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Influence of Muncipal Solid Waste Leachate on Compreesive Strength of Concrete

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Abstract: Concrete structures exposed to chemically aggressive environments may undergo deterioration in their durability and strength. Artificial leachate contains harmful chemicals, chlorides, sulfates, and organic compounds that can adversely affect concrete performance. This study investigates the durability behavior of M20, M40, and M60 grade concrete exposed to artificial leachate under controlled laboratory conditions. Concrete specimens were tested for compressive strength, water absorption, density variation, and weight loss after exposure to artificial leachate solutions. The results were compared with specimens cured under normal water conditions. Experimental observations indicated that prolonged exposure to artificial landfill leachate reduced the strength and durability properties of concrete due to chemical interactions with cementitious materials. [4], [7], [12] The study emphasizes the need for durable concrete in structures exposed to landfill environments.

Keywords: Artificial landfill leachate, Concrete durability, Compressive strength, Leachate exposure, Dry–wet cycles, Chemical attack, Surface deterioration, Water absorption, Sustainable construction, Concrete degradation,

1. INTRODUCTION

Concrete is one of the most widely used construction materials due to its high strength, durability, versatility, and cost-effectiveness. It is extensively used in the construction of buildings, bridges, roads, dams, and other infrastructure projects. However, the durability and long-term performance of concrete can be adversely affected when it is exposed to aggressive chemical environments. Artificial leachate, prepared to simulate actual landfill leachate, contains harmful chemicals such as chlorides, sulphates, ammonia, dissolved salts, and organic compounds that can gradually deteriorate concrete properties over time. These chemical constituents react with the cement matrix and may reduce the service life of concrete structures exposed to such environments. [13], [14], [16]

When concrete is exposed to artificial leachate, various chemical and physical reactions occur within the concrete matrix. These reactions may result in decomposition of hydration products, increased porosity, micro-cracking, surface deterioration, and weakening of the bond between cement paste and aggregates. Consequently, the concrete may experience reduction in compressive strength, higher water absorption, density variation, and weight loss. The extent of deterioration depends on factors such as concentration of chemicals in the leachate, duration of exposure, and the grade of concrete used. Therefore, understanding the behavior of concrete under chemically aggressive conditions is important for ensuring the safety, durability, and performance of structures.

This study investigates the durability behavior of M20, M40, and M60 grade concrete exposed to artificial leachate under controlled laboratory conditions. Durability-related tests such as compressive strength, water absorption, density variation, and weight loss analysis are conducted to evaluate the effect of artificial leachate on concrete properties. The research aims to understand the deterioration mechanism of concrete under aggressive chemical exposure and to emphasize the need for durable and high-performance concrete for structures exposed to landfill or leachate-prone environments. The findings of this study may help in improving material selection and enhancing the durability of concrete structures in chemically aggressive conditions. [4], [5], [6], [7], [10].

2. OBJECTIVES

The objectives of this study are:

- To study the effect of leachate on the durability properties of concrete.
- To evaluate the changes in compressive strength of concrete exposed to leachate under different curing periods.
- To investigate the influence of leachate on the physical properties of concrete such as water absorption, porosity, and density.
- To compare the performance of concrete specimens cured in normal water and leachate solutions.
- To assess the resistance of different grades of concrete (such as M20, M40, and M60) against aggressive leachate exposure.
- To study the deterioration characteristics of concrete due to long-term exposure to landfill leachate.

3. METHODOLOGY

A. Material Selection for the experiment

Ordinary Portland Cement (OPC 53 grade), fine aggregates, coarse aggregates, potable water, and landfill leachate were used for the experimental investigation. Fine aggregates

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consisted of river sand and manufactured sand (M-sand) conforming to IS 383:1970, while crushed angular aggregates of 20 mm size were utilized as coarse aggregates. Potable water free from harmful impurities was used for both mixing and curing of concrete specimens. To simulate aggressive environmental conditions, artificial landfill leachate was prepared using suitable chemical constituents. All the materials were tested according to relevant IS standards to ensure their suitability for concrete production.

