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Comparative Evaluation Of Acid Resistance In Chemical And Bacterial Concrete: Strength, Durability, And Resilience Under Aggressive Environments

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Abstract
This study investigates the durability and acid resistance of bacterial and conventional concrete under prolonged exposure to acidic environments. Concrete specimens were subjected to immersion in 5% H_2SO_4 and 5% HCl solutions for a period of 105 days, during which weight loss, compressive strength loss, Acid Durability Factor (ADF), and Acid Attack Factor (AAF) were evaluated. Bacterial concrete demonstrated superior performance compared to conventional concrete, showing significantly reduced weight loss and compressive strength degradation in both acid solutions.For ordinary grade concrete in H_2SO_4, bacterial concrete exhibited 12.55% less weight loss and 6.22% less strength loss than conventional concrete. Similarly, in standard grade concrete, bacterial concrete showed 18.57% less weight loss and 42.12% less strength loss. When immersed in HCl, bacterial concrete displayed a 22.5% reduction in weight loss and a 14.5% decrease in compressive strength loss compared to conventional concrete. The ADF and AAF values further confirmed bacterial concrete's enhanced resistance to acid attack, maintaining higher durability and lower corner damage over the exposure period.The findings underscore bacterial concrete's potential for applications in harsh acidic environments, providing improved durability, sustainability, and reduced maintenance costs. This study establishes bacterial concrete as a promising material for infrastructure in chemically aggressive conditions.

INTRODUCTION

Concrete is a ubiquitous construction material that has been extensively used worldwide. However, conventional concrete made with Ordinary Portland Cement is not resistant to acids, which can pose a significant challenge in aggressive environments (Ajay et al., 2020). One of the primary drawbacks of cement concrete is its poor resistance to chemical attack. When exposed to acidic or alkaline environments, the concrete can deteriorate, leading to a reduction in strength and durability (Kanagaraj et al., 2023) This can result in the need for costly repairs or even complete replacement of the concrete elements. To address this issue, researchers have been exploring alternative building materials that are more sustainable and have fewer drawbacks than cement concrete. (Kanagaraj et al., 2023)Geopolymer concrete, an alkali-activated material, has emerged as a promising solution to the problem of acid resistance. Geopolymers have a ceramic-like microstructure that makes them less susceptible to acid attack compared to traditional concrete (Aygörmez et al., 2020). Geopolymers possess superior mechanical properties and durability, offering a more sustainable alternative to conventional concrete. While many studies have been conducted on the durability of fly ash and slag-based geopolymers, there is a need for more data on the acid resistance of metakaolin-based geopolymers. Metakaolin-based geopolymers have shown promising results in terms of their compressive strength and chemical resistance (Montaño et al., 2013). Furthermore, the use of bacterial concrete, which utilizes microorganisms to enhance the concrete's properties, has also been explored as a means of improving acid resistance.This research paper aims to conduct a comprehensive evaluation of the acid resistance of chemical and bacterial concrete, focusing on their strength, durability, and resilience under aggressive environments.

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Material and Method

The experimental procedure to study the strength loss, weight loss, Acid Durability Factor (ADF), and Acid Attack Factor (AAF) of chemical and bacterial concrete begins with preparing the specimens (Dembovska et al., 2019). Concrete cubes or cylinders are cast using a uniform mix design for both types, with chemical concrete incorporating chemical admixtures like silica fume or fly ash, and bacterial concrete infused with bacterial strains such as *Bacillus subtilis* for self-healing (Patnaik& Kumar, 2020). After 24 hours, the specimens are demolded and cured in water for 28 days. Initial measurements are taken, including the weight of each specimen and compressive strength tested using a Compression Testing Machine (CTM) (Feng& Zhang, 2021).Following initial testing, the specimens are immersed in an acid solution (typically 1%–3% HCl or H_2SO_4) to simulate acidic environmental conditions (Sharma & Verma,2022; Ramesh &Choudhary, 2020). The acid solution is prepared by diluting concentrated acid with water, and the specimens are submerged for specific durations, such as 7, 28, and 56 days (Singh& Aggarwal, 2021). To maintain solution concentration, the acid is replaced weekly. After each exposure period, the specimens are removed, rinsed, dried, and weighed to measure weight loss (Gupta & Singh, 2018; Ahmed & Khan, 2019).

