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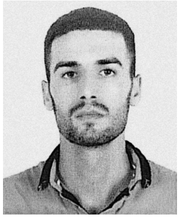
Impact of used engine oil on the water absorption of concrete



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High water absorption in concrete significantly impacts its structural integrity. This article investigated the impact of used engine oil on concrete to assess water absorption, which enhances its durability while also serving as a method for disposing of waste oils, thus reducing environmental risks. Used engine oil was added to the concrete mix at 0.1% to 1.6% by weight of cement. The results showed that used engine oil enhanced concrete properties and reduced water absorption by 51% while maintaining strength without any significant negative effects, also addressed waste management issues in line with environmental sustainability goals.

Keywords: water absorption, concrete, used engine oil, ASTM C1585, durability.

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Влияние отработанного моторного масла на водопоглощение бетона

Высокое водопоглощение бетона существенно влияет на целостность конструкции. В данной статье исследовалось влияние отработанного моторного масла на бетон для оценки водопоглощения, которое повышает его долговечность, а также служит способом утилизации отработанных масел, снижая тем самым экологические риски. Отработанное моторное масло добавлялось в бетонную смесь в количестве 0,1–1,6% от массы цемента. Результаты показали, что использование моторного масла улучшило свойства бетона и снизило водопоглощение на 51%, сохранив при этом прочность без существенных негативных последствий, а также позволило решить проблемы управления отходами в соответствии с целями экологической устойчивости.

Ключевые слова: водопоглощение, бетон, отработанное моторное масло, ASTM C1585, долговечность.

Introduction

Hydraulic structures, such as dams, locks, spillways and canals are crucial for water resource management. They must withstand significant hydrodynamic forces and environmental challenges, where the concrete is in direct contact with water. Key design criteria include structural stability, water tightness, resistance to degradation and durability [30]. Durability against environmental factors is critical, as hydraulic structures face deterioration from freeze-thaw cycles and leaching due to infiltrating water. These factors can cause surface damage and internal decay, especially at the waterline [3; 21]. Water absorption in concrete refers to the amount of water that concrete or aggregates can absorb, influencing physical and mechanical properties critical for structural soundness. Variations in moisture content due to environmental factors can alter structural behavior. Increased water absorption may lead to internal damage from freeze-thaw cycles, worsening deterioration when absorbed moisture freezes within the pore matrix [21; 29]. Understanding how different mixtures interact with moisture is vital for maximizing durability. Additives or adjustments to conventional mixtures can significantly alter water absorption characteristics [19]. Construction practices, including mixing and consolidation, impact the pore structure; improper techniques can increase porosity or hinder hydration, undermining long-term durability [15]. In hydraulic engineering, maintaining optimal moisture levels is crucial for structural integrity.

Research shows that excessive water absorption can cause spalling and cracking in freezing conditions [30]. Therefore, careful consideration of material selection and construction methods is essential to mitigate moisture-related risks. Water absorption of concrete is the ability of concrete to absorb water into pores and capillaries when immersed in water. Water absorption occurs when water initially contacts the unsaturated concrete surface pores and then moves inward due to the liquid‘s surface tension. For improving concrete durability and prolonging the service life of concrete structures, a complete grasp of capillary water absorption is essential. The presence and movement of water are key factors contributing to the degradation of concrete durability [25; 29].

Researchers have focused on incorporating additives in concrete to enhance its characteristics and reduce water absorption. In the study

[1], the addition of graphene oxide to the concrete led to reduced water absorption. Volumetric hydrophobization of gypsum cement-pozzolan concrete made it possible to reduce water absorption to 79% [5]. The results in the research [8] showed that the addition of 10% acrylic latex reduces water absorption by 20–25% compared to the control specimens. In the research [10], the effect of modification on the properties of hydraulic concrete was established by reducing the content of Portland cement and replacing it with finely dispersed glassy perlite, which make it possible to improve the water absorption of concrete. Change in W/C ratio revealed a substantial effect on the rate of water absorption with higher W/C ratio mixtures exhibiting significant increase in sorptivity index [14; 31]. Increased curing of concrete specimens led to decrease in sorptivity index, mineral admixtures such as fly ash, metakaolin and silica fume proved to be substantially effective in mitigating water admittance and reducing sorption rate vastly higher [4; 22; 31]. Concrete water absorption decreases with the addition of steel fibers or rubber fibers from waste tire, as it affects the water transport through the interfacial interactions between the fibers and the matrix and a physical blocking effect that impedes water movement [25; 27]. In the research [2] good results were obtained for compressive strength and water absorption using a complex mineral additive, which includes waste from the tailings of the mining and Processing plant and silica (oxides of silicon, aluminum and others). The study [9] proposed modification concrete with a complex additive together with wollastonite (superplasticizer + polymer + metakaolin) for tunnel structures, it allows to obtain high-quality heavy concrete with decreased water absorption by 60.9%; the water resistance grade increased by 4 loading stages compared to the control composition.