Figure 1: Primary testing on materials

B. Preparation of different grades 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. The investigation included two types of concrete mixes: conventional concrete and modified concrete containing supplementary cementitious materials.

For the modified concrete mixes, silica fume and fly ash were used as partial replacements for cement in suitable proportions to improve durability and enhance the resistance of concrete against aggressive landfill leachate exposure. Before the mixing process, all materials were properly batched and accurately weighed. Concrete mixing was carried out carefully to obtain a uniform, homogeneous, and workable mix. Trial mixes were initially conducted to verify the adequacy of the mix proportions and the achievement of target strength. After obtaining satisfactory results from the trial mixes, the final mix proportions were selected for casting the concrete specimens used in the experimental study.

C. Casting of Specimens with various grades of concrete

Concrete specimens were cast using standard cube moulds as per relevant IS code procedures. Before casting, the moulds were properly cleaned, bolts were tight properly 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 demoded and transferred for further experimental testing.

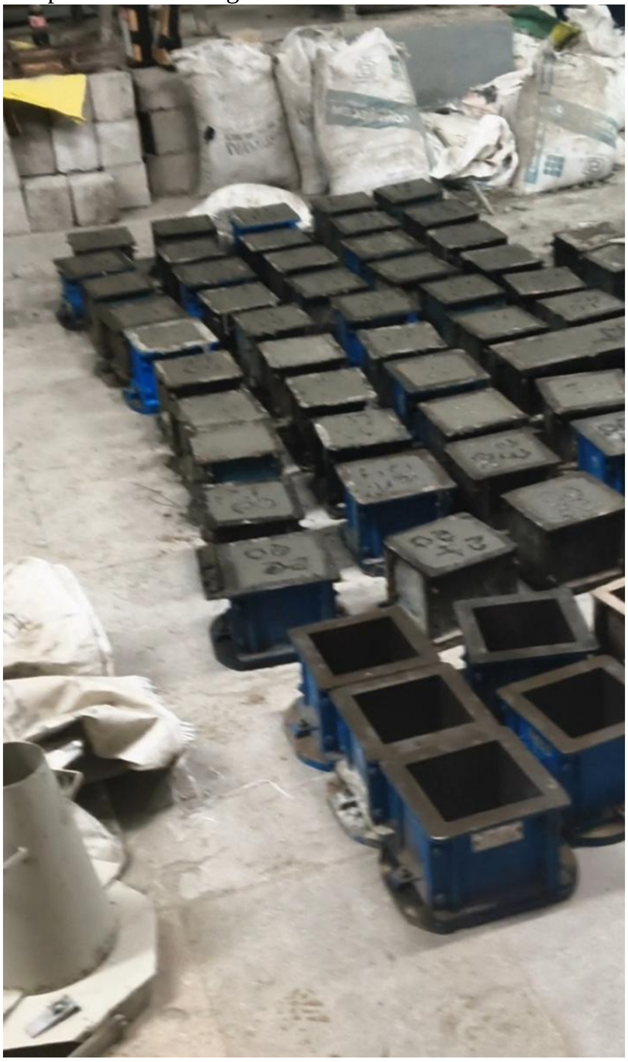

Figure 2: Concrete casting

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 behavior 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_2SO_4)	1630mg/lit
2	Sodium Chloride (NaCl)	3300mg/lit
3	Sodium Nitrate ($NaNO_3$)	680mg/lit
4	Sodium Bicarbonate ($NaHCO_3$)	1530mg/lit
5	Calcium Chloride ($CaCl_2$)	4000mg/lit
6	Dextrose ($C_6H_{12}O_6$)	9000mg/lit
7	Glutamic Acid	4000mg/lit
8	Ammonium chloride (NH_4Cl)	1530mg/lit

Table I: Chemical used for preparation of 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.

