

Comparative Study on Strength and Durability of Conventional and Modified Concrete under Leachate Exposure

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Abstract: The rapid increase in municipal solid waste generation has raised serious concerns regarding landfill leachate and its impact on concrete structures. Landfill leachate contains organic matter, heavy metals, chlorides, sulphates, ammonia, and other aggressive compounds that adversely affect the physical and chemical properties of concrete over time [2, 13,14]. Proper leachate management and environmental protection measures are therefore essential to minimize infrastructure deterioration and environmental pollution [1,3]. Studies have shown that prolonged exposure of concrete to landfill leachate results in strength loss, increased permeability, cracking, surface degradation, and microstructural damage due to aggressive chemical interactions [4, 7, 17]. To improve concrete durability in such aggressive environments, researchers have investigated the use of supplementary cementations materials such as silica fume and fly ash. These materials enhance pore structure, reduce permeability, and improve resistance against chemical attack, thereby increasing the long-term performance of concrete [5, 9, 10]. Durability-based approaches and protective techniques have also been recommended to enhance the service life and sustainability of concrete structures [6,8,11]. Furthermore, cyclic dry–wet exposure has been found to accelerate deterioration through repeated expansion, shrinkage, and chemical penetration within the concrete matrix [12,18].

Keywords: Leachate exposure, Silica fume, Fly ash, Compressive strength, Dry–wet cycles, Surface degradation, Supplementary cementations materials (SCMs), Sustainable construction

1. INTRODUCTION

The rapid increase in municipal solid waste generation has created serious environmental concerns related to landfill leachate, a highly contaminated liquid formed by the percolation of water through waste materials [1,13]. Landfill leachate contains organic matter, heavy metals, chlorides, sulfates, ammonia, and other aggressive compounds that can contaminate soil and groundwater and negatively affect nearby infrastructure [2, 3, 14, 16].

Effective leachate management and treatment are therefore essential for sustainable waste disposal systems [15, 16]. Concrete is widely used in civil engineering because of its strength and durability; however, exposure to aggressive environments such as landfill leachate can significantly reduce its performance [4,7].

Chemical interactions between leachate and cement hydration products lead to increased permeability, cracking, surface deterioration, and loss of compressive strength [17, 18]. Long-term exposure can therefore shorten the service life of concrete structures used in landfill-related applications. To improve concrete durability, researchers have investigated the use of supplementary cementations materials such as silica fume and fly ash [5, 9].

These materials refine the pore structure, reduce permeability, and improve resistance against chemical attack [10]. Their use also supports sustainable construction by

enhancing long-term durability and reducing cement consumption [6]. In addition, cyclic dry–wet exposure has been found to accelerate deterioration due to repeated expansion, and chemical penetration within concrete [12,18].

2. OBJECTIVES

The objectives of this study are:

- To compare the resistance of different concrete mixes against synthetic leachate.
- To evaluate the effect of leachate on concrete strength and durability.
- To assess the effectiveness of silica fume and fly ash in improving concrete durability.
- To study the impact of cyclic dry–wet exposure on concrete deterioration.
- To compare the compressive strength of conventional and modified concrete.
- To analyse the long-term performance of concrete under aggressive leachate conditions.

3. METHODOLOGY

A. Material Selection

The materials used for the experimental work included Ordinary Portland Cement (OPC 53 grade), fine aggregate,

coarse aggregate, potable water, silica fume, fly ash, and landfill leachate. River sand and M-sand conforming to IS 383:1970 were used as fine aggregates while 20 mm crushed angular aggregates were used as coarse aggregates. Potable water free from harmful impurities was used for mixing and curing of concrete. Silica fume and fly ash were used as supplementary cementations materials to improve durability. Synthetic landfill leachate was prepared using suitable chemicals to simulate aggressive environmental conditions. All materials were tested as per relevant IS codes to ensure their suitability for concrete production



