
EFFECTS OF HYDROCARBON IMPURITIES ON CONCRETE STRENGTH AND DURABILITY: A COMPREHENSIVE REVIEW

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ABSTRACT

Concrete performance is strongly influenced by the quality of its constituent materials. Hydrocarbon contamination of aggregates, mixing water, or concrete during handling and service can alter workability, cement hydration, strength development, permeability, and durability. This review synthesizes experimental evidence on the effects of crude oil, diesel, gasoline, and used engine oil on fresh and hardened concrete. The review focuses on the mechanisms through which hydrocarbons interact with cement paste and aggregate surfaces, the resulting changes in mechanical and durability properties, and approaches for mitigating the effects of contamination. The reviewed evidence indicates that the magnitude of deterioration depends on hydrocarbon type, contamination level, mode of contamination, water-to-cement ratio, curing regime, and testing age. Low levels of some hydrocarbons may increase slump through a lubrication or plasticizing effect, but this does not necessarily indicate improved structural performance. At moderate and high contamination levels, disruption of hydration and interfacial bonding generally results in reduced strength and, in many studies, increased porosity and permeability. The review also identifies gaps concerning long-term field performance, standardized permissible contamination limits, microstructural characterization, and sustainable remediation. These issues are particularly relevant to sustainable construction and infrastructure development in hydrocarbon-producing and industrial areas.

Keywords: Concrete; hydrocarbon contamination; diesel; crude oil; used engine oil; compressive strength; durability; cement hydration

1.0 INTRODUCTION

Concrete remains one of the most widely used construction materials because of its strength, durability, versatility, and availability (Neville, 2011). Nevertheless, its performance can be compromised by environmental and chemical contaminants, including petroleum hydrocarbons. Hydrocarbon contamination may occur through oil spills, leakage from storage facilities, industrial discharges, transportation, construction-site handling, or the use of contaminated aggregates and water (Ajagbe et al., 2012; Osuji and Nwankwo, 2015).

Hydrocarbons such as crude oil, diesel, gasoline, kerosene, and used engine oil can interact with concrete at different stages of production and service. Their effects depend strongly on the type and concentration of the hydrocarbon and whether it is introduced through aggregates, mixing water, curing water, or external exposure. In contaminated aggregates, hydrocarbon films can alter the aggregate–paste interface and interfere with effective bond formation. During mixing, some petroleum products may also increase fluidity at low dosage because of lubrication or plasticizing effects, while simultaneously interfering with hydration and cohesion (Ajagbe et al., 2012; Elinwa & Mahmoud, 2023; Tetteh et al., 2025).

The consequences of contamination are important for sustainable construction because premature deterioration increases repair, replacement, material consumption, and environmental burdens. In Nigeria, where hydrocarbon production, transportation, storage, and industrial activities are significant, understanding the performance of contaminated concrete is relevant to resilient infrastructure development and sustainable management of polluted construction materials.

This review therefore synthesizes published evidence on hydrocarbon–concrete interactions, with emphasis on cement hydration, fresh properties, mechanical strength, density, durability, microstructural changes, mitigation strategies, and areas requiring further investigation.

1.1 Problem Statement

The use of hydrocarbon-contaminated construction materials can compromise concrete reliability. Experimental studies have reported reductions in compressive and flexural strength as contamination increases, although the magnitude of deterioration varies considerably with hydrocarbon type, contamination route, mix design, and curing conditions (Ajagbe et al., 2012; Ejeh and Uche, 2009; Oyelami et al., 2024). Despite the growing body of research, findings are dispersed across studies using different materials and experimental conditions. A structured synthesis is therefore required to distinguish general trends from condition-specific results and to identify practical mitigation and research needs.

1.2 Aim and Objectives

Aim

To critically review the effects of hydrocarbon impurities on concrete strength and durability.

Objectives

1. To examine the mechanisms through which hydrocarbons influence cement hydration and interfacial bonding.
2. To evaluate their effects on fresh and hardened concrete properties.
3. To compare reported experimental findings while accounting for hydrocarbon type, contamination level, and test conditions.
4. To identify practical mitigation strategies and priority areas for future research.

2.0 REVIEW METHODOLOGY

This paper adopts a structured narrative-review approach. Literature was identified from major scholarly and publisher platforms, including Google Scholar, ScienceDirect, SpringerLink, MDPI, institutional repositories, and journal websites. The principal search terms included combinations of hydrocarbon contamination concrete, crude oil contaminated concrete, diesel contaminated concrete, used engine oil concrete, oil contaminated sand concrete, concrete strength, concrete durability, cement hydration, and hydrocarbon concrete microstructure. The research emphasized literature published from 2009 to 2026, while allowing foundational earlier work where it directly informed the subject.

