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Effect of Used Engine Oil as a Chemical Admixture on the Properties of Normal and Pozzolanic Concrete

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ABSTRACT

The increasing environmental burden associated with the disposal of used engine oil (UEO) and the carbon emissions from Portland cement production has created a need for sustainable concrete materials and waste-management strategies. This study investigated the effect of UEO as a chemical admixture on the properties of normal and pozzolanic concrete containing rice husk ash (RHA). UEO was incorporated at 0, 0.2, 0.4, 0.6, 0.8, and 1.0% by weight of cement using a 1:2:4 mix ratio and a water-cement ratio of 0.58. The concrete specimens were evaluated for workability, density, water absorption, compressive strength, and splitting tensile strength. The result revealed that, the increasing UEO content improved workability from 39 to 76 mm for normal concrete and from 35 to 68 mm for pozzolanic concrete respectively. Conversely, density decreased from 2681.48 to 2385.19 kg/m³ and from 2533.33 to 2237.04 kg/m³, respectively. At 28 days, compressive strength decreased from 26.88 to 15.57 N/mm² for normal concrete and from 21.55 to 10.85 N/mm² for pozzolanic concrete as UEO increased from 0 to 1.0%, representing reductions of 42.1% and 49.7%, respectively. Splitting tensile strength also decreased with increasing UEO content. At the recommended 0.2% UEO dosage, normal concrete experienced a relatively modest 3.1% reduction in 28-day compressive strength, from 26.88 to 26.05 N/mm². Overall, UEO improved workability but reduced density and mechanical strength at higher dosages. Therefore, 0.2% UEO is recommended as the optimum dosage, although it's relatively high chloride and sulphate contents warrant caution in reinforced concrete applications and further durability investigation.

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INTRODUCTION

Concrete is one of the most widely used construction materials worldwide because of its strength, durability, versatility and availability (Sangoju et al., 2021; Ozmen & Tanrıverdi, 2025). It is generally produced by combining cement, fine aggregate, coarse aggregate, and water, with chemical admixtures incorporated when necessary to modify specific fresh or hardened properties (Barbhuiya et al., 2025). The performance of concrete is influenced by the properties and proportions of its constituent materials, water-cement ratio, curing conditions, and the use of supplementary cementitious materials (Raghav et al., 2021). Consequently, increasing attention has been given to the use of alternative and locally available materials that can reduce the consumption of conventional resources, lower construction costs, and improve the sustainability of concrete production. Chemical admixtures are added to concrete in relatively small quantities to modify properties such as workability, setting time, water demand, strength development, and durability (Faqe et al., 2020). Common commercial admixtures include water reducers, accelerators, retarders, and air-entraining agents (Wang et al., 2024). Although these materials can provide specific performance benefits, their cost and availability may limit their use in some developing regions. This has encouraged research into alternative materials, particularly waste-derived products that can provide useful modifications to concrete properties while contributing to waste management and resource conservation (Choudhary & Wanjari, 2025). Used engine oil (UEO) is a waste material generated from automobiles, generators, industrial machinery, and other mechanical equipment. It contains hydrocarbons, additives, degraded lubricants, and contaminants accumulated during engine operation (Chen et al., 2023; Chen et al., 2025). When improperly disposed of, UEO can contaminate soil and water and consequently pose environmental risks (Armioni et al., 2024; Ossai et al., 2025). Its incorporation into concrete has therefore attracted interest as a potential means of recovering value from a problematic waste material. Previous studies have reported that UEO can modify the fresh and hardened properties of concrete, particularly workability, density, water absorption, compressive strength, and tensile strength (Ali et al., 2020; Shar et al., 2023; Chen et al., 2023; Chen et al., 2025). Chen et al. (2023), for example, reported the potential of recycling UEO in concrete because of its ability to function similarly to certain chemical additives. However, the effects of UEO are dependent on its dosage and the characteristics of the concrete mixture. At relatively low dosages, UEO may improve the flow of the fresh mixture, whereas higher dosages can adversely affect strength development. These variations indicate that UEO dosage is an important factor in determining its suitability as a concrete admixture.

In addition to waste-derived chemical admixtures, supplementary cementitious materials have been investigated as a means of reducing cement consumption and improving the environmental performance of concrete. Rice husk ash (RHA) is an agricultural by-product obtained from the controlled burning of rice husks and is characterized by a high silica content. When adequately processed, RHA can exhibit pozzolanic activity and react with calcium hydroxide released during cement hydration to form additional cementitious products. Other materials, including fly ash and silica fume, have similarly been used as supplementary cementitious or pozzolanic materials (Nadir & Ahmed, 2021; Thomas, 2018; Tulashie et al., 2021). The partial replacement of cement with suitable pozzolanic materials can reduce cement consumption and, consequently, contribute to more sustainable concrete production (Olaiya et al., 2025; Torres-Ortega et al., 2025). However, the incorporation of RHA changes the composition and hydration characteristics of the cementitious system, which may result in concrete behaviour that differs from that of conventional concrete. Despite previous studies on UEO in conventional concrete and RHA as a pozzolanic material, limited research has examined their combined effect on concrete properties. In particular, the influence of UEO dosage on the fresh and hardened properties of RHA-based concrete compared with normal concrete remains insufficiently established. Therefore, this study investigates the effect of used engine oil as a chemical admixture on the properties of normal and pozzolanic concrete.

MATERIALS AND METHODS

Sample Collection and Preparation

Cement

Bua Cement of 43 grade, conforming to NIS 444-1:2018-CEM II/A-L, was used as the primary cementitious material. The cement was obtained from a commercial outlet in Makurdi, Nigeria.

Fine Aggregate

River sand obtained from River Benue, Makurdi, Nigeria, was used as the fine aggregate. The sand was passed through a 4.75 mm sieve to remove pebbles and other oversized particles before use.