Figure 1: Primary testing on materials

B. Preparation of Concrete Mixes

Concrete mixes were prepared using Ordinary Portland Cement (OPC 53 grade), fine aggregate, coarse aggregate, potable water, silica fume, and fly ash. Different grades of concrete were designed according to relevant IS code provisions to achieve the required strength and workability. Two types of mixes were prepared: conventional concrete and modified concrete containing supplementary cementations materials. For modified concrete, silica fume and fly ash were used as partial replacement of cement in suitable proportions to improve the durability and resistance of concrete against aggressive landfill leachate conditions. All materials were properly weighed and batched before mixing. The mixing process was carried out carefully to ensure uniform distribution of materials and to obtain a homogeneous concrete mix with good workability. Trial mixes were initially prepared to verify the mix proportions and target strength. After satisfactory results, the final mix proportions were selected for casting the concrete specimens used in the experimental study.



Figure 2: Concrete mixing

C. Casting of Specimens

Concrete specimens were cast using standard cube moulds as per relevant IS code procedures. Before casting, the moulds were properly cleaned and oiled to prevent the concrete from sticking to the surfaces. Freshly prepared concrete mixes were placed into the moulds in three equal layers. Each layer was compacted properly using a tamping rod or vibration method to remove entrapped air and achieve dense and uniform concrete. After proper compaction, the top surface of the specimens was leveled and finished smoothly using a trowel. The moulds were then kept undisturbed at room temperature for 24 hours to allow initial setting and hardening of concrete. After this period, the specimens were carefully demolded and transferred for curing under normal water and landfill leachate exposure conditions for further experimental testing.



Figure 3: Concrete casting

D. Leachate preparation

Synthetic landfill leachate was prepared in the laboratory to simulate the aggressive environmental conditions commonly observed in municipal solid waste landfill sites. The purpose of preparing synthetic leachate was to create a controlled exposure medium that closely represents the chemical characteristics of actual landfill leachate and to ensure consistency throughout the experimental program. The

prepared solution was used to study the deterioration behaviour and durability performance of concrete specimens under chemically aggressive conditions. The synthetic leachate solution was prepared by dissolving suitable organic and inorganic chemicals in potable water in predetermined proportions. The chemicals selected for preparation of the leachate mainly included chlorides, sulphates, ammonia compounds, and other dissolved salts that are generally present in landfill leachate and are known to adversely affect concrete structures. All chemicals were accurately weighed using a digital balance before mixing. The measured chemicals were gradually added to water and continuously stirred until complete dissolution was achieved, ensuring the formation of a homogeneous and stable solution. The pH and concentration of the solution were maintained within the desired range to simulate realistic landfill conditions. The leachate solution was periodically checked and replaced at regular intervals to maintain uniform chemical concentration throughout the exposure duration. This controlled preparation and maintenance of synthetic leachate helped in achieving reliable and consistent testing conditions for evaluating the effect of landfill leachate on the strength, durability, and deterioration characteristics of both conventional and modified concrete specimens.

Sr.no	Chemicals used	Quantity
1	Sodium Sulphate (Na ₂ SO ₄)	978gm
2	Sodium Chloride (NaCl)	1980gm
3	Sodium Nitrate (NaNO ₃)	408gm
4	Sodium Bicarbonate (NaHCO ₃)	2400gm
5	Calcium Chloride (CaCl ₂)	1800gm
6	Dextrose (C ₆ H ₁₂ O ₆)	5400gm
7	Glutamic Acid	2400gm
8	Ammonium chloride (NH ₄ Cl)	918gm

Table I: Chemical used in synthetic leachate

E. Curing of Specimens

After 24 hours of casting, the concrete specimens were carefully demoulded and subjected to curing. Initially, all specimens were cured in clean water to ensure proper hydration of cement and development of strength. The curing process was carried out under controlled laboratory conditions. After the initial curing period of 3 days, the specimens were divided into three groups. The test specimens were immersed in prepared Synthetic leachate solution to simulate aggressive environmental conditions. Some specimens were also subjected to cyclic dry-wet exposure to study the effect of repeated wetting and drying on concrete durability. The curing and exposure periods were maintained for 7, 14, and 28 days, after which the specimens were tested for compressive strength and

durability characteristics.