Studies were considered eligible when they reported experimental or review evidence directly related to petroleum hydrocarbons and concrete, mortar, aggregates, mixing/curing water, or concrete durability. Preference was given to peer-reviewed journal articles and traceable scholarly sources containing sufficient information on contamination type, dosage or exposure condition, and measured concrete properties. Sources were excluded when they did not address concrete or cement-based materials, lacked sufficient bibliographic information for verification, or merely mentioned hydrocarbons without reporting relevant performance evidence.

The selected literature was synthesized thematically under cement hydration, fresh properties, hardened properties, durability, microstructure, experimental evidence, mitigation, and research gaps. Quantitative results were not pooled statistically because the reviewed studies used substantially different hydrocarbon types, contamination routes, mix proportions, specimen sizes, curing regimes, and test ages. Instead, reported values are presented with their study conditions to avoid misleading direct comparisons.

3.0 CONCEPT OF HYDROCARBON CONTAMINATION IN CONCRETE

Hydrocarbon contamination occurs when petroleum-based substances such as crude oil, diesel, gasoline, kerosene, or used engine oil are present in concrete constituents or come into contact with concrete during production or service. Depending on the contamination route, hydrocarbons may coat aggregate surfaces, alter the liquid phase of the mixture, affect cement hydration, or modify pore structure (Ajagbe et al., 2012; Osuji and Nwankwo, 2015).

3.1 Cement Hydration

Cement hydration involves reactions between cement compounds and water that produce hydration products, particularly calcium silicate hydrate (C–S–H), which contributes substantially to

strength development. Hydrocarbons can interfere with this process by coating cement particles or aggregate surfaces and reducing effective contact between cement, water, and aggregate. The extent of interference depends on the hydrocarbon and its concentration. Consequently, contaminated concrete may show slower strength development or lower ultimate strength than uncontaminated concrete (Ajagbe et al., 2012; Osuji and Nwankwo, 2015; Oyelami et al., 2024).

3.2 Effects on Fresh Concrete Properties

Hydrocarbon contamination can change the rheology and stability of fresh concrete. At low dosages, some petroleum products can increase slump because their lubricating or plasticizing action reduces interparticle friction. However, increased slump should not be interpreted as evidence of improved concrete quality. At higher contamination levels, hydrocarbon films may reduce cohesion and promote segregation, while interference with cement–water interaction may delay hydration and setting. Thus, the apparent increase in workability and the delay in hydration are not contradictory: they represent different effects of the same contaminant acting on fresh-mixture rheology and cement chemistry, respectively (Tetteh et al., 2025).

1. Workability (slump): Low levels of some hydrocarbons can increase slump through lubrication or plasticizing action; excessive contamination may reduce cohesion and mix stability.

2. Segregation and bleeding: Disruption of cohesion can increase the tendency for non-uniform distribution of constituents.

3. Setting time: By reducing effective cement–water interaction, hydrocarbons may delay hydration and setting, although the magnitude depends on contaminant type and dosage.

4. Cohesion and stability: Oil films at particle surfaces can weaken interparticle interaction and make compaction and uniform placement more difficult.

5. Mechanism: The combined effects arise from surface coating, hydrophobicity, altered rheology, and interference with hydration.

3.3 Effects on Hardened Concrete Properties

Hydrocarbon contamination generally has a more pronounced effect on hardened concrete when contamination is sufficiently high to disrupt hydration and aggregate–paste bonding. Reported outcomes include reductions in compressive, tensile, and flexural strength, changes in density, and deterioration in selected durability indicators. However, the magnitude and even direction of individual properties can vary at low contamination levels and under different exposure conditions.

3.3.1 Effect on Compressive Strength

Compressive strength is one of the properties most consistently affected by hydrocarbon contamination. Ajagbe et al. (2012) reported an 18–90% strength loss for concrete made with sand contaminated with 2.5–25% crude oil, with the larger losses occurring at the higher contamination levels. The study also found that contamination above 5% caused more than 50% strength reduction. These values should not be interpreted as a universal range for all hydrocarbons; they describe a specific crude-oil-contaminated-sand system and its test conditions. Other studies have reported smaller or different losses because they used different hydrocarbons, contamination routes, dosages, water-to-cement ratios, and curing conditions (Oyelami et al., 2024; Mmonwuba et al., 2025; Abbas, 2026).

3.3.2 Strength Development

Hydrocarbon-contaminated concrete may develop strength more slowly than control concrete because early hydration and interfacial bond formation are disturbed. The literature indicates that early-age strength can be particularly sensitive to contamination. Nevertheless, strength development is not governed by contamination alone; curing duration, mix proportions, hydrocarbon type, and contamination route also influence the observed rate of strength gain (Ajagbe et al., 2012; Oyelami et al., 2024).