Coarse Aggregate

Granite with a maximum nominal size of 20 mm was used as the coarse aggregate. The granite was obtained from Court 5, North Banks, Makurdi, Nigeria. The aggregate was prepared and characterized prior to concrete production.

Water

Potable water obtained from the Civil Engineering Laboratory, Joseph Sarwuan Tarka University, Makurdi, Nigeria, was used for concrete mixing and curing.

Used Engine Oil (UEO)

Used engine oil (UEO) was obtained from the mechanic village at North Bank, Makurdi, Benue State, Nigeria, and was used as a chemical admixture. The UEO was dark brown in colour, with a reported flash point of 238 °C and a viscosity of 132 centistokes (cSt).

Rice Husk Ash (RHA)

Rice husk was locally sourced from a rice processing factory in Wurukum Benue State, and burnt in a furnace at a controlled temperature of 500 °C. The rice husk was left in the furnace for two hours. It was then removed and allowed to cool for 24 h, which was sufficient to turn most of the burnt ash into white ash. The ash collected was then sieved through a standard sieve with a size of 75 µm.

Methods

Concrete mixtures were produced using cement, river sand, granite, RHA, UEO, and potable water. A nominal mix ratio of 1:2:4 and a constant water-cement ratio of 0.58 were adopted based on the specified mix design procedure. Two concrete systems were investigated: normal concrete and pozzolanic concrete. For the pozzolanic concrete, 10% of the cement was replaced by RHA. The 10% RHA replacement level was selected based on previous literature and experimental investigations that reported its suitability for concrete production (Adedeji et al., 2026; Adefisoye et al., 2025; Alhassan et al., 2023; Barua et al., 2018; Li et al., 2022; Patil, 2024). UEO was incorporated into both normal and pozzolanic concrete at 0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% by weight of cement as shown in Table 1. The constituent materials were measured according to the required mix proportions. The cement, RHA where applicable, fine aggregate, and coarse aggregate were first combined and manually mixed using a shovel until a visually uniform dry mixture was obtained. The required quantity of mixing water was then incorporated, followed by the predetermined quantity of UEO. The mixture was manually mixed until the constituents were adequately distributed and a uniform concrete mixture was obtained. The same mixing procedure was maintained for all mixtures to minimize variations arising from the mixing process.

The concrete was placed into 150 mm × 150 mm × 150 mm cube moulds for compressive-strength and 150 mm × 300 mm cylindrical moulds for splitting tensile-strength testing. The fresh concrete was placed in the moulds and compacted adequately to minimize entrapped air and ensure proper consolidation. After casting, the specimens were kept under suitable conditions before demoulding and subsequent curing. For each mix proportion, nine (9) cube specimens were cast and cured for 7, 14, and 28 days. In addition, three cylindrical specimens were prepared for both normal and pozzolanic concrete and cured for 28 days.

Experimental Method

Chemical Composition

The chemical compositions of rice husk ash (RHA) and used engine oil (UEO) were determined using appropriate analytical techniques. The chemical composition of the RHA was determined by X-ray Fluorescence (XRF) spectrometry using a Bruker CTX Portable Benchtop XRF, Models 500 (Ci-U) and 500s/800 (Mg-U). The chemical composition of the UEO was characterized using a combination of Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and Fourier Transform Infrared Spectroscopy (FTIR). The ICP-OES analysis was performed using a PerkinElmer Avio® 3000 ICP-OES, while the FTIR analysis was conducted using a Bruker Vertex 80v (Bench) coupled with a Hyperion 3000 (Microscope). The analyses were carried out in accordance with ASTM D5185 and ASTM E2412 standards, respectively.

Table 1: Mix Proportions for Normal and Pozzolanic Concrete with Different UEO Dosages

Mix ID	UEO (% of cement)	Cement (kg/m³)	RHA (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Water (kg/m³)	UEO (kg/m³)
NC-0.0	0.0	319.40	0.00	638.80	1,277.60	185.25	0.00
NC-0.2	0.2	319.40	0.00	638.80	1,277.60	185.25	0.64
NC-0.4	0.4	319.40	0.00	638.80	1,277.60	185.25	1.28
NC-0.6	0.6	319.40	0.00	638.80	1,277.60	185.25	1.92

Mix ID	UEO (% of cement)	Cement (kg/m³)	RHA (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Water (kg/m³)	UEO (kg/m³)
NC-0.8	0.8	319.40	0.00	638.80	1,277.60	185.25	2.56
NC-1.0	1.0	319.40	0.00	638.80	1,277.60	185.25	3.19
PC-0.0	0.0	287.46	31.94	638.80	1,277.60	185.25	0.00
PC-0.2	0.2	287.46	31.94	638.80	1,277.60	185.25	0.64
PC-0.4	0.4	287.46	31.94	638.80	1,277.60	185.25	1.28
PC-0.6	0.6	287.46	31.94	638.80	1,277.60	185.25	1.92
PC-0.8	0.8	287.46	31.94	638.80	1,277.60	185.25	2.56
PC-1.0	1.0	287.46	31.94	638.80	1,277.60	185.25	3.19

Note: NC = normal concrete; PC = pozzolanic concrete; UEO = used engine oil; RHA = rice husk ash.

Grading of Aggregate

Particle-size distribution analysis was performed on the river sand and granite to determine their grading characteristics. The analysis was conducted in accordance with BS EN 933-1 (1997) and BS 812-103 (1990). Representative samples of the aggregates were dried, weighed, and passed through a series of standard sieves arranged in descending order of aperture size. The mass retained on each sieve was determined and expressed as a percentage of the total sample mass. The resulting data were used to establish the particle-size distribution and grading characteristics of the aggregates.