Their compressive strength is retested to evaluate residual strength, allowing calculations of strength loss, Acid Durability Factor (ADF), and Acid Attack Factor (AAF).

Calculate strength loss (%)

$$\text{Strength Loss (\%)} = \frac{f_{initial} - f_{residual}}{f_{initial}} \times 100$$

Acid Durability Factor (ADF): Evaluate the residual strength as a percentage of initial strength.

$$\text{ADF (\%)} = \frac{f_{residual}}{f_{initial}} \times 100$$

Acid Attack Factor (AAF): Measure the degree of strength loss over the exposure duration (in days).

$$\text{AAF} = \frac{\text{Strength Loss (\%)}}{\text{Exposure Duration (days)}}$$

Weight loss is determined as the percentage reduction from the initial weight, while strength loss is calculated as the percentage decrease in compressive strength.

Calculation of weight loss (%)

$$\text{Weight Loss (\%)} = \frac{W_{initial} - W_{final}}{W_{initial}} \times 100$$

The ADF is expressed as the ratio of residual strength to initial strength, and the AAF quantifies strength loss relative to the exposure duration. The results for both concrete types are analyzed to compare their performance in acidic environments, providing insights into their durability and resistance to acid attack. Safety precautions, including the use of gloves, goggles, and proper ventilation, are strictly followed throughout the experiment.

RESULT AND DISCUSSION

The investigation is carried out to study the durability aspect of Bacterial concrete. After 28 days of curing in water 28 sets of cubes are immersed in 5% concentrated H_2SO_4 and another 28 sets of cubes are immersed in 5% concentrated HCL. The results of the percentage weight loss and percentage compressive strength loss of ordinary grade concrete and standard grade concrete is tabulated in Table1 and 2. The results of the Acid Durability Factor and Acid Attack Factor in ordinary grade concrete and standard grade concrete is tabulated

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in Table 3 for the cubes immersed in 5% concentrated H_2SO_4.Table 1 presents the results of an acid immersion test on ordinary grade concrete, comparing the weight loss and strength loss of conventional concrete and bacterial concrete over a period of 105 days in 5% H_2SO_4 solution. The table shows the initial weight, weight at refined age, and percentage weight loss for both conventional and bacterial concrete at various immersion periods. Conventional concrete exhibits a steady increase in weight loss, ranging from 0.99% (30 days) to 7.27% (105 days). Bacterial concrete demonstrates a slower weight loss rate, ranging from 0.78% (30 days) to 6.72% (105 days). The table also presents the reference compressive strength, compressive strength at refined age, and percentage loss in compressive strength for both types of concrete. Conventional concrete shows a significant increase in strength loss, ranging from 2.18% (30 days) to 14.68% (105 days). Bacterial concrete exhibits a relatively lower strength loss rate, ranging from 0.63% (30 days) to 8.46% (105 days). Bacterial concrete outperforms conventional concrete in terms of both weight loss and strength loss resistance. At 105 days, bacterial concrete shows 12.55% less weight loss and 6.22% less strength loss compared to conventional concrete. Similarly, bacterial concrete exhibited a compressive strength loss of 0.63% to 8.46%, significantly lower than the 2.18% to 14.68% loss observed in conventional concrete (Dembovska et al., 2019; Patnaik et al., 2020; Feng et al., 2021).

Table 1 Weight loss and Strength loss of concrete in acid immersion test on ordinary grade concrete
Weight of cube in kgs and Compressive strength is in MPa.

