. Pumice based concrete with its improved strength and durability has also showed potential even in marine environments while Flyash and Silica fume enhance concrete to avoid corrosion and prolonged usage [8, 9]. Besides this, several advance evaluations have indicated the benefit of pumice and scoria to improve the structural lightweight concrete's durability while various recycling treatments improve the resistance against chloride transport [10, 11].

In conclusion, Pumice has a significant potential in providing a new way for making concrete both Lightweight and Durable. [12] study the red mud pumice concrete performance, [13] analyse recycled aggregate concrete (RAC) performance. The purpose of this study was to examine the accelerated corrosion performance of RAC with pumice so that to determine the proper percentage of replacement of recycled aggregate by pumice to enhance concrete to get desirable strength, durability and sustainable concrete structures.

Fig. 1. Pumice stone

2 Review of Literature

Lightweight concrete made with lightweight aggregate (LWAC), which contains natural or artificial lightweight aggregates in place of traditional aggregates, has attracted considerable research interest in the construction industry because it can effectively decrease the self-weight of the structures without significantly reducing their mechanical and durability performances. [1-4] utilized lightweight aggregate made with natural volcanic pumice for lightweight concrete (LWC) to investigate the mix proportion optimization and the resulting properties. Their studies reported that LWC prepared with pumice showed reduced density and also obtained adequate compressive strength value in structural use. In addition, [5-7] showed that lightweight concrete with pumice aggregates enhanced the workability, reduced dead load, and also reached favorable durability properties although the mechanical performance was inferior to the traditional concrete.

The durability properties of the pumice-based concrete have also been explored by researchers. [7-9] conducted comparative studies on natural lightweight and artificial lightweight aggregate concrete and concluded that the long term durability properties of pumice based LWC, such as resistance to chloride ions and carbonation, was superior and satisfactory. [9-11] additionally incorporated pumice powder and nano clay into the pervious concrete which can be considered as one type of structural LWC; in which the low permeability of mixture can be achieved and the strength also increased with their presence, suggesting that the pozzolanic function of pumice could be used as a Supplementary Cementitious Materials (SCMs) in the specialty concrete mix design. [12-13] used pumice and scoria as the partial replacements of cement for the preparation of concretes and obtained an excellent durability performance resulting from the pozzolanic reaction and a reduced porous structure and improved durability of resistance to aggressive media. A literature review conducted by provided an overview of the research advances of self-compacting LWACs where pumice has been considered as an aggregate source in self-compacting concrete for lower density and higher fluidity and superior durability of resistance against environment exposure. LWAC with pumice provides reduction of concrete density with good strength, and can offer excellent durability characteristics if properly used as a constituent with some SCMs or nanotechnology, which offers great possibility for sustainable construction.

3 Materials and Methodology

Table 1. Experiments were carried out on ordinary Portland cement of 53 Grade.

Tests	Findings acquired	Standard results as per IS: 12269-1987
Normal consistency (%)	32%	-
Initial setting time (min)	50	Not less than 30
Final setting time (min)	215	Not be greater than 600
Fineness (m^2/kg)	290.3 m^2/ kg	Not less than 225 m^2/kg
Specific gravity	3.06	-
Compressive strength (N/mm^2) 7 days 28 days	43 N/ mm^2 62 N/mm^2	Should not be less than 37 N/mm^2 Should not be less than 53 N/mm^2

The study was conducted using 53-grade Ordinary Portland Cement with a specific gravity of 3.06, conforming to IS 12269-1987 (Table 1) and tested in accordance with IS 4031-1988. Crushed angular coarse aggregate of 20 mm size was used, with a specific gravity of 2.76, a fineness modulus of 1.68, a bulk density of 1500 kg/m^3, and a water absorption of 0.8%. Local fine aggregate was also used, with a specific gravity of 2.77, a bulk density of 1400 kg/m^3, a water absorption of 1.25%, and a fineness modulus of 2.92.