Water Absorption Test

This test was carried out in accordance with BS EN 1097-6 (2013). The cube samples were oven-dried and their dry masses were recorded. The dry aggregate samples were soaked in water for 24 hours. The samples were then removed from the water and allowed to drain. The excess surface water was blotted using a damp cloth. Water absorption was calculated using Equation (1):

$$W_a = \frac{M_2 - M_1}{M_1} \times 100 \quad (1)$$

Where; W_a = Water absorption (%), M_1 = weight of oven dried cube in kg, M_2 = weight of wet cube in kg

Specific Gravity Test

The specific gravity of the aggregate samples was determined in accordance with BS EN 1097-6 (2013) using the flask method. The specific gravity was calculated from the measured masses using equation (2):

$$Gs = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad (2)$$

Where, Gs = specific gravity, M_1 = weight of empty flask, (g), M_2 = weight of empty flask + weight of the sample, (g), M_3= weight of empty flask + weight of the sample + water, (g), M_4 = weight of empty flask + water, (g)

Workability

The workability of the fresh concrete was evaluated using the slump test in accordance with BS EN 12350-2 (2000a). Fresh concrete was placed into a standard slump cone in successive layers and compacted appropriately. After filling and levelling the cone, it was lifted vertically, allowing the concrete to subside. The difference between the original height of the concrete and its height after subsidence was measured and recorded as the slump in millimetres. The same procedure was used for all concrete mixtures.

Density of Concrete Test

The density of the hardened concrete specimens was determined in accordance with BS 12350: Part 6 (2000b). The mass and volume of each specimen were determined, and density was calculated using equation (3).

$$\rho = \frac{M}{V} \quad (3)$$

Where; ρ is the Density (kg/m³), M is the mass of cube (kg), V is the volume of cube (m³)

Compressive Strength Test

The compressive strength of the concrete was determined in accordance with BS EN 12390-3 (2009). The cured cube specimens were removed from the curing medium, surface-dried, and placed centrally between the platens of the compression-testing machine. Load was applied continuously until failure occurred. The maximum load at failure was recorded and the compressive strength was calculated using equation (4).

$$\sigma = \frac{F}{A} \quad (4)$$

Where; σ is the Compressive Strength (N/mm²), F = crushing load of cube (N), A= Area of cubes (mm²)

Splitting Tensile Strength

The splitting tensile strength of the cylindrical concrete specimens was determined in accordance with BS EN 12390-6 (2009). The cylindrical specimens were removed from curing, surface-dried, and positioned horizontally between the loading platens of the testing machine. Load was applied continuously until the specimen failed along its diametral plane. The maximum applied load was recorded, and the splitting tensile strength was calculated using equation (5).

$$T_s = \frac{2F}{\pi l d} \quad (5)$$

Where: T_s is the splitting tensile strength (N/mm^2), F is the maximum applied load (in Newtons) by the testing machine, l is the length of the specimen (mm), and d is the diameter of the specimen (mm).

RESULTS AND DISCUSSION

Chemical Composition of Rice Husk Ash (RHA)

Table 2 presents the chemical composition of the Rice Husk Ash (RHA) used in the study. The result shows that silica (SiO_2) was the predominant chemical constituent, with a content of 79.57%. The high silica content indicates that the RHA possesses considerable pozzolanic potential, since reactive silica can react with calcium hydroxide released during cement hydration to form additional calcium silicate hydrate (C–S–H) gel. The formation of additional C–S–H can contribute to improved strength and densification of the concrete matrix. The other major oxides identified were ferrous oxide (Fe_2O_3) at 9.78%, calcium oxide (CaO) at 8.87%, and magnesium oxide (MgO) at 5.72%. The presence of CaO is particularly relevant because calcium compounds can contribute to cementitious reactions, while Fe_2O_3 and Al_2O_3 may participate in secondary hydration reactions and influence the overall chemical stability of the binder system. Loss on ignition (LOI) was 4.64%, suggesting a relatively moderate amount of unburnt carbonaceous or volatile materials in the ash. The RHA also contained potassium oxide (K_2O) at 4.03%, aluminium oxide (Al_2O_3) at 3.39%, sodium oxide (Na_2O) at 2.90%, and copper oxide (CuO) at 1.21%. Although these oxides occurred in smaller proportions, they contribute to the overall chemical characteristics of the ash and may influence its behaviour when incorporated into cement-based materials. The relatively high silica content compared with the other oxides confirms that the RHA is predominantly siliceous and can function as a supplementary cementitious material. The result is consistent with the findings reported by Jongpradist et al. (2018) and Shatat (2016), who reported that rice husk ash contains substantial amounts of silica and can contribute to cementitious reactions and improved properties of cement-based materials.

Table 2: Chemical Composition of Rice Husk Ash (RHA)

Parameter	Chemical Formula	Percentage (%)
Silica	SiO_2	79.57
Ferrous oxide	Fe_2O_3	9.78
Calcium oxide	CaO	8.87
Magnesium oxide	MgO	5.72
Loss of Ignition (LOI)	-	4.64
Potassium oxide	K_2O	4.03
Aluminium oxide	Al_2O_3	3.39
Sodium oxide	Na_2O	2.90
Copper oxide	CuO	1.21