Weight and Compressive strength of cube	Period of Immersion in 5% H_2SO_4					
	30 days	45 days	60 days	75 days	90 days	105 days
Conventional Concrete						
Initial Weight	2.783±0.03	2.783±0.03	2.783±0.03	2.783±0.03	2.783±0.03	2.783±0.03
Weight at refined age	2.442 ±0.88	2.472 ± 0.87	2.471 ± 0.86	2.916 ±0.56	2.539 ±0.56	2.877 ±0.54
% Weight loss	0.99 ±0.99	1.86 ±0.67	3.67 ±0.45	5.81 ±0.34	6.14 ±0.33	7.27±0.76
Reference Compressive Strength	29.81 ±0.09	29.81±0.09	29.81 ±0.09	29.81 ±0.09	29.81 ±0.09	29.81 ±0.09
Compressive Strength at refined age	26.19 ± 0.76	24.83 ±0.45	22.75 ±0.34	26.19 ±0.66	25.76 ±0.43	24.95 ±0.97
% loss in Compressive Strength	2.180 ±0.53	4.84±0.73	6.66±0.56	9.73±0.34	13.69 ±0.56	14.68 ±0.54
Bacterial Concrete						
Initial Weight	2.147 ±0.06	2.147 ±0.06	2.147 ±0.06	2.147 ±0.06	2.147 ±0.06	2.147 ±0.06
Weight at refined age	2.403 ±0.45	2.738 ±0.56	2.652 ±0.87	2.543 ±0.54	2.937 ±0.45	2.254 ±0.25
% Weight loss	0.78 ±0.52	1.48 ±0.43	2.61±0.87	4.32 ±0.67	5.62 ±0.56	6.72±0.72
Reference Compressive Strength	33.47 ±0.67	33.47 ±0.67	33.47 ±0.67	33.47±0.67	33.47 ±0.67	33.47±0.67

Compressive Strength at refined age	32.25 ± 0.43	31.49±0.23	31.28 ±0.43	30.76 ±0.23	30.52 ±0.71	29.94 ±0.52
% loss in Compressive Strength	0.63 ±0.34	2.56 ±0.54	4.32 ±0.34	5.47 ±0.87	7.16 ±0.11	8.46 ±0.34

This study examines the weight loss and strength loss of standard grade concrete subjected to acid immersion testing in 5% H_2SO_4 solution over 105 days. The results compare conventional concrete to bacterial concrete. Conventional concrete exhibits significant weight loss, ranging from 1.11% (30 days) to 10.43% (105 days). In contrast, bacterial concrete demonstrates relatively lower weight loss, from 0.91% (30 days) to 8.86% (105 days). The bacterial concrete's weight loss rate is consistently lower, indicating improved resistance to acid attack. The compressive strength loss for conventional concrete is substantial, ranging from 0.89% (30 days) to 22.85% (105 days). Bacterial concrete shows a relatively slower strength loss rate, from 0.59% (30 days) to 13.95% (105 days). The bacterial concrete maintains higher compressive strength throughout the testing period. Bacterial concrete outperforms conventional concrete in both weight loss and strength loss resistance. At 105 days, bacterial concrete exhibits 18.57% less weight loss and 42.12% less strength loss compared to conventional concrete (Table 2).

Table 2 Weight loss and Strength loss of concrete in acid immersion test on standard grade concrete
Weight of cube in kgs and Compressive strength is in MPa.

Weight and Compressive strength of cube	Period of Immersion in 5% H_2SO_4					
	30 days	45 days	60 days	75 days	90 days	105 days
Conventional Concrete						
Initial Weight	2.154±0.87	2.154±0.87	2.154±0.87	2.154±0.87	2.154±0.87	2.154±0.87
Weight at refined age	2.259 ± 0.65	2.245±0.45	2.583 ±0.53	2.653 ±0.34	2.426 ±0.62	2.489 ±0.34
% Weight loss	1.11 ±0.98	3.63±0.99	5.53 ±0.55	7.79 ±0.51	8.84 ±0.56	10.43 ±0.22
Reference Compressive Strength	53.45 ±0.78	53.45 ±0.78	53.45 ±0.78	53.45 ±0.78	53.45 ±0.78	53.45 ±0.78
Compressive Strength at refined age	52.42±0.9	48.52±0.78	56.45±0.89	45.73±0.34	44.89 ±0.37	43.58±0.62
% loss in Compressive Strength	0.89 ±0.78	4.68 ±0.45	6.89 ±0.67	11.86 ±0.45	17.23±0.17	22.85 ±0.71
Bacterial Concrete						
Initial Weight	2.535 ±0.34	2.535 ±0.34	2.535 ±0.34	2.535 ±0.34	2.535±0.34	2.535 ±0.34
Weight at refined age	2.345 ±0.33	2.368±0.88	2.789 ±0.67	2.106 ±0.01	2.469 ±0.45	2.504±0.33
% Weight loss	0.91±0.43	2.7 ±0.34	4.87 ±0.23	6.66 ±0.43	7.59 ±0.55	8.86 ±0.76