3.1 Proportioning, Casting, and Curing

The Self-Compacting Concrete (SCC) mix was prepared using cement, fly ash, pumice, sand, coarse aggregates, water, and a superplasticizer in carefully designed proportions to achieve the required performance. After meeting the fresh state requirements, the mix was poured into molds, allowed to flow and self-settle, and the excess material was levelled off. The specimens were left for 24 h at room temperature, demolded, and cured in potable water until testing was performed. Figure 2 shows the experimental images of the curing process.

Fig. 2. Casting and curing of Specimen

Table 2. Required materials for 1 cubic meter of various trials of FRSCC:

Mix designation	Cement	Fly Ash	Water	Coarse Aggregtae	Fine Aggregate	Sp	Pumice Aggregate
M30 Control Mix	438	350	240	700	885	12.2	0%
M30 15% p	438	350	240	700	885	12.2	15%
M30 15% p	438	350	240	700	885	12.2	25%
M30 15% p	438	350	240	700	885	12.2	35%

The control mix was prepared without pumice. Experimental mixes incorporated 15%, 25%, and 35% pumice as partial replacements for coarse aggregate, along with fly ash as shown in the Table 2.

3.2 Workability of SCC

Workability tests including slump flow, J-Ring, V-Funnel, U-Box and L-Box are presented in the Table 3. The workability of fresh SCCs were assessed following EFNARC recommendations. SCCs workability is reported to generally decrease with an increase in pumice substitution, but the results of all workability tests for pumice substituted SCCs were in acceptable range: The slump flow values reduced a little bit with increased pumice addition (Control mix: 750mm, Mix 3: 700mm). However all of the values were between 640 and 800 mm. The passing ability results from the J-ring test were reduced a little (Control mix: 6mm, Mix 3: 9mm), whereas the V-Funnel values had increased slightly (6.17-8.25s) (see Figures 3-4). U-Box test also demonstrates good filling ability with results between 23 to 27mm. L-box ratio values improved by adding pumice from 0.82 to 0.95 which is an indication for better passing ability through reinforcements. In general all mixes complied with the EFNARC criteria and it can be concluded that SCC mixes made with pumice maintained satisfactory workability although there was a slight decrease in slump flow values.

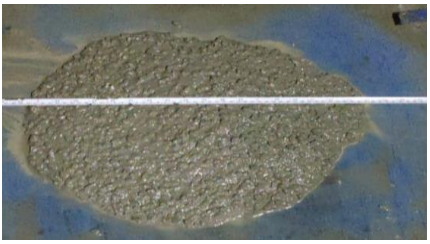


Fig. 3. Flow Table Test and J Ring Test


Fig. 4. V Funnel Test and U-Box Test

Table 3. Results of the workability characteristics of the mixes

Designation	Flow Table test	J-Ring	V-Funnel	U-Box	L-Box
M30 Control	750	6	6.17	27	0.82
M30 15% p	720	8	6.76	25	0.89
M30 25% p	705	8	7.57	23	0.92
M30 35% p	700	9	8.25	23	0.95
Range	640-800	0-10	6-12	0-30	0.8-1

3.3 Test Methods

3.3.1 Compressive Strength

Cubes of 100x100x100 mm of M30 grade gave highest strength in the control mixture i.e., 25.96 MPa and 37.93 MPa at the ages of 7 days and 28 days respectively. Replacement of cement with pumice powder decreased the compressive strength. The 15% pumice replaced mixture developed strength of 24.42 MPa and 35.63 MPa. The 35% pumice replaced mixture developed lowest strength of 22.23 MPa and 30.19 MPa.

3.3.2 Tensile Strength

Cylinders of size 100 × 200 mm gave split tensile strengths of 6.51 MPa and 8.28 MPa at 7 and 28 days, respectively, for the control mixture. The pumice-replaced mixtures yielded lower tensile strengths than the control. For 15% pumice replacement, the values obtained were 6.38 MPa and 8.05 MPa, while for 35% replacement they were 5.93 MPa and 7.68 MPa.