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 3: 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 normal water, exposure to leachate 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. Concrete under exposed to normal water

The concrete specimens cured in normal water showed the highest strength and best durability performance among all conditions. Proper hydration of cement resulted in formation of dense calcium silicate hydrate (C-S-H) gel, leading to

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improved compressive strength and reduced permeability. M60 concrete exhibited maximum strength due to lower water-cement ratio and denser microstructure, whereas M20 concrete showed comparatively lower performance because of higher porosity. No visible deterioration, cracking, or surface damage was observed in water-cured specimens.

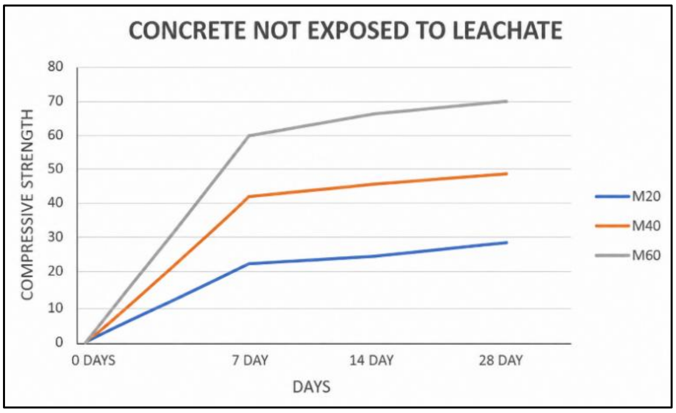

Figure 5: Concrete under exposed to normal water

B. Concrete exposed to leachate

Concrete specimens fully exposed to landfill leachate exhibited maximum deterioration among all three conditions. Continuous exposure allowed aggressive chemicals to penetrate deeper into the concrete matrix, causing significant reduction in compressive strength.

The harmful effects observed included:

- Increase in porosity
- Surface discoloration
- Minor cracking
- Material degradation
- Increased water absorption

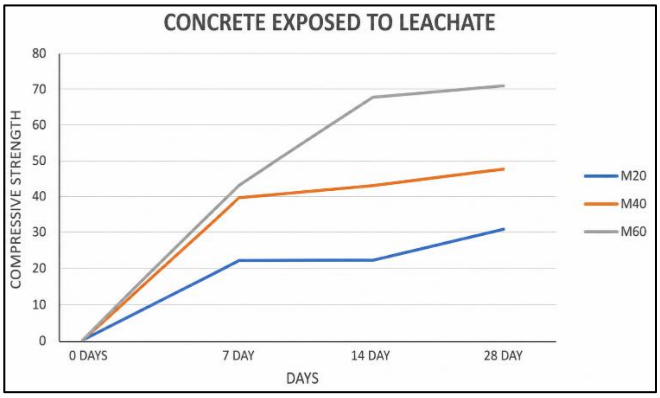

Figure 6: Concrete exposed to leachate

The deterioration mechanism mainly involved sulphate attack, acid attack, and dissolution of calcium hydroxide from cement paste.M20 concrete experienced severe deterioration because of its higher permeability and porous structure. M40 concrete showed moderate resistance, while M60 concrete maintained comparatively better performance because of its highly dense microstructure and low permeability.

C. Concrete exposed to leachate dry wet cycle

The partially exposed concrete specimens showed moderate deterioration in strength and durability properties. The reduction in compressive strength occurred due to penetration of aggressive chemicals present in landfill leachate. Chemical constituents such as sulphates, chlorides, ammonia compounds, and organic acids reacted with cement hydration products, causing gradual weakening of the concrete matrix.