There has been considerable interest in leveraging industrial by-products, such as used engine oil UEO, as potential additives or admixtures in concrete manufacturing. This approach is rooted in the dual advantages of reducing waste while simultaneously enhancing certain properties of concrete [24; 26]. Right now, the smart and responsible use of petroleum products has taken center stage, waste petroleum oils and used lubricants are burned, polluting the environment with uncontrolled emissions of hazardous combustion products [6]. There is a negative impact on the environmental and economic side of the problem of disposal of waste from the operation of motor transport such as used engine oil UEO [7; 12]. The investigation into incorporating UEO as a component in concrete aligns with a wider movement towards sustainable construction practices, where discarded materials are transformed into valuable resources rather than being wasted. Researches [11; 20; 23; 24] and also [26; 28; 32] shows that we can add used engine oil UEO to improve workability in fresh concrete blends, increasing slump, air content and better freeze-thaw resistance without negatively affecting compressive strength. The UEO in concrete exhibited a progressive increase in compressive strength over time and demonstrated a decreased susceptibility to chloride penetration and enhanced fire performance [16–18; 26].

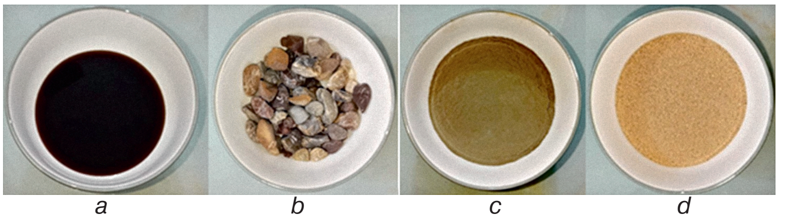

Illustration 1. Materials used in the concrete mix (*a*) used engine oil UEO, (*b*) gravel, (*c*) cement and (*d*) sand. Author A. W. R. Razzaq

Despite preliminary studies indicate promising outcomes regarding improvements in workability and durability when adding used engine oil UEO to concrete, further investigation is essential to gain a comprehensive understanding of the long-term implications on structural integrity and overall performance when using various dosages of UEO. There is still a lack of studies on effect of adding used engine oil UEO on the water absorption of concrete. This parameter is extremely important especially for concrete exposed to water such as hydraulic structures and building foundations. Thus, the main objective of this research is to investigate the water absorption behavior of concrete with adding used engine oil UEO. The findings aim to provide both theoretical insights and practical guidance for reducing the water absorption behavior and enhancing the durability of reinforced concrete and reduce the environmental damage caused by used engine oil.

Research methodology

The one-dimensional flow under capillary action method (ASTM C1585) is typically used to measure the flow of water within concrete [13]. This technique is straightforward and efficient for assessing the near-surface transport characteristics of concrete. In absorption testing, however, the rate of water penetration into concrete is analyzed and represented as an absorption coefficient, which provides a clear indication of the microstructure near the surface of the concrete. It is a commonly used approach to assess concrete durability because it is closely linked to the concrete's pore structure. When one face of a concrete specimen is exposed to water, the water percolates through the interconnected micro-pores within the concrete. When introducing additives such as used engine oil to concrete, we can use ASTM C1585 to outline the procedure for measuring the rate of water absorption in hydraulic-cement concrete [13]. This method is crucial for understanding how changes in concrete mixtures can affect their permeability and overall performance under different environmental conditions.

Materials

The materials used for this research work are locally available materials (sand, gravel, cement and water and used engine oil UEO), Portland cement type 42.5sr was used in the preparation of concrete mixtures (Illustration 1). Aggregates were well graded sand and crushed gravel with a maximum size of 14 mm. Ordinary water was used in the preparation of mixtures in this research, as well as it was used in the curing of concrete specimens. The used engine oil UEO was used as an additive to the concrete mix, where it was collected from local mechanical car service station.

Mix Proportions

The concrete mix was designed to achieve of the compressive strength of 35 MPa (at 28 days), the weights of concrete mix materials were calculated according to the method of the American Concrete Institute (ACI 211.1–91). Various percentages of UEO were added to the mix 0, 0.1, 0.3, 0.6, 1.0, 1.3 and 1.6% by weight of cement. Table 1 shows details of the concrete mixtures.