3.3.3 Effect on Durability

Durability describes the ability of concrete to maintain acceptable performance under anticipated environmental exposure. Hydrocarbon contamination can modify porosity, permeability, water absorption, and resistance to aggressive exposure. Ajagbe et al. (2018), found that crude-oil-impacted-sand concrete showed changes in electrical resistivity and water absorption with contamination level, while fire exposure caused additional strength deterioration. These findings demonstrate that durability responses are not always uniformly negative across every indicator and should be interpreted in relation to the particular contaminant and test method (Adesina et al., 2021; Elinwa & Mahmoud, 2023).

3.3.4 Long-Term Strength and Integrity

Long-term performance remains less consistently documented than early-age strength. Available studies suggest that contamination can continue to influence strength development and durability, but reported magnitudes vary. Therefore, a single percentage reduction should not be presented as a universal long-term loss. Long-term behavior should instead be reported with the contamination type, exposure condition, curing age, and test method explicitly stated.

3.4 Tensile and Flexural Strength

Hydrocarbon contamination can reduce tensile and flexural performance by weakening the cement paste–aggregate interface and increasing internal discontinuities. Ajagbe et al. (2012) reported reductions in flexural strength as crude-oil contamination increased. Similar mechanisms have been associated with reductions in splitting tensile strength, including weaker interfacial transition zones, reduced cohesion, and increased susceptibility to crack initiation.

1. Reduced splitting tensile strength.
2. Increased susceptibility to crack initiation and propagation.
3. Weakening of the interfacial transition zone (ITZ).
4. Reduced flexural capacity where contamination significantly affects internal bonding.

3.5 Density

Density is influenced by particle packing, compaction, entrapped air, and the composition of the concrete matrix. Hydrocarbon contamination can alter these factors by affecting cohesion, compaction, and pore structure. However, changes in density are not necessarily identical across all hydrocarbon types and dosages; therefore, density trends should be interpreted alongside air content, porosity, and the contamination route rather than treated as a direct measure of strength (Abbas, 2026).

3.6 Effect on Concrete Durability

Hydrocarbon contamination may influence durability through changes in hydration, pore connectivity, interfacial bonding, and permeability. Where contamination produces a weaker and more connected pore structure, the ingress of water and aggressive agents may increase. However, some low-level hydrocarbon exposures have produced mixed results for individual durability indicators. Ajagbe et al. (2018) reported improved electrical-resistivity-related durability indicators with increasing crude-oil contamination in their particular test system, while also observing reduced strength after fire exposure. This illustrates why durability conclusions must be tied to the specific indicator and exposure condition rather than generalized across all hydrocarbons.

3.7 Microstructural Effects of Hydrocarbon Impurities

At the microstructural level, hydrocarbon contamination can modify cement hydration and the aggregate–paste interface. Reported mechanisms include incomplete development of hydration products, weak ITZs, altered pore structure, and microcracking. These changes provide a mechanistic explanation for many observed reductions in strength and durability, although microstructural evidence remains less extensive than conventional strength testing in the literature.

1. Reduced or altered development of C–S–H and other hydration products.
2. Weakening of the aggregate–paste interfacial transition zone.

3. Changes in porosity and pore connectivity.
4. Formation or propagation of microcracks and discontinuities.

3.8 Experimental Studies on Hydrocarbon-Contaminated Concrete

Experimental studies differ substantially in hydrocarbon type, contamination route, dosage, concrete composition, and curing regime. Accordingly, direct numerical comparison must be made cautiously.

Table 3.0: Experimental Studies on Hydrocarbon-Contaminated Concrete

Study	Hydrocarbon	Key condition	Main finding	Interpretation
Ejeh & Uche (2009)	Crude oil contamination	Concrete materials	Compressive strength decreased with contamination.	Supports the adverse effect of crude oil on strength.
Ajagbe et al. (2012)	Crude-oil-contaminated sand	2.5–25% oil; 3–168 days	18–90% strength loss; >50% loss above 5% contamination.	Large losses are condition-specific and linked to contaminated sand.
Osuji & Nwankwo (2015)	Crude oil contamination	Concrete constituents	Oil hindered bond formation and affected strength.	Supports hydration/bonding mechanism.
Adesina et al. (2021)	Oil-contaminated concrete	Durability-focused	Reported deterioration in durability-related performance.	Shows that strength and durability should be evaluated together.
Oyelami et al. (2024)	Oil-contaminated sand	Mechanical performance	Strength decreased with increasing contamination; early ages were sensitive.	Confirms concentration- and age-dependent effects.
Ajagbe et al. (2018)	Crude-oil-impacted sand	Durability and fire exposure	Durability indicators changed with contamination; fire exposure caused additional strength loss.	Demonstrates property-specific responses.
Mmonwuba et al. (2025)	Petroleum-contaminated sand	RHA and cassava starch remediation	27.76% strength reduction from contamination; additives improved strength.	Supports sustainable remediation approaches.
Tetteh et al. (2025)	Used engine oil as admixture	0.15–30%; varying water-cement ratio	Low dosages improved workability; higher dosages reduced strength.	Shows that low-dose fluidity effects do not imply improved structural performance.