Table 3 presents the chemical composition of the used engine oil employed in the study. The result indicates that SO_3 recorded the highest concentration of 38.20%, followed by ZnO at 17.90%, Cl^- at 15.50%, CaO at 15.20%, P_2O_5 at 9.10%, and Fe_2O_3 at 0.44%. The presence of these chemical constituents reflects the complex composition of used engine oil, which is influenced by the original lubricating oil, engine wear, combustion products, additives, and contaminants accumulated during service. The relatively high SO_3 content of 38.20% indicates a substantial concentration of sulphur-containing constituents in the UEO. This finding is relevant to concrete durability because sulphate ions can react with cement hydration products, particularly aluminate-bearing phases, to form expansive products such as ettringite and gypsum. Zhang et al. (2024) reported that severe sulphate exposure may result in expansion, cracking, spalling, increased permeability and deterioration of concrete mechanical properties. Thus, the high SO_3 content observed in the UEO represents a potential durability concern, although the actual effect would depend on the quantity of UEO incorporated, the availability of sulphate species for reaction, cement composition and exposure conditions. The 15.50% chloride (Cl^-) content is also significant because chlorides can penetrate concrete and disrupt the passive protective film surrounding embedded steel reinforcement, thereby increasing the risk of corrosion when adequate moisture and oxygen are present. Chloride-induced corrosion is widely recognized as a major cause of deterioration in reinforced concrete structures (Tian et al., 2025). Evidence further indicates that combined chloride and sulphate exposure can influence concrete degradation and reinforcement corrosion. Therefore, the measured chloride concentration should be regarded as a potential durability concern, particularly where UEO-treated concrete is intended for reinforced structural applications.

Table 3: Chemical Composition of Used Engine Oil

Parameter	Chemical Formula	Value (%)
Calcium Oxide	CaO	15.20
Ferrous Oxide	Fe_2O_3	0.44
Sulphur Trioxide	SO_3	38.20
Phosphorus Pentoxide	P_2O_5	9.10
Chloride	Cl^-	15.50
Zinc Oxide	ZnO	17.90

The CaO content of 15.20% may be associated with additives and deposits accumulated in the engine during operation, while ZnO at 17.90% is likely related to metallic-based additives commonly associated with lubricating oils and engine wear products. The P_2O_5 content of 9.10% may also originate from oil additives and degradation products. In contrast, Fe_2O_3 recorded only 0.44%, indicating a relatively low concentration of iron-containing compounds in the tested used engine oil. The chemical composition therefore confirms that used engine oil is a chemically complex material and its incorporation into concrete should be carefully controlled. The result is similar with Alsadey (2018), who reported the presence of various chemical constituents in used engine oil and highlighted its potential influence on the properties of concrete.

Sieve Analysis

Figure 1 and 2 shows the grading curve for river sand and granite respectively. The results show that river sand recorded a coefficient of uniformity (Cu) of 3.40 and a coefficient of curvature (Cc) of 1.20, whereas granite had a Cu of 1.64 and Cc of 1.00. The higher Cu value obtained for river sand indicates a wider range of particle sizes and a more varied particle-size distribution compared with granite. The Cc value of 1.20 also suggests that the river sand has a relatively good grading. In contrast, the lower Cu value of 1.64 for granite indicates a more uniform particle-size distribution, while its Cc value of 1.00 indicates satisfactory gradation.

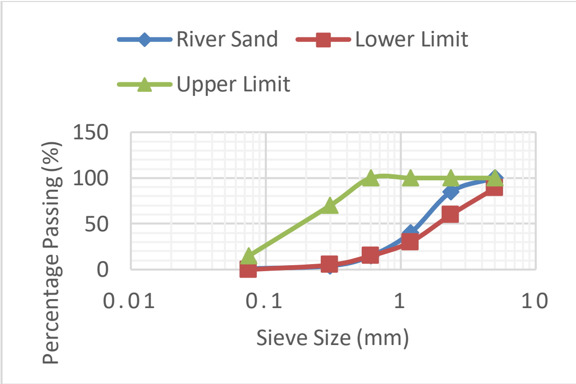

Figure 1: Grading Curve for River Sand

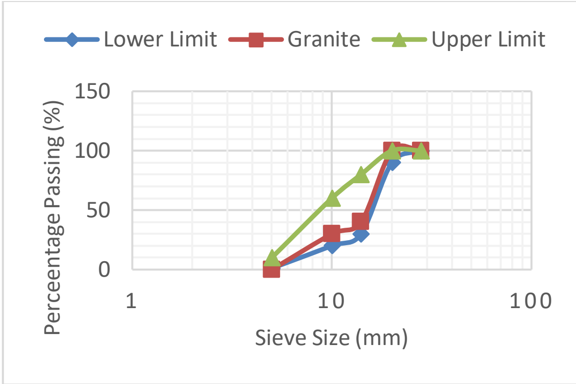

Figure 2: Grading Curve for Granite

The relatively better grading of river sand promotes effective particle packing, reduces void spaces, and can decrease the amount of cement paste required to fill the voids. This may enhance concrete workability and contribute to improved strength. The more uniform nature of the granite particles, however, may result in increased void spaces, requiring adequate fine aggregate and cement paste for proper packing and compaction. According to the grading criteria specified in BS 1377-2 (1990), the granite, with a Cu value below 3 and a Cc value between 0.5 and 2.0, can be considered uniformly graded with satisfactory curvature characteristics.

Specific Gravity

Table 4 presents the specific gravity values obtained for river sand, Rice Husk Ash (RHA), and granite, which were 2.50, 1.23, and 2.62, respectively. The RHA recorded the lowest specific gravity of 1.23, showing its relatively lightweight and porous nature compared with the conventional aggregate materials. This characteristic is consistent with the nature of RHA and may contribute to a reduction in the density of concrete when used as a partial cement replacement.