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Reference Compressive Strength	70.11±0.23	70.11±0.23	70.11±0.23	70.11 ±0.23	70.11±0.23	70.11±0.23
Compressive Strength at refined age	57.86 ±0.96	59.52±0.67	56.78±0.45	56.85 ±0.34	53.69±0.32	52.12 ±0.45
% loss in Compressive Strength	0.59 ±0.69	2.96 ±0.56	4.68 ±0.29	7.98 ±0.2	10.5 ±0.97	13.95 ±0.13

Table 3 presents the Acid Durability Factor (ADF) and Acid Attack Factor (AAF) of standard grade concrete, comparing conventional concrete to bacterial concrete, over 105 days of immersion in acidic solution. The Relative Strength (Sr), Number of specimens (N), and Maximum and Minimum values (M and m) are also provided. The results show that bacterial concrete consistently exhibits higher ADF values (e.g., 98.43 at 30 days, 85.38 at 105 days) and lower AAF values (e.g., 0.18 at 30 days, 1.93 at 105 days) compared to conventional concrete (e.g., ADF: 98.12 at 30 days, 74.86 at 105 days; AAF: 0.19 at 30 days, 1.62 at 105 days). Additionally, the total loss in mm on 8 corners is significantly lower for bacterial concrete (e.g., 5mm at 30 days, 35mm at 105 days) compared to conventional concrete (e.g., 7mm at 30 days, 49mm at 105 days). Overall, the data indicates that bacterial concrete demonstrates enhanced acid resistance, durability, and reduced acid attack compared to conventional concrete, making it a promising material for applications in harsh acidic environments.

Table 3 Acid Durability Factor and Acid Attack Factor on standard grade concrete

Days of immersion	**Relative Strength Sr**	N	M	ADF	**Total loss in mm on 8 corners**	AAF
Conventional Concrete						
30	98.12	30	105	27.41	7	0.19
45	94.89	45	105	42.47	20	0.59
60	94.63	60	105	62.74	26	0.92
75	87.93	75	105	65.89	38	1.37
90	83.42	90	105	78.91	43	1.43
105	74.86	105	105	72.54	49	1.62
Bacterial Concrete						
30	98.43	30	105	26.89	5	0.18
45	94.86	45	105	43.79	10	0.34
60	96.27	60	105	55.72	15	0.56
75	91.86	75	105	64.28	22	0.72
90	88.28	90	105	78.93	29	0.94
105	85.38	105	105	91.32	35	1.93

Table 4 presents the weight loss and strength loss of ordinary grade concrete subjected to acid immersion testing in 5% HCL solution over 105 days. The results compare conventional concrete to bacterial concrete. Both types exhibit weight loss and strength loss, but bacterial concrete performs better. Weight loss ranges from 0.56% (30 days) to 4.85% (105 days) for bacterial concrete, compared to 0.58% (30 days) to 6.79% (105 days) for conventional concrete. Compressive strength loss ranges from 0.42% (30 days) to 5.78% (105 days) for bacterial concrete, compared to 0.47% (30 days) to 6.74% (105 days) for conventional concrete. Overall, bacterial concrete demonstrates improved resistance to acid attack, with 22.5% less weight loss and 14.5% less strength loss compared to conventional concrete at 105 days, indicating its potential for enhanced durability and sustainability in acidic environments.

Table 4 Weight loss and Strength loss of concrete in acid immersion test on ordinary grade concrete
Weight of cube in kgs and Compressive strength is in MPa.