Absorption test

Mixing was carried out at a room temperature of 27 °C and at 70% relative humidity. To obtain a homogeneous mix, the aggregates were poured in the mixer with half of the mixing water, and mixed for one minute, after which cement was added gradually and mixed for another minute. The UEO was mixed with the remaining half of the water and then added to the mix and mixed for 3 minutes.

The fresh mix was casted in moulds having diameter 100 mm and height 200 mm. After 24 hours the molds were removed and the cylindrical discs of diameter 100 mm and height 50 mm were cut out of the cylindrical specimens. These specimens were then cured in water for 28 days. At the end of curing period, the specimens were conditioned using guidelines of ASTM C1585 [13]; wherein specimens were kept in environmental chamber at 50 °C for 3 days, which was followed by their storing inside sealable containers for a period of 15 days. After removing the specimens from sealable containers, a surface for the absorbent was selected, the opposite side of the absorbing surface was sealed with plastic film, while the remaining sides were sealed with epoxy resin, evenly coated to ensure that the specimen absorbed water in one dimension during the experiment. Absorption test was carried out as per arrangement (Illustration 2).

The first mass of each specimen (m_0) was recorded after the epoxy resin had completely cured. The specimens were subsequently positioned on a stainless steel mesh rack in a water tank, with tap water kept 2 ± 1 mm above the bottom of the specimens as shown in llustration 3. The controlled conditions consist of a relative humidity of 65 ± 5% and a temperature of 20 ± 1 °C.

The specimens were weighed at 1, 5, 10, 20, 30, 60, 120, 180, 240, 300 and 360 min from the time of first contact with water, the mass was recorded once a day during 2d to 8d. The absorption was calculated as described in Eq. (1). For each group, at least two disc specimens were tested, and the average was adopted [13].

$$I = \frac{m_t}{a \times d}, \quad (1)$$

where: I = the absorption, m_t = the change in specimen mass in grams, at the time t, a = the exposed area of the specimen, in mm², and d = the density of the water in g/mm³.

Results and discussion

The absorbed volume of water by the specimen is proportional to the square root of time, and thus the results of absorption tests are usually plotted as a function of this variable instead of linear time. Moreover, the absorbed volume of water is usually normalized against the surface area in contact with the water. A concrete surface that comes into contact with an external source of liquid water starts to absorb the water due to capillary suction. Water begins its ascent, climbing the walls of the larger capillary pores. Once these expansive pores hit that of partial saturation, they can no longer hold onto the water. Instead, it is directed to the smaller capillary pores thanks to its greater capillary forces. This subtle shift orchestrates a transfer of water, moving fluidly from the larger to the more confined spaces within the specimen. As this dynamic unfolds, those big pores, once bustling with activity, absorb water at a slowing pace, inching towards a state of dynamic equilibrium. Meanwhile, for the pores that fall below the size of UEO pores, the story takes a different turn: here, water becomes something ethereal, transporting itself in the form of vapor, unable to infiltrate these tiny microstructures as liquid water. It‘s a delicate balance, a breathtaking interplay of forces that captivate the very essence of water movement.

The water absorption process of concrete can be divided into a initial absorption stage (rapid) and a secondary absorption stage (slow). The rapid absorption stage is generally considered to be the capillary absorption process of porous media. Once the concrete contacts with water, the pore walls are infiltrated by water and the meniscuses are formed. The surface tension causes water to rise along the pore walls. When the water-air interface reaches a stable or metastable configuration, water no longer rises, and the capillary absorption process is assumed to be complete. The slow absorption stage occurs after the rapid absorption stage. Due to the absence of capillary potential, the water absorption rate at this stage is significantly reduced. The rapid absorption stage is considered to be within the first 6 hr. as seen in Illustration 4, while the slow absorption stage is from 2 d to later time, and the time between the rapid absorption stage and the slow absorption stage is regarded as the transition period as seen in Illustration 5.

From Illustration 4 and 5, at Initial absorption stage; after 1 minute the absorption I of the mix_1, mix_2 and mix_3 was 0.0741 mm while the absorption I of the mix_4, mix_5, mix_6 and mix_7 were 0.0733, 0.0704, 0.0674 and 0.0659 mm respectively. After 6 hour, the absorption I of the mix 1 increases sharply to 0.1178, while the mix_2, mix_3, mix_4, mix_5, mix_6 and mix_7 increase to 0.1119, 0.1091, 0.1025, 0.0989, 0.0883 and 0.0789 respectively.

