# UTILIZATION OF USED-ENGINE OIL IN CONCRETE AS A CHEMICAL ADMIXTURE

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## ABSTRACT

As an attempt for reducing the harmful impacts of throwing the used-engine oil (UEO) in the environment on marine, human and underwater lives and agriculture production, this study have been undertaken, aiming to adopt such waste material in concrete industry as a chemical admixture. Therefore, an experimental program was designated initially to investigate the effectiveness of UEO on the various fresh properties of concrete (consistency, rate of slump loss, setting time and air content). The performance of concrete containing UEO in its hardened state was then thoroughly studied, through assessing the various mechanical and microstructure-related properties, namely, 28 day-compressive strength, surface hardness, homogeneity, sorptivity, porosity and degree of hydration. Ten OPC concrete mixes and another ten OPC paste mixes made with different contents of UEO, water reducing admixture and air-entraining admixture (0, 0.15, 0.30 and 0.60%, by cement mass) were consequently prepared. The results showed that utilizing of UEO in OPC mixes has reasonably altered its fresh parameters, where, an increase in initial slump and air content, and a decrease in rate of slump loss and initial setting time were found. A slight reductions in the 28-day compressive, homogeneity, density and degree of hydration, and an increase in porosity and rate of water inflow into cover zone were noted when UEO was induced into OPC mixes. The results also indicated that the fresh and hardened characteristics of OPC concretes containing either UEO or air entraining admixture are comparable.

***Key words:*** Waste Materials, Used-Engine Oil, Environmental Impacts, Admixtures.

## 1. INTRODUCTION

There is a current trend all over the world to investigate the utilization of processed and unprocessed by-products and domestic wastes as raw materials in concrete, as components of concrete binder, as aggregates, a portion of aggregate, or ingredients in manufactured aggregates. Some wastes can be used as chemical admixtures and additives, which can alter the fresh and hardened properties of concrete [1]. However, successful use of industrial by-products or wastes in concrete depends mainly on the requisite properties of the end product. Several by-products or wastes have been reported in literature to be used in concrete and construction industry; such as recycled concrete aggregate, pozzolans, fly ash, blast furnace slag, silica fume, rice husk ash, waste-derived fuels, organic fiber materials, etc [2].

It is estimated that less than 45% of the used-engine oil is being collected worldwide while the remaining 55% is thrown by the end user in the environment. The discharge of used oil can become a serious problem or a valuable resource depending upon how it is managed. Simply reflect on the fact that one oil change contains four quarts of foils, which when improperly disposed of sufficient to ruin one million gallons of fresh water, which in turn adversely impacting human life, fish and plant life [2,3]. So, in this context, the proper management of used oil is essential to eliminate or minimize potential environmental impacts.

Historically, reference books on concrete technology and cement chemistry indicated that the leakage of oil into the cement in older grinding units has led to a greater resistance to freezing and thawing, which led few researchers in two separate studies to adopt and utilize used-engine oil (UEO) in concrete mixes. They have added UEO to concrete mix ingredients aiming to obtain a similar effect to that reported from using air entraining admixture in concrete mixes [1,4]. Hamad et al [1] have therefore investigated the effects of UEO on the fresh hardened properties concrete. Their preliminary results showed that UEO increased the slump, and % air of fresh concrete, and not adversely affect the compressive strength of hardened concrete. Hamad and Reteil [4] found that UEO did not have significant effect on the structural behavior of reinforced concrete elements, where the ultimate load or load deflection diagrams have not been altered due to adding UEO to concrete mix ingredients.

The efficiencies of used-engine oil and new-engine oil on improvement of properties of fresh concrete and hardened concrete have been recently investigated by Shafiq et al [5]. Their results showed that the used-engine oil increased the slump between 18 to 38% and air content between 26 to 58% with respect to the control mix containing no admixture. Used engine oil reasonably reduced the porosity and did not adversely affect the strength properties of concrete. They also found that the performance of concrete made with either UEO or new-engine oil were more or less similar. This means that UEO behaved as a chemical plasticizer and air entraining admixtures in concrete as the fluidity and air content of concrete have been increased with adding UEO to concrete mix. However, this hypothesis has to be backed with an experimental proof.

## 2. RESEARCH SIGNIFICANCES

It is apparent that not all fresh and hardened properties of concrete incorporating UEO have not been thoroughly investigated and understood yet. Where, there is still a lack of knowledge regarding the impacts of UEO on rate of setting, rate of fluidity loss, homogeneity, and microstructure-related characteristics (degree of hydration, porosity and rate of fluid transport into cover zone). Moreover, there is a need to a comparative study to understand the main differences or coincidence between the various properties of concrete made with UEO and with the corresponding of that made with traditional-chemical admixture (plasticizer and air-entraining). Clarifying such aspects is essential prior to recommending such waste material in concrete industry. Consequently, the main objectives of this study can be summarized as follows:

1- To clarify the impacts of used-engine oil (UEO) on air content, consistency, initial setting time and rate of fluidity loss of concrete.
2- To investigate the compressive strength, surface hardness, homogeneity, and