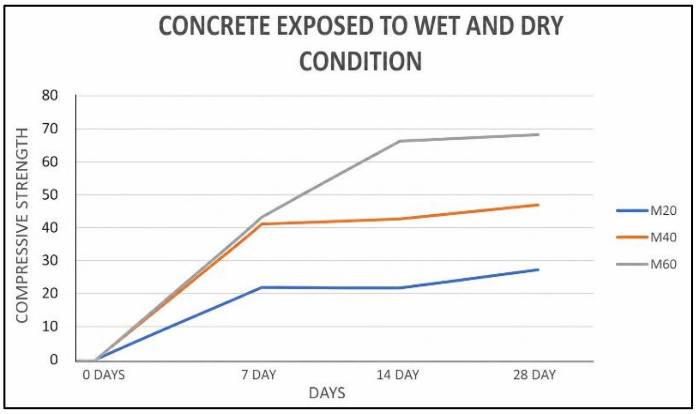

Figure 7: Concrete under exposed to leachate in dry-wet cycle

The increase in water absorption indicated development of microcracks and additional pore spaces. However, the deterioration was limited because exposure duration and contact area with leachate were comparatively lower. Among all grades, M60 concrete demonstrated superior resistance against chemical attack due to its dense and compact structure.

5. CONCLUSION

The present study investigated the effect of artificial landfill leachate on the strength and durability characteristics of conventional concrete under different exposure conditions. Concrete specimens of grades M20, M40, and M60 were exposed to normal water curing, direct leachate exposure, and leachate dry–wet cycle conditions to evaluate their behavior under aggressive environmental conditions. The experimental investigation demonstrated that landfill leachate has a considerable adverse influence on both the mechanical and durability properties of concrete.

The results indicated that continuous exposure to landfill leachate caused gradual deterioration of the concrete matrix due to the presence of harmful chemical constituents such as sulphates, chlorides, ammonia compounds, dissolved salts, and organic matter. These chemicals penetrated into the pore structure of concrete and reacted with cement hydration products, resulting in reduction of compressive strength, increase in permeability, and development of microstructural damage. The deterioration became more severe with increase in exposure duration, confirming that long-term contact with leachate significantly weakens the internal structure of concrete.

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Among all exposure conditions, concrete specimens continuously immersed in landfill leachate exhibited maximum deterioration. Visible signs such as discoloration, surface roughness, minor cracking, and scaling were observed on the exposed surfaces. The aggressive chemical action promoted leaching of calcium hydroxide and decomposition of cementitious compounds, which reduced the bonding within the concrete matrix. In addition, sulphate attack led to the formation of expansive products such as ettringite and gypsum, generating internal stresses that further accelerated cracking and deterioration. The dry–wet cycle exposure condition also affected the durability properties of concrete due to repeated ingress and evaporation of leachate solution, although the deterioration was comparatively lower than that observed under continuous immersion.

The study also revealed that the resistance of concrete against landfill leachate largely depends upon the grade and quality of concrete. Higher-grade concrete demonstrated better durability performance because of its dense microstructure, lower porosity, and reduced permeability. M60 concrete exhibited the highest resistance against chemical attack and showed minimum reduction in compressive strength under all exposure conditions. On the other hand, M20 concrete was found to be more vulnerable to deterioration due to its comparatively porous structure, which allowed easier penetration of aggressive ions into the concrete mass. M40 concrete showed intermediate performance between the two grades.

Water absorption and permeability characteristics were also significantly influenced by leachate exposure. Increased water absorption values indicated the formation of additional pore spaces and microcracks within the concrete structure. This increased permeability facilitated further ingress of harmful chemicals, thereby accelerating the deterioration process. The findings confirmed that dense concrete with lower water-cement ratio provides better resistance against aggressive environmental exposure.

The study highlights the importance of considering durability aspects while designing concrete structures associated with landfill sites, waste retaining structures, underground drainage systems, leachate collection tanks, and treatment facilities. Ordinary conventional concrete without adequate durability considerations may not provide satisfactory long-term performance under aggressive landfill conditions. Therefore, the use of dense and high-strength concrete, proper compaction, adequate curing, low water-cement ratio, and suitable protective measures becomes essential to improve service life and structural performance.

Overall, the investigation concludes that landfill leachate significantly affects the strength and durability of concrete and may lead to progressive deterioration if proper preventive measures are not adopted. However, the extent of damage can be minimized by using durable concrete mixes with improved impermeability and resistance to chemical attack. The findings of this research contribute to the development of sustainable and durable concrete infrastructure for waste management and landfill-related applications.

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