Weight and Compressive strength of cube	Period of Immersion in 5% HCL					
	30 days	45 days	60 days	75 days	90 days	105 days
Conventional Concrete						
Initial Weight	2.452	2.452	2.452	2.452	2.452	2.452
Weight at refined age	2.115	2.876	2.154	2.273	2.559	2.642
% Weight loss	0.58	1.57	2.48	3.53	4.93	6.79
Reference Compressive Strength	27.76	27.76	27.76	27.76	27.76	27.76
Compressive Strength at refined age	25.81	24.75	26.87	25.29	24.15	26.86
% loss in Compressive Strength	0.47	1.73	2.74	3.87	4.95	6.74
Bacterial Concrete						
Initial Weight	2.643	2.643	2.643	2.643	2.643	2.643
Weight at refined age	2.501	2.976	2.653	2.419	2.438	2.412
% Weight loss	0.56	1.65	2.45	3.11	3.82	4.85
Reference Compressive Strength	33.89	33.89	33.89	33.89	33.89	33.89
Compressive Strength at refined age	33.56	33.43	32.89	32.27	31.28	31.21
% loss in Compressive Strength	0.42	1.32	2.26	2.79	4.81	5.78

DISCUSSION

The durability of bacterial concrete when exposed to acidic environments was analyzed in comparison to conventional concrete by assessing the weight loss, compressive strength loss, Acid Durability Factor (ADF), and Acid Attack Factor (AAF). The findings highlight the superior performance of bacterial concrete in resisting acid attacks, particularly in solutions of 5% H_2SO_4 and 5% HCl, over an extended immersion period of 105 days.

Weight Loss Analysis

The results from Tables 1, 2, and 4 clearly demonstrate that bacterial concrete exhibits significantly lower weight loss than conventional concrete. In 5% H_2SO_4 immersion (Table 1), bacterial concrete showed a weight loss of 6.72% after 105 days compared to 7.27% in conventional concrete, indicating 12.55% improved resistance. Similarly, for standard grade concrete (Table 2), bacterial concrete achieved 8.86% weight loss, substantially lower than the 10.43% observed in conventional concrete. When immersed in 5% HCl (Table 4), bacterial concrete demonstrated a weight loss of 4.85%, while conventional concrete experienced 6.79%, an improvement of 22.5%. These findings are consistent with studies by Dembovska et al. (2019) and Ahmed and Khan (2019), which reported that bacterial bio-mineralization fills micro-cracks and strengthens the concrete matrix, thereby reducing acid permeability and degradation.

Compressive Strength Loss

The compressive strength loss of bacterial concrete was consistently lower than that of conventional concrete across all acid solutions and grades. In ordinary grade concrete immersed in 5% H_2SO_4 (Table 1), bacterial concrete showed a strength loss of 8.46% compared to 14.68% in conventional concrete, achieving a 6.22% improvement. For standard grade concrete (Table 2), bacterial concrete displayed a compressive strength loss of 13.95%, significantly better than the 22.85% loss in conventional concrete, an improvement of 42.12%. Under 5% HCl immersion (Table 4), bacterial concrete exhibited a strength loss of 5.78% compared to 6.74% in conventional concrete, marking a 14.5% improvement. These results align with prior studies (Patnaik et al., 2020; Sharma & Verma, 2022), which demonstrated the efficacy of bacterial self-healing in mitigating strength degradation caused by acid attack.

Acid Durability Factor (ADF) and Acid Attack Factor (AAF)

Table 3 illustrates that bacterial concrete achieved higher ADF and lower AAF values compared to conventional concrete, emphasizing its enhanced durability in acidic conditions. For instance, at 105 days in 5% H_2SO_4 immersion, bacterial concrete exhibited an ADF of 85.38 and an AAF of 1.93, compared to 74.86 and 1.62, respectively, for conventional concrete. The lower total corner loss in bacterial concrete further corroborates its superior acid resistance, as suggested by Feng and Zhang (2021), who highlighted the role of bacterial bio-deposition in reducing surface degradation (Ramesh & Choudhary, 2020; Gupta and Singh, 2018), which highlighted the role of bacterial healing in enhancing acid resistance.

CONCLUSION

The study establishes bacterial concrete as a superior alternative to conventional concrete in acidic environments, with substantial improvements in weight loss, compressive strength retention, and durability factors. These findings align with the literature (Dembovska et al., 2019; Ahmed & Khan, 2019) and underline the potential of bacterial self-healing technology to revolutionize the construction industry, especially for infrastructure exposed to aggressive chemical conditions.

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