Table 4: Results of Specific Gravity Tests of the River Sand, Rice Husk Ash and Granite

Description	River Sand			Rice Husk Ash			Granite		
Soil specimen	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Mass of flask + sample + water (M_3) g	127.5	129.5	127.9	113.6	114.4	114.0	779.6	771.4	782.1
Mass of flask + sample (M_2) g	65.20	68.20	65.30	49.30	49.50	50.90	294.0	242.7	252.8
Mass of flask + water (M_4) g	112.0	112.0	112.0	112.0	112.0	112.0	649.0	649.0	649.0
Mass of flask (M_1) g	39.10	39.10	39.10	39.10	39.10	39.10	37.90	37.90	37.90
$(M_2 - M_1)$ g	26.10	29.10	26.20	10.20	10.40	11.80	206.1	204.8	214.9
$(M_4 - M_1)$ g	72.90	72.90	72.90	72.90	72.90	72.90	611.1	611.1	611.1
$(M_3 - M_2)$ g	62.30	61.30	62.60	64.30	64.90	63.10	535.6	528.7	529.3
$[(M_4 - M_1) - (M_3 - M_2)]$ g	10.60	11.60	10.30	8.60	8.00	9.80	75.50	82.40	81.80
$Gs = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$	2.46	2.51	2.54	1.20	1.30	1.20	2.73	2.49	2.63
Average Specific Gravity		2.50			1.23			2.62	

The specific gravity of the river sand was 2.50, while granite recorded 2.62. These values indicate that both materials possess adequate density characteristics for use as fine and coarse aggregates, respectively, in concrete production. However, the value obtained for river sand is lower than the 2.70 reported by Olaleye et al. (2026), while the granite value of 2.62 is slightly lower than their reported 2.65. The differences may be attributed to variations in mineralogical composition, source, particle characteristics, and testing conditions. The specific gravity of granite (2.62) falls within the 2.6–3.0 range reported by Neville (1997) and agrees with the commonly reported range of 2.6–2.7 for granite aggregates. Therefore, the results confirm that the river sand and granite are suitable for use as conventional aggregates, while the relatively low specific gravity of RHA indicates its potential to produce lighter concrete when incorporated as a supplementary cementitious material.

Slump Test

Figure 3 shows the results of the slump test conducted on the concrete mixtures. The slump results show that normal concrete increased from 39 mm to 76 mm and that of pozzolanic concrete increased from 35 mm to 68 mm. The increased in used engine oil content increases the slump of both normal and pozzolanic concrete.

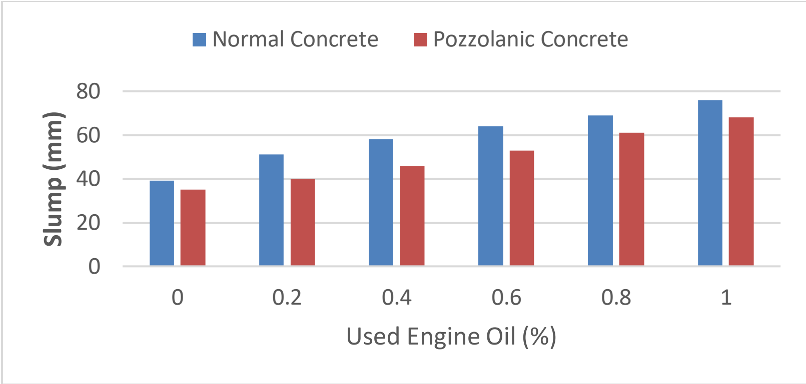

Figure 3: Slump Test Result

The findings is in line with Olaleye et al. (2026), Akinpelu et al. (2019) and Beddu et al. (2016) who reported that the incorporation of used engine oil enhances the workability of high-strength concrete. The higher slump values obtained with increasing UEO content indicate that the used engine oil improved the workability of the concrete mixes. This behaviour may be attributed to the lubricating effect of UEO, which reduces friction between cement, aggregate and other particles, allowing the concrete to flow more easily. The comparatively lower slump values recorded for the pozzolanic concrete may be associated with the presence of Rice Husk Ash (RHA). The RHA contained a high SiO_2 content of 79.57%, indicating its highly siliceous and pozzolanic nature. The fine and porous nature of RHA particles can increase water demand because they tend to absorb or retain part of the mixing water, thereby reducing the free water available for lubrication within the concrete mixture.

Density of Cubes

Density is an important property of concrete because it influences its self-weight, load-carrying capacity, and suitability for various structural applications. As presented in Figure 4, the results indicate a progressive reduction in concrete density with increasing UEO content from 0.0% to 1.0%. For normal concrete, the density decreased from 2681 kg/m³ at 0.0% UEO to 2385 kg/m³ at 1.0% UEO, while the density of pozzolanic concrete decreased from 2533 kg/m³ at 0 % to 2237 kg/m³ at 1.0% UEO. Falade et al. (2011) classified concrete as lightweight, normal-weight, or heavyweight, with density ranges of 300–1,920 kg/m³, 2,240–2,480 kg/m³, and above 2,500 kg/m³, respectively. Based on this classification, the concrete produced in the study falls within the normal- to heavyweight-concrete categories.