3.3.3 Flexural Strength

Prisms of 100x100x500 mm developed a flexural strength of 3.8 MPa and 6.2 MPa for control mixture. Pumice replacement for the mix reduced the flexural strength; the 15% and 35% replacement achieved a flexural strength of 3.52 MPa and 5.96 MPa, and 3.15 MPa and 5.39 MPa respectively.

4 Results and Discussion

The effect of the mix proportions is evident in Figure 4, which compares the values obtained for the different proportions. Figures 5 to 7 illustrate the hardened properties of the FR-SCC. From Table 5 and Figure 9, it can be concluded that 15% pumice gives reasonable values, and that further increases in pumice content reduce these values. Figures 11 to 16 also indicate that 15% pumice with fly ash gives the optimum strength and workability compared with the higher replacement levels. The control mix, without fly ash or pumice, was used as the benchmark. Replacing 15%, 25%, and 35% of the coarse aggregate with pumice, in the presence of fly ash, improved both the fresh and hardened properties.

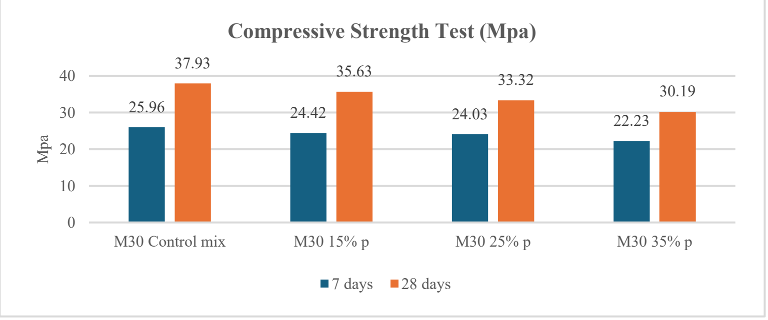

Fig. 5. Compressive strength (MPa) on day 7 and day 28

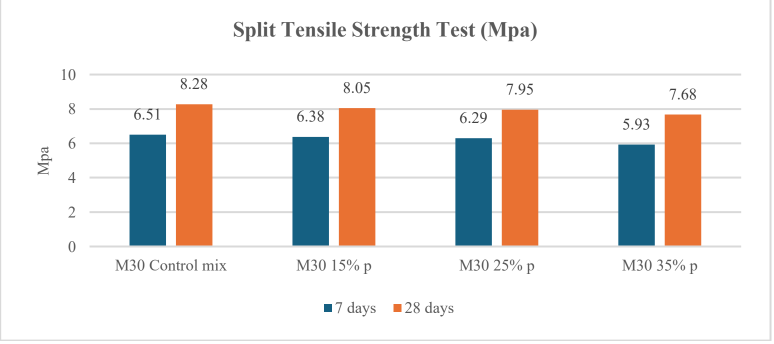

Fig. 6. Split Tensile strength (MPa) on day 7 and day 28

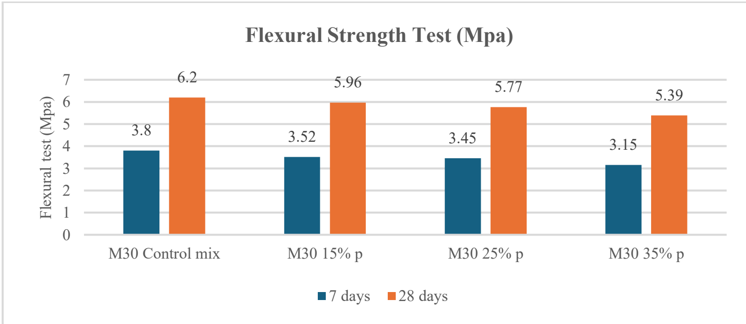

Fig. 7. Flexural strength test (MPa) on day 7 and day 28

4.1 Permeation Properties and Water Absorption

Water absorption of samples was studied in Figure 8 in order to investigate their permeation characteristic which could relate to their porosity. Water sorptivity and rapid chloride permeability tests RCPT were conducted to obtain additional information of the transport properties and resistance to the chloride ion attack. Rapid corrosion tests also were performed to understand the influence on the corrosion process of the chloride attack. In the water absorption test (ASTM C1585-13) on 100×100×100 mm cubes, the control mix showed the lowest absorption (2.3% at 7 days, 1.8% at 28 days). Absorption rose with pumice content: 15% mix (2.6%, 2.1%), 25% mix (2.8%, 2.3%), and 35% mix (2.9%, 2.6%). These results indicate that higher pumice levels increase porosity, with the 15% replacement offering the best balance of strength and durability among pumice concretes. Table 4 shows the experimental image of water absorption test.