Illustration 6 shows how cumulative capillary water absorption in concrete changes over time. The findings

Table 1. Concrete mix proportions. Author A. W. R. Razzaq

label	UEO %	Water (kg/m³)	Cement (kg/m³)	Coarse aggregate (kg/m³)	Fine aggregate (kg/m³)
mix 1	0%	206	451	1014	703
mix 2	0.1%				
mix 3	0.3%				
mix 4	0.6%				
mix 5	1%				
mix 6	1.3%				
mix 7	1.6%				

a *b*

Illustration 2. Concrete disc (diameter 100 mm and height 50 mm) that was cut out from the cylindrical specimens. (*a*) Before coating. (*b*) After sealing the opposite side of the absorbing surface with plastic film and coating the remaining sides with epoxy resin. Author A. W. R. Razzaq

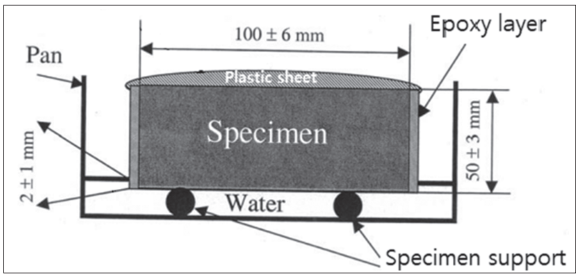

Illustration 3. Illustration of the water absorption test setup. ASTM C1585 [13]

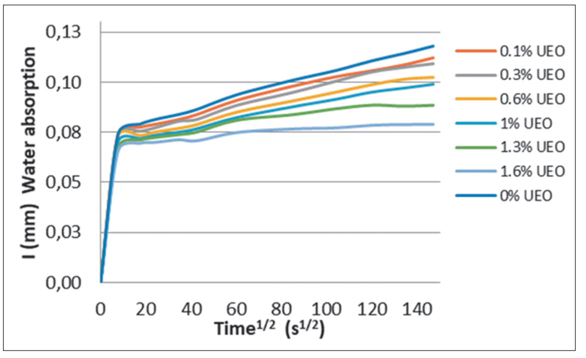

Illustration 4. Time evolution of initial cumulative water absorption (within 6 hr.) of concrete with different proportions of used engine oil UEO. Author A. W. R. Razzaq

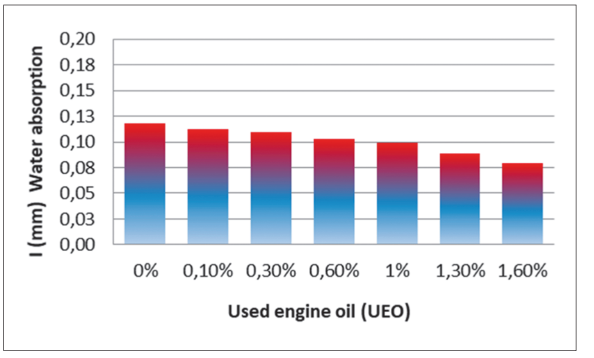

Illustration 5. Initial water absorption (within 6 hr.) of concrete with different proportions of used engine oil UEO.
Author A. W. R. Razzaq

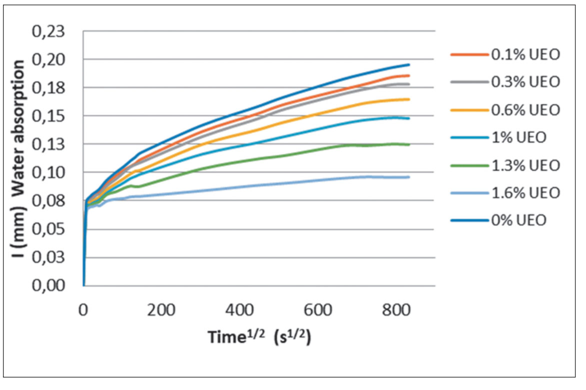

Illustration 6. Time evolution of cumulative water absorption of concrete with different proportions of used engine oil UEO.
Author A. W. R. Razzaq