Figure 3: Curing in leachate

F. Testing and Comparative Analysis

After completion of the curing and exposure periods, the concrete specimens were tested to evaluate their strength and durability performance. Compressive strength tests were conducted on the concrete cubes at 7, 14, and 28 days using a Compression Testing Machine (CTM). During testing, the maximum load carried by each specimen was recorded and the corresponding compressive strength was calculated. Visual observations such as surface deterioration, cracking, and changes in texture were also noted to assess the effect of landfill leachate on concrete. The test results of conventional concrete specimens were compared with modified concrete containing silica fume and fly ash under both normal curing and leachate exposure conditions. The comparative analysis helped in evaluating the influence of landfill leachate on concrete performance and determining the effectiveness of supplementary cementations materials in improving resistance against aggressive environmental conditions.



Figure 4: Compression Testing Machine

4. RESULTS AND DISCUSSION

The study was carried out on three different grades of

concrete, namely M20, M40, and M60, to evaluate their behavior under exposure to leachate, exposure to leachate with the addition of admixture and exposure to leachate in wet and dry cycle. The specimens were tested at curing periods of 7, 14, and 28 days in order to examine the variation in strength with age. For each condition, parameters such as weight of specimens, individual compressive strength values, and average compressive strength were recorded systematically. In addition, graphical representations are used to illustrate the variation in compressive strength and to highlight the trends more effectively.

A. Conventional concrete under exposed to leachate

Conventional concrete exposed to landfill leachate undergoes gradual deterioration due to the presence of aggressive chemicals such as chlorides, sulfates, ammonia, and organic acids in the leachate. These chemicals penetrate the concrete pores and react with cement compounds, leading to reduction in compressive strength

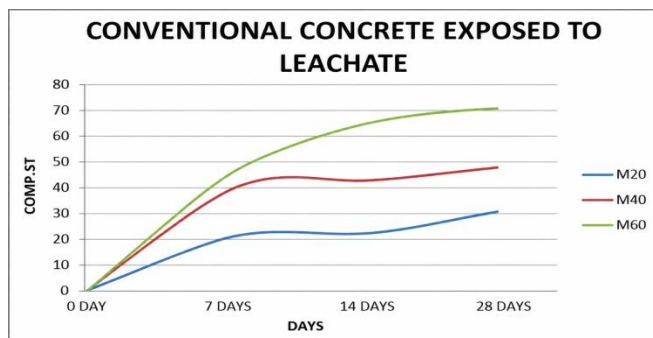


Figure 5: Conventional concrete under exposed to leachate

The M20 concrete shows the lowest strength throughout the study increasing gradually. The M40 concrete gains strength rapidly up to 7 days with constant increase. The M60 concrete exhibits the highest compressive strength and better resistance to leachate exposure

B. Modified concrete under exposed to leachate

Modified concrete exposed to landfill leachate shows better strength and durability performance compared to conventional concrete. The addition of supplementary cementations materials such as silica fume and fly ash improves the concrete microstructure by reducing pore spaces and permeability. Even under continuous leachate exposure, the concrete maintains higher compressive strength and demonstrates better long-term durability due to its dense and refined internal structure.