Fig. 8. Water absorption samples

Table 4. Water Absorption Percentages

Mix	7 DAYS	28 DAYS
M30 Control mix	2.3%	1.8%
M30 15% p	2.6%	2.1%
M30 25% p	2.8%	2.3%
M30 35% p	2.9%	2.6%

4.2 Permeability test

The RCPT results showed improved chloride resistance with higher pumice replacement levels. At 7 d, the control mix recorded the highest charge (3500.67 C), whereas the 15%, 25%, and 35% pumice mixes recorded 3312.86, 2800.23, and 2100.73 C, respectively. By 28 days, the values decreased to 2100.73 C for the control, 2000.32 C for 15% replacement, 1705.28 C for 25% replacement, and 1366.85 C for 35% replacement. The 25% and 35% mixes fell into the low-permeability range, confirming enhanced durability against chloride-initiated corrosion. Figure 9 shows the experimental images of the RCPT and RCMT tests. Figures 10 – 12 depicts the test results of chloride ion permeability, chloride migration coefficient and sorptivity coefficients respectively.

Fig. 9. RCPT and RCMT setup

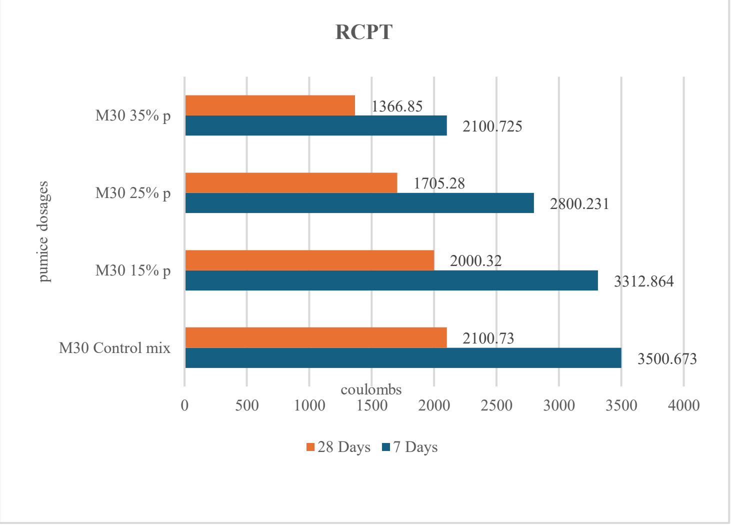

Fig. 10. Chloride Ion Permeability Results for 7 and 28-Day

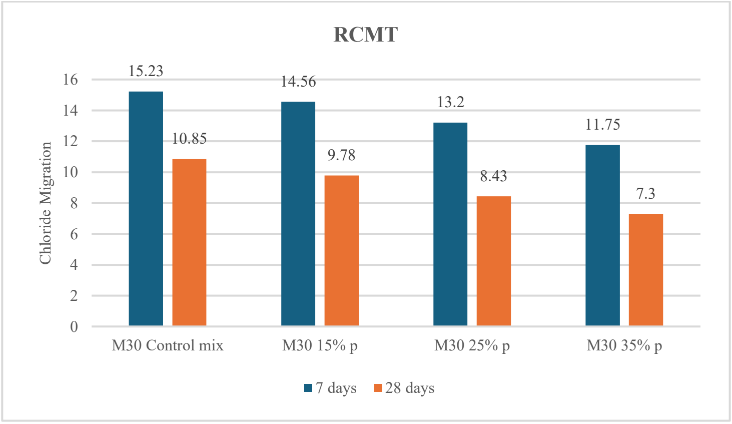

Fig. 11. Chloride Migration Coefficient for 7 and 28 Days