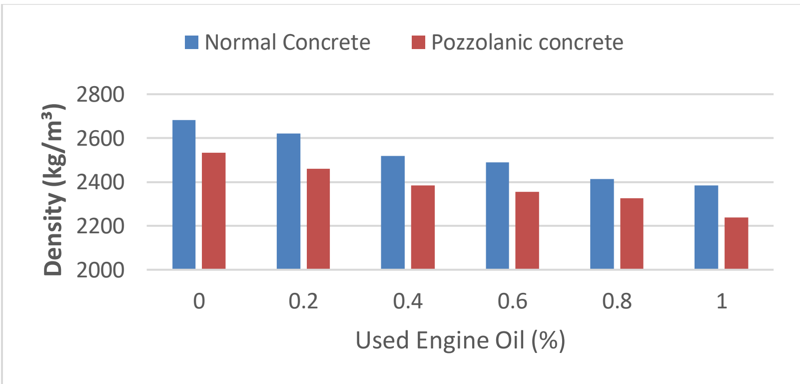

Figure 4: Result for Density Test

The observed reduction in density with increasing UEO content may be attributed primarily to the lower density of UEO compared with the conventional solid constituents of concrete. Its incorporation therefore reduces the overall unit weight of the concrete. In addition, the presence of UEO may create or retain small voids within the concrete matrix, further contributing to the reduction in density. The pozzolanic concrete consistently recorded lower density values than the normal concrete at all levels of UEO replacement. This may be attributed to the incorporation of rice husk ash (RHA), which has a relatively porous and lightweight structure compared with cement and can consequently reduce the overall density of the concrete. The lowest density of 2237 kg/m³ was recorded for pozzolanic concrete at 1.0% UEO, whereas the highest density of 2681 kg/m³ was obtained for normal concrete at 0.0% UEO. Generally, the results demonstrate that increasing UEO content reduces the density of both concrete types, with the effect being more pronounced in the pozzolanic concrete.

Water Absorption Test

Figure 5 presented result for water absorption test. The water absorption ranged from 3.95–4.95% for normal concrete and 4.35–6.15% for pozzolanic concrete. Increasing UEO generally reduced water absorption, with the lowest value of 3.95% at 0.8% UEO in normal concrete and 4.35% at 1.0% UEO in pozzolanic concrete. This result is inline with Razzaq and Alekhin, (2025) who reported that the increase in UEO content reduced the water absorption of concrete. The reduction can be attributed to the hydrophobic nature of UEO, which may block or coat capillary pores and limit water penetration. The high SiO_2 content of RHA (79.57%) also promotes pozzolanic reactions and additional C-S-H formation, which helps refine the pore structure. However, the higher absorption of the pozzolanic concrete at low UEO contents may be due to the porous nature and high-water demand of RHA. Awoyemi et al. (2023) reported that the rate of absorption of water in concrete varies from mix to mix as the volume of voids in concrete varies. According to Neville (2012), concrete with water absorption below 10% can be considered sufficiently durable. Therefore, the findings of this study fall within the range.

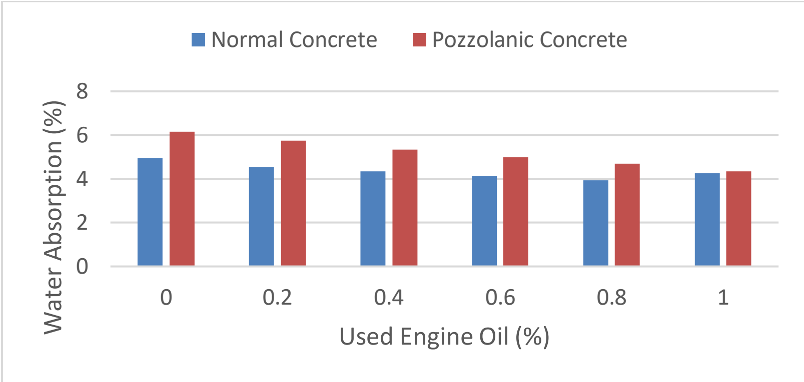

Figure 5: Presented result for water absorption test

Compressive Strength Test

Figure 6–8 presents the compressive strength development of the concrete specimens at 7, 14, and 28 days. The results show that normal concrete recorded compressive strength values ranging from 13.50 to 19.55 N/mm² at 7 days, 14.41 to 21.49 N/mm² at 14 days, and 15.57 to 26.88 N/mm² at 28 days (Figure 6). For the pozzolanic concrete, the corresponding values ranged from 8.10 to 17.98 N/mm², 8.76 to 19.61 N/mm², and 10.85 to 21.55 N/mm², respectively (Figure 7). Therefore, across all curing ages and UEO contents, the compressive strength ranged from 8.10 to 26.88 N/mm².

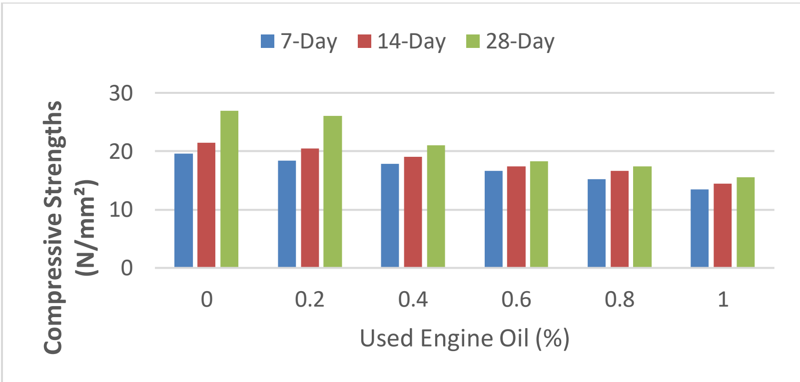

Figure 6: Compressive Strength of Normal Concrete at 7, 14, and 28 days.

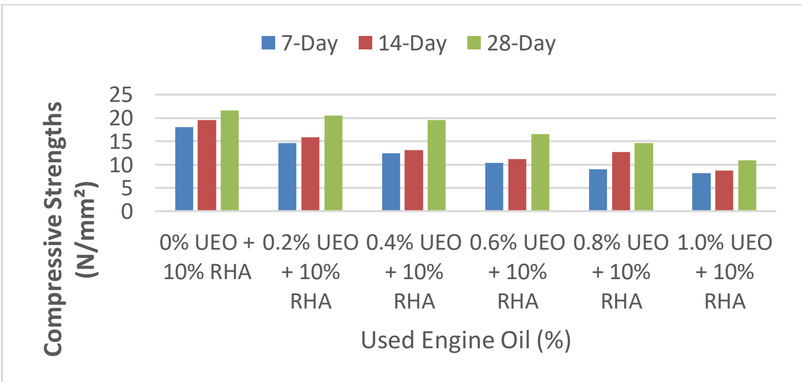

Figure 7: Compressive Strength of Pozzolanic Concrete at 7, 14, and 28 days.