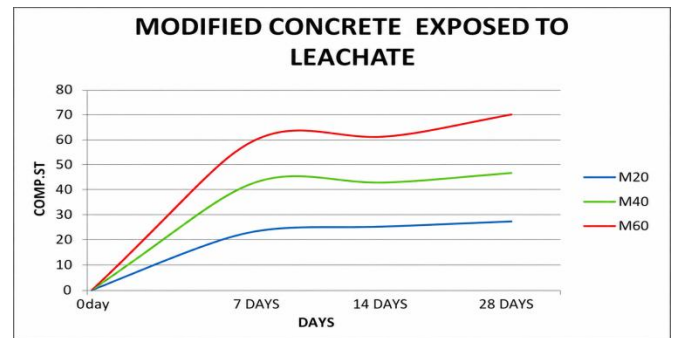


Figure 6: Modified concrete under exposed to leachate

The M20 concrete shows gradual strength development. The M40 concrete gains strength rapidly up to 7 days and maintains higher strength. The M60 concrete exhibits the highest compressive strength throughout. The modified concrete performs better than conventional concrete because materials such as silica fume and fly ash reduce pore spaces and permeability, limiting the penetration of harmful chemicals.

C. Conventional concrete under exposed to leachate

Conventional concrete exposed to landfill leachate is affected by harmful chemicals. The effect becomes more severe with prolonged exposure and under dry-wet cycles, as repeated moisture variation accelerates the penetration of leachate into the concrete. Therefore, conventional concrete in dry- wet cycle shows lower durability and reduced long-term performance in aggressive leachate environments.

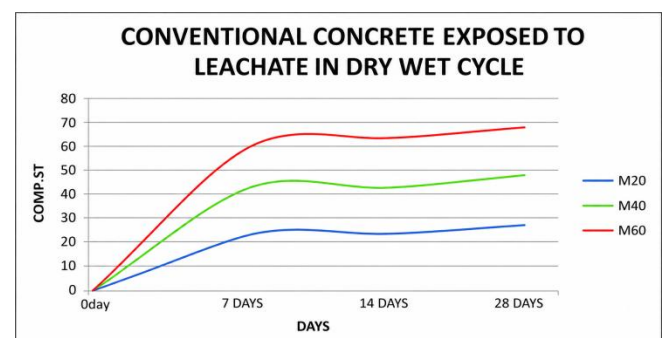


Figure 7: Conventional concrete under exposed to leachate in dry-wet cycle

The M20 concrete shows the lowest strength among all grades. The M40 concrete exhibits moderate strength development, increasing rapidly up to 7 days. The M60 concrete shows the highest compressive strength. A slight decrease in strength is observed around 14 days for all mixes. This reduction occurs because repeated dry-wet cycles allow harmful leachate chemicals to penetrate the concrete pores, causing temporary deterioration and internal stress.

5. CONCLUSION

The experimental investigation revealed that the compressive strength of all concrete grades increased progressively with curing age under every exposure

condition at the early period. This increase in strength is mainly attributed to the continuous hydration of cementations compounds, which enhanced the bonding characteristics and densified the internal concrete matrix over time. Although all grades exhibited strength development from 0 to 28 days, the rate of increase varied depending upon the concrete grade and exposure condition. Among all the grades studied, higher-strength concrete, particularly M60 grade, consistently demonstrated superior compressive strength and durability performance throughout the testing period.

The enhanced behaviour of M60 concrete can be attributed to its lower water–cement ratio, denser microstructure, improved particle packing, and reduced pore connectivity. These characteristics minimized the penetration of harmful leachate constituents into the concrete matrix and improved resistance against chemical deterioration. In comparison, M20 concrete exhibited relatively lower strength and greater vulnerability to aggressive exposure conditions because of its comparatively porous structure and weaker cementations bonding.

The results further indicated that conventional concrete exposed to continuous leachate conditions experienced moderate strength development; however, exposure to dry–wet leachate cycles caused noticeable fluctuations in compressive strength values. The alternate wetting and drying action appears to accelerate internal deterioration mechanisms, including micro crack formation, leaching of calcium compounds, and weakening of the cement paste. This cyclic exposure condition produced comparatively larger reductions in strength, especially in lower-grade concrete mixes. Therefore, the study confirms that dry–wet cyclic exposure is more aggressive and detrimental than continuous immersion exposure. Modified concrete exposed to leachate demonstrated comparatively better resistance against strength loss and showed more stable compressive strength development during the curing period. As a result, the modified concrete mixes were able to resist the penetration and adverse effects of leachate more effectively than conventional concrete.