RCMT results confirmed improved chloride resistance with increasing pumice content. At 7 days, the control mix had a coefficient of 15.23 × 10^{-12} m²/s, while 15%, 25%, and 35% replacements measured 14.56, 13.20, and 11.75 × 10^{-12} m²/s, respectively. By 28 days, values dropped to 10.85 × 10^{-12} m²/s for the control, and 9.78, 8.43, and 7.30 × 10^{-12} m²/s for the pumice mixes, demonstrating enhanced chloride resistance at higher replacement levels.

4.3 Sorptivity

The sorptivity results showed that water uptake increased with pumice content. The control mix had the lowest values (0.17 and 0.13 mm/min^0.5), followed by the 15% pumice mix (0.19 and 0.15 mm/min^0.5). Greater sorption was associated with higher percentage replacement level (35% and 25%).

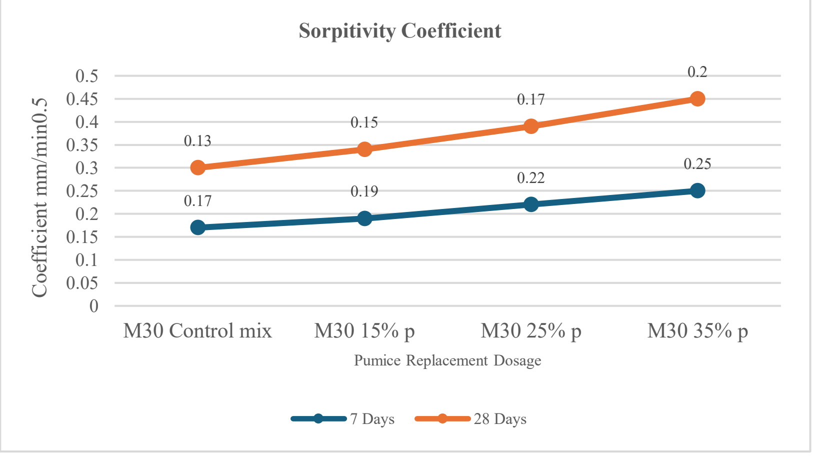

Fig. 12. Sorptivity Coefficients on day 7 and day 28

4.4 Acid Test

Cubes (100×100×100 mm) were exposed to 5% HCl for 7 and 28 days. The control mix lost 4.2% mass, 15% strength, and 0.25% dimension. The 15% pumice mix performed best with lower losses (3.8% mass, 12% strength, 0.22% dimension) and 15% durability loss. The 25%

mix showed moderate values, while the 35% mix had the highest losses (4.5% mass, 17% strength, 0.28% dimension) and 20% durability loss. Thus, 15% pumice replacement gave the best acid resistance. Figure 13 depicts the percentage losses of concrete mixes after 28-Day period. Figure 14 shows the experimental image of the acid test.