3.9 Comparative Analysis of Existing Studies

The apparently wide range of reported strength reductions is not necessarily contradictory. The 18–90% range reported by Ajagbe et al. (2012) resulted from 2.5–25% crude-oil contamination of sand and therefore represents a specific experimental system. The more than 50% reduction reported in that study at contamination above 5% is part of the same dataset rather than an independent universal value. By contrast, Mmonwuba et al. (2025) reported a 27.76% reduction for petroleum-contaminated sand under a different experimental design, and Oyelami et al. (2024) reported concentration-dependent strength losses in oil-contaminated sand. These differences arise from hydrocarbon composition, contamination level, whether the aggregate or water was contaminated, water-to-cement ratio, mix proportions, curing age, specimen preparation, and test conditions. The review therefore avoids presenting 18–90%, 25%, 50%, or 27.76% as universal strength-loss values.

Another important distinction concerns low-level hydrocarbon addition as an admixture versus accidental contamination of concrete constituents. Some used-engine-oil studies report increased slump at low dosages, while higher dosages reduce strength. Such findings should not be generalized to contaminated aggregates or uncontrolled field exposure because the mechanisms, dispersion, and dosage basis are different (Tetteh et al., 2025).

4.0 MITIGATION STRATEGIES

Mitigation should prioritize preventing contaminated materials from entering structural concrete. Where contamination is detected, appropriate cleaning or treatment of aggregates should be considered, subject to verification by laboratory testing. Other measures include strict material quality control, protection of aggregates during storage, avoidance of contaminated mixing or curing water, and site monitoring in areas exposed to petroleum products.

Supplementary cementitious materials and other remediation additives may provide additional benefits in selected applications. Mmonwuba et al. (2025), reported improved mechanical performance when rice husk ash and cassava starch were used with petroleum-contaminated sand. However, such approaches should be validated for the specific contamination type and structural application before adoption.

5.0 CONCLUSION

The reviewed literature demonstrates that hydrocarbon contamination can significantly alter concrete performance, particularly when contamination is moderate to high or when aggregate surfaces are substantially coated. The dominant mechanisms include disruption of cement hydration, alteration of aggregate–paste bonding, and changes in pore structure. These mechanisms commonly lead to reduced compressive and flexural strength and can impair durability, although individual durability indicators may respond differently depending on the hydrocarbon and exposure condition.

The review also shows that quantitative strength losses reported in the literature cannot be treated as universal constants. Ajagbe et al. (2012) reported a 18–90% range corresponds specifically to 2.5–25% crude-oil contamination of sand, whereas the 27.76% reduction reported by Mmonwuba et al. (2025) arose from a different petroleum-contaminated-sand system. Consequently, future studies should report contamination route, dosage basis, hydrocarbon composition, mix design, curing conditions, and testing age in sufficient detail to permit meaningful comparison.

5.1 Recommendations

1. Avoid using visibly or demonstrably hydrocarbon-contaminated aggregates and water in structural concrete unless an appropriate treatment and laboratory verification demonstrate suitability.
2. Introduce routine quality-control testing of aggregates and water in areas exposed to petroleum products.
3. Investigate washing, treatment, or other remediation methods before considering contaminated aggregates for reuse.
4. Evaluate supplementary cementitious materials and sustainable additives as potential remediation strategies, with structural performance verified experimentally.

5. Develop evidence-based guidance on permissible contamination levels for different hydrocarbon types and concrete applications.

5.2 Further Research Focus

1. Long-term durability and field exposure: Most available studies are laboratory-based and use limited curing or exposure periods. Long-term field studies are needed to establish how contaminated concrete performs under realistic wetting, drying, chemical, thermal, and loading cycles.

2. Standardized contamination limits: Reported strength losses vary widely because studies use different contamination bases and hydrocarbon types. Standardized procedures for defining contamination level and reporting dosage are needed before regulatory limits can be developed.

3. Advanced microstructural characterization: More coordinated SEM, XRD, porosity, permeability, and chemical analyses are needed to link observed strength loss directly to hydration products, ITZ changes, and pore connectivity.

4. Sustainable remediation: The promising results obtained with agricultural and supplementary materials warrant further work on low-cost, environmentally responsible methods for recovering contaminated aggregates without compromising structural safety.

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