The reduced fluctuation in strength values also indicates improved durability and long-term stability under chemically aggressive environmental conditions. The percentage analysis additionally confirmed that M60 concrete exhibited the least reduction in strength under all exposure conditions. In modified concrete conditions, M60 showed nearly no reduction in compressive strength, highlighting its excellent resistance to leachate attack. On the other hand, M20 concrete showed the maximum percentage decrease, indicating that lower-grade concrete is

more susceptible to deterioration in aggressive environments. M40 concrete demonstrated intermediate behaviour with moderate stability and satisfactory performance. Overall, the comparative analysis establishes that concrete grade, exposure condition, and modification technique significantly influence compressive strength performance under leachate environments. Higher-grade modified concrete mixes, especially M60, provide better structural integrity, durability, and resistance against aggressive chemical exposure. Therefore, M60 modified concrete can be considered the most suitable material for construction in landfill sites, wastewater treatment plants, sewage structures, and other aggressive environmental conditions where long-term durability and strength retention are critical requirements.

REFERENCES

- [1] Solsky, S. V., & Samofalov, D. P., "Study on water management and leachate control in municipal solid waste landfills," 2003.
- [2] Guman, O. M., & Dolinina, I. A., "Hydrogeochemical behavior and characteristics of landfill leachate," 2003.
- [3] Al'-Akhval', N. S., & Semin, E. G., "Environmental impact assessment of municipal solid waste landfills in Yemen," 2010.
- [4] Chen, Y., Wang, M., Xu, T., Liu, J., Zang, Z., Li, S., Jia, X., & Ma, J., "Effect of landfill leachate and environmental factors on concrete deterioration," 2024.
- [5] Gana, M. S., Erasmus, P. D., & Shehu, I. A., "Durability performance of blended cement concrete in aggressive chemical environments," 2020.
- [6] Zhang, et al., "Role of durability in improving environmental performance of concrete structures," 2020.
- [7] Li, X., Xie, Y., Liu, Z., et al., "Interaction between concrete and landfill leachate and its effect on durability," 2022.
- [8] Kobetičová, K., et al., "Environmental impact and ecotoxicity of concrete leachate," 2022.
- [9] Miah, M. J., Huaping, R., Paul, S. C., et al., "Long-term durability of concrete with supplementary cementitious materials," 2023.
- [10] Wen, P., Wang, C., et al., "Strategies to improve durability of concrete in aggressive environments," 2021.
- [11] Pacheco, et al., "Protective techniques for enhancing concrete durability," 2022.
- [12] Wang, Y., Zhang, R., et al., "Behavior of concrete exposed to landfill leachate and durability improvements," 2024/2025.
- [13] Kjeldsen, P., Barlaz, M. A., Rooker, A. P., et al., "Composition and characteristics of landfill leachate and need for synthetic leachate," 2002.
- [14] Renou, S., Givaudan, J. G., Poulain, S., et al., "Landfill leachate treatment and laboratory simulation," 2008.
- [15] "Landfill leachate treatment and laboratory simulation," 2008.
- [16] Kurniawan, T. A., Lo, W. H., & Chan, G. Y. S., "Physico-chemical treatment and characteristics of landfill leachate," *Journal of Hazardous Materials*, vol. 129, no. 1–3, pp. 80–100, 2006.
- [17] Hartwich, P., & Vollpracht, A., "Influence of leachate composition on the leaching behaviour of concrete," *Cement and Concrete Research*, vol. 100, pp. 67–76, 2017.
- [18] He, J., Feng, X. Y., Zhou, L. R., & Zhang, L., "Effect of leachate seepage on mechanical properties and microstructure of solidified materials," *Journal of Environmental Management*, vol. 287, 2021.