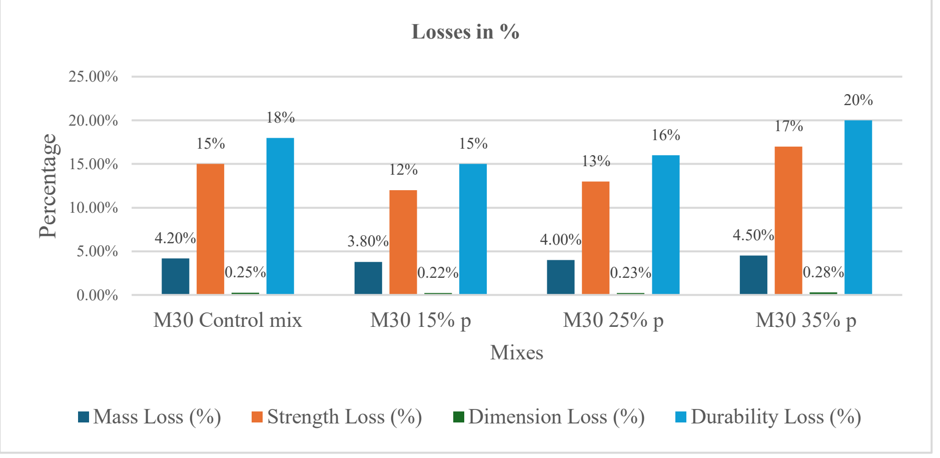

Fig. 13. Percentage losses of Concrete Mixes After 28-Day Period

Fig. 14. Acid Test samples

4.5 Accelerated Corrosion Test

Concrete cylinders (100 × 200 mm) with embedded 12-mm steel bars were subjected to accelerated corrosion testing (ACT) under a constant 10 V to assess corrosion resistance. At 7 days, the control mix exhibited 2.8% mass loss, a corrosion current of 0.30 mA, and a depassivation time of 6 days. In comparison, the 15%, 25%, and 35% pumice mixes showed improved performance, with mass losses of 2.4%, 2.1%, and 1.8%, corrosion currents of 0.26, 0.22, and 0.18 mA, and depassivation times of 7, 8, and 9 days, respectively, as shown Table 5. The control mix presented a loss in mass of 4.5% for 28 days, while for the mixes containing pumice it was 4.0%, 3.6% and 3.2% respectively. The 35% replacement achieved the lowest corrosion current and the longest depassivation period. Overall, pumice incorporation enhanced corrosion resistance, with 35% replacement demonstrating the best performance. Figure 15 shows the experimental image of corrosion test. Figure 16 shows the percentage losses of concrete mixes after 28-day period.

Fig. 15. Accelerated Corrosion Test

Table 5. Observations of Failure Cracks and percentage Reduction in Mass of Concrete Mixes after 28 Days

Mix	Mass Loss %	Critical corrosion current (mA)	Post-depassivation time (days)
M30 Control mix	4.5%	0.25	8
M30 15% p	4.0%	0.21	10
M30 25% p	3.6%	0.18	12
M30 35% p	3.2%	0.15	14

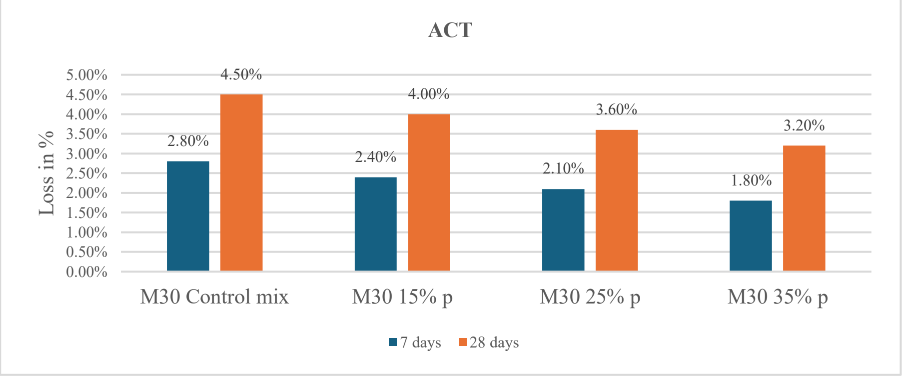

Fig. 16. Accelerated Corrosion Results for 7 and 28 Days

5 Conclusions

- Flow ability decreased with an increase in pumice content, however, all mixes met the EFNARC limits, and 15% pumice provided the best balance.
- The passing ability and viscosity changed slightly with pumice but remained acceptable, with 15% showing stable performance.
- The compressive, tensile, and flexural strengths decreased at higher pumice levels whereas 15% pumice maintained good strength compared to the control.
- Water absorption and porosity increased with pumice, the and 15% pumice mix showed the most balanced durability.
- The 15% pumice mix performed best overall, offering a compromise between workability, strength, and durability, making it the most suitable replacement level.

Conflict of interest: The authors declare no conflicts of interest.

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Data Availability: Data is available upon request

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