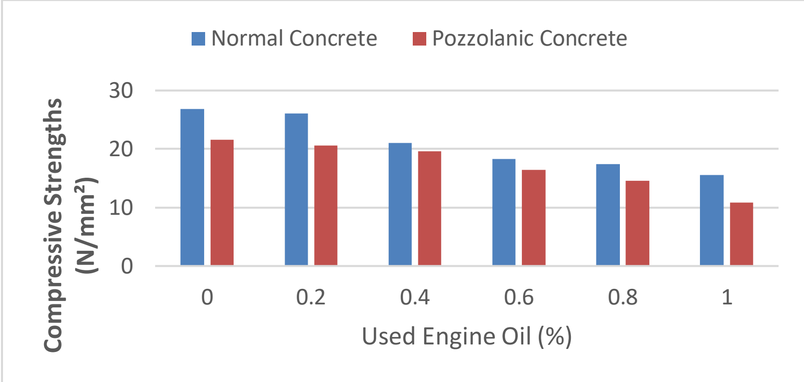

Figure 8: Compressive Strength of Normal and Pozzolanic Concrete at 28 days.

At 28 days (Figure 8), normal concrete generally achieved higher compressive strength than the pozzolanic concrete, with ranges of 15.57–26.88 N/mm² and 10.85–21.55 N/mm², respectively. This difference may be attributed to the incorporation of rice husk ash (RHA) in the pozzolanic concrete. The pozzolanic reaction of RHA develops progressively and may result in slower strength gain at early ages compared with ordinary cement hydration. Consequently, the pozzolanic concrete may require a longer curing period to achieve substantial strength development, which can explain the lower strength values observed, particularly at 28 days. This observation is consistent with Obam et al. (2025), who reported that pozzolanic concrete tends to develop strength more gradually with age compared with conventional concrete. The results further show that increasing UEO content generally caused a reduction in compressive strength at all curing ages. This observation agrees with the findings of Olaleye and Akintunde (2026), who reported that the incorporation of UEO reduced compressive strength even at 7 days, indicating that its adverse effect on cement hydration begins at an early stage. The reduction in strength may be attributed to the formation of an oil film around cement particles, which can restrict contact between cement and water and subsequently hinder hydration and the formation of strength-developing hydration products. Although UEO may enhance the workability of fresh concrete, increased UEO content can negatively influence both early-age and long-term strength development, as reported by Chen et al. (2025), Akinpelu et al. (2019), Ali et al. (2020), Shar et al. (2023), Chen et al. (2023), Alsadey (2018), Beddu et al. (2016), and Abdelaziz (2015). The reduction in compressive strength observed with increasing used engine oil (UEO) content is consistent with previous studies. In the present study, the 28-day compressive strength of normal concrete decreased from 26.88 N/mm² for the control mix to 26.05 N/mm² at 0.2% UEO, representing a modest reduction of 3.1%. Although the reduction at this dosage was relatively small, compressive strength progressively decreased as UEO content increased, indicating a trade-off between improved workability and hardened strength. Similar findings were reported by Shafiq et al. (2018), who observed that UEO improved concrete slump but reduced the compressive strength of ordinary Portland cement concrete by approximately 17%. Hamad et al. also reported that UEO increased concrete fluidity while reducing several hardened properties, including flexural and splitting tensile strengths. Olaleye and Akintunde (2026) found that increasing UEO dosage from 0.15% to 0.30% substantially reduced 56-day compressive strength from 53.8 to 39.2 and 25.7 MPa, respectively, while simultaneously increasing slump. These findings confirm the characteristic trade-off between workability improvement and strength reduction with increasing UEO dosage. The relatively small 3.1% strength reduction at 0.2% UEO may therefore be considered practically acceptable, particularly where improved workability and waste-oil utilization are desired. Yaphary et al. (2020) similarly reported that UEO can improve workability through water-reducing and air-entraining effects, although excessive incorporation may adversely affect mechanical properties.

Split Tensile Strength Test

Figure 9 shows the average split tensile strength of the concrete specimens. The results indicate a progressive reduction in split tensile strength with increasing UEO content for both normal and pozzolanic concrete. For the normal concrete, the split tensile strength decreased from 3.40 N/mm² at 0.0% UEO to 2.07 N/mm² at 1.0% UEO, while the pozzolanic concrete decreased from 2.66 N/mm² at 0.0 % UEO to 1.62 N/mm² at 1.0% UEO. The findings agree with Akinpelu et al. (2019) who reported split tensile strength values ranging from 0.55 to 3.23 N/mm², and Obam et al. (2024) who obtained values between 1.20 and 3.40 N/mm². Similarly, Varghese and Sakaria (2017) reported values ranging from 2.5 to 3.7 N/mm². However, the present findings are contrary to those reported by Hasan and Fattah (2023), who obtained higher split tensile strength values ranging from 4.2 to 5.0 N/mm². The consistent reduction in split tensile strength with increasing UEO content agrees with the findings of Olaleye and Akintunde (2026) and Shar et al. (2023). The decrease may be attributed to the presence of UEO within the concrete matrix, which can interfere with cement hydration and weaken the bond between the cement paste and aggregate particles. UEO may also form a coating around cement particles and aggregate surfaces, thereby reducing effective interfacial bonding and increasing the susceptibility of the concrete to crack initiation and propagation under tensile loading. The normal concrete consistently recorded higher split tensile strength than the pozzolanic concrete at all UEO contents. This difference may be associated with the incorporation of rice husk ash (RHA) in the pozzolanic concrete. The pozzolanic reaction of RHA generally develops more gradually than the hydration of ordinary cement, resulting in slower strength development, particularly at early and intermediate curing ages. The lower tensile strength recorded for the pozzolanic concrete may therefore be related to its slower strength gain, as reported by Obam et al. (2025).

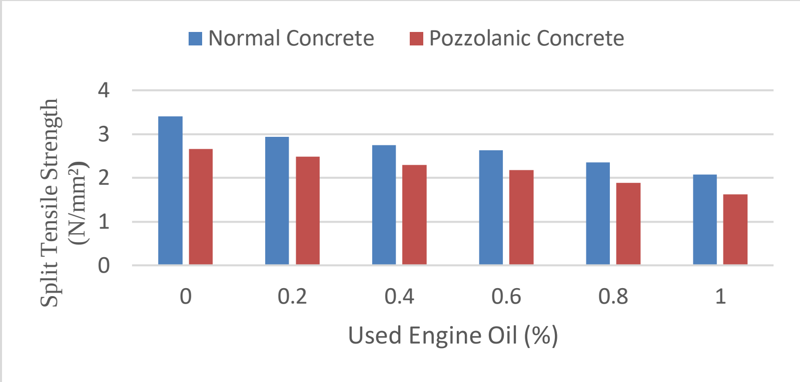

Figure 9: Split Tensile Strength Results

Statistical Treatment Using Two-Way ANOVA

Table's 5-6 shows statistical treatment using Two-Way ANOVA for normal and pozzolanic concrete. The descriptive statistics indicate that both UEO content and concrete type influenced concrete strength. At 0% UEO, normal concrete recorded a mean strength of 24.67 N/mm², compared with 21.00 N/mm² for pozzolanic concrete. At 1.0% UEO, the mean strength decreased to 17.00 N/mm² for normal concrete and 13.83 N/mm² for pozzolanic concrete. Thus, increasing UEO content from 0 to 1.0% resulted in strength reductions of approximately 31.1% for normal concrete and 34.1% for pozzolanic concrete. The overall mean strength also decreased from 22.83 N/mm² at 0% UEO to 15.42 N/mm² at 1.0% UEO, demonstrating a clear negative trend with increasing UEO content.

The two-way ANOVA confirmed that the effect of UEO content on strength was statistically significant, $F(1,20) = 86.663$, $p < 0.001$. This indicates that the reduction in strength associated with increasing UEO content was unlikely to have occurred by chance. The result suggests that although UEO may improve the workability of concrete, increasing its dosage can adversely affect hardened strength. This may be associated with the lubricating and air-entraining effects of UEO, which can interfere with the development of a dense cementitious matrix when present in excessive quantities. Concrete type also had a significant effect on strength, $F(1,20) = 18.392$, $p < 0.001$. Normal concrete had a higher overall mean strength of 20.83 N/mm², compared with 17.42 N/mm² for pozzolanic concrete. The lower strength recorded for pozzolanic concrete may be attributed to the partial replacement of cement with RHA, which can reduce early-age strength because pozzolanic reactions generally develop more gradually than cement hydration. However, the interaction between UEO content and concrete type was not significant, $F(1,20) = 0.098$, $p = 0.757$. This indicates that the effect of UEO on strength was statistically similar for normal and pozzolanic concrete. Therefore, UEO did not produce a significantly different strength response depending on the concrete type. The overall model was significant, $F(3,20) = 35.051$, $p < 0.001$, with $R^2 = 0.840$ and adjusted $R^2 = 0.816$. Hence, UEO content and concrete type jointly explained 84.0% of the variation in concrete strength, indicating a strong model fit.

Table 5: Descriptive Statistics

UEO_Content	Concrete Type	Mean	Std. Deviation	N
0	Normal	24.67	2.875	6
	Pozzolanic	21.00	.894	6
	Total	22.83	2.791	12
1	Normal	17.00	.894	6
	Pozzolanic	13.83	2.317	6
	Total	15.42	2.353	12
Total	Normal	20.83	4.489	12
	Pozzolanic	17.42	4.100	12
	Total	19.13	4.552	24

Table 6: Two-Way ANOVA Result for Normal and Pozzolanic Concrete

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	400.458[a]	3	133.486	35.051	.000
Intercept	8778.375	1	8778.375	2305.044	.000
UEO_Content	330.042	1	330.042	86.663	.000
ConcreteType	70.042	1	70.042	18.392	.000
UEO_Content * ConcreteType	.375	1	.375	.098	.757
Error	76.167	20	3.808		
Total	9255.000	24			
Corrected Total	476.625	23			

a. R Squared = .840 (Adjusted R Squared = .816)

CONCLUSION

Based on the findings, the physical characteristics of the constituent materials influenced the performance of the concrete. The incorporation of UEO improved workability but generally reduced concrete density and mechanical strength as the dosage increased. At the recommended 0.2% UEO dosage, the 28-day compressive strength of normal concrete decreased from 26.88 to 26.05 N/mm², representing a relatively modest strength penalty of 0.83 N/mm² (3.1%) compared with the control. This indicates that 0.2% UEO provides a reasonable balance between improved workability and acceptable strength performance. Therefore, 0.2% UEO is recommended as the optimum dosage for both normal and pozzolanic concrete, while higher dosages should be avoided because of their greater adverse effect on strength. However, the relatively high chloride (15.50%) and sulphate (SO_3) content (38.20%) of the UEO raises durability concerns, particularly for reinforced concrete, where these constituents may contribute to reinforcement corrosion and deterioration. Consequently, the use of UEO in reinforced concrete should be undertaken cautiously, subject to appropriate durability assessment. Further studies are recommended to evaluate the long-term durability, chloride penetration, sulphate resistance, and reinforcement corrosion of UEO-modified concrete under different exposure conditions.

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