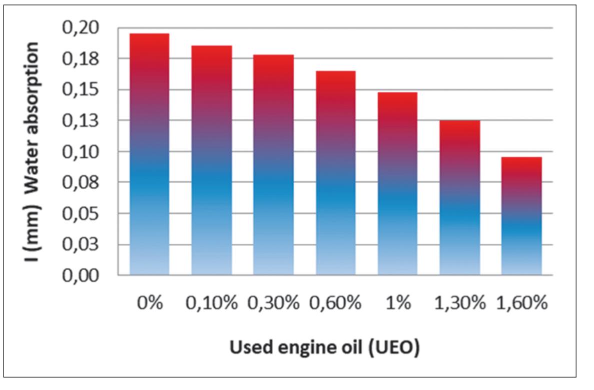

Illustration 7. Water absorption of concrete with different proportions of used engine oil UEO. Author A. W. R. Razzaq

indicate that cumulative capillary water absorption rises over time, with a quick absorption rate in the beginning phases that later slows down gradually. The absorption curves showing that even with more time added, cumulative capillary water absorption does not increase noticeably anymore.

From illustrations 6 and 7, at secondary absorption stage; after 8 days the absorption increases more in all concrete mixtures and here it is noticed that mix_7 has the lowest absorption I 0.0958 mm, while the mix_1, mix_2, mix_3, mix_4, mix_5 and mix_6 was 0.1955, 0.1857, 0.1779, 0.1648, 0.1482 and 0.1251 respectively.

The secondary absorption stage is governed by the moisture redistribution from capillary pores to gel and interlayer pores, as well as the diffusion and dissolution of the trapped air, which are mainly dependent on gel and interlayer pores and trapped air. The UEO admixture affects the viscosity and fluidity of concrete, thereby affecting the trapped air content. It also significantly affects the morphology and structure of $C-S-H$, thus influencing the amount and shape of gel and interlayer pores. For the mix_7, no noticeable change in weight was recorded from the 6 hr. to 8 days which means UEO has a huge effect on such property of concrete which can be used in places where high humidity presents. That's because of the barrier or water repellant effect that UEO creates in the matrix of concrete which closes all capillaries that water might pass through. This means that used engine oil UEO play an important role regarding the water absorption percentage as we saw that in presence of used engine oil UEO in concrete the absorption percentage decreased. Used engine oil UEO can lower the absorption of concrete approximately by half the percent of that without UEO.

Illustration 7 illustrates the water absorption of concrete with varying UEO ratios. Over time, water absorption decreased for UEO concrete, indicating improved durability and reduced porosity with extended curing. These insights are crucial for developing sustainable concrete mixes that incorporate industrial byproducts like UEO while ensuring long-term structural integrity. The UEO fill the spaces between cement grains, reducing the overall porosity of the concrete and making it less permeable to water. This gradual densification of the concrete matrix explains the observed decrease in water absorption with age. The UEO plays a crucial role in enhancing the durability and long-term performance of concrete, effectively mitigating the increase in water absorption.

Conclusion

This research investigated the effect of used engine oil UEO on hydraulic concrete, included the study of the effect of UEO on the water absorption of concrete. The integration of UEO into concrete formulations with proportions (0, 0.1, 0.3, 0.6, 1.0, 1.3 and 1.6% by weight of cement) led to reduce water absorption 51%. Where it was found that there are two stages to the water absorption process of concrete: the quick absorption stage and the slow absorption stage. As the used engine oil UEO proportion rises, the difference in water absorption rate between these two phases of concrete becomes more pronounced and the rate of capillary absorption will decrease. The water absorption in the concrete decreases with the height of the UEO ratio, as the UEO penetrates into the voids, forming an insulating material in the concrete, as it does not evaporate as in water, where it remained inside the concrete, forming an insulating layer that clogs the pores and reduces the water absorption of the concrete which helps mitigate issues related to freeze-thaw cycles and premature cracking, chloride resistance and sulfate attack in hydraulic structures. To achieve optimal results when incorporating UEO into concrete, careful attention to mixing ratios and methods is essential. When used UEO in appropriate amounts can enhance certain properties of concrete like improve workability and reduce water absorption and slightly affect the compression resistance, typically starting at a concentration of 0.1% to 1.6% by weight of cement, the higher concentrations may reduce compressive strength and durability. Mixing procedures should focus on achieving homogeneity to ensure consistent performance. UEO should be added gradually during mixing to prevent clumping. A high-speed mixer may aid in this process, but over-mixing must be avoided to protect material properties. Integrating used engine oil UEO into concrete addresses waste management issues and promotes sustainability in construction, aligning with broader sustainability goals in urban development. The study advises using UEO modified concrete for non-structural uses and urges more investigation into its long term sustainability and ecological effects. The proof indicates that used engine oil is a viable building material for waste management since it offers a practical way to reduce our reliance on artificial admixtures and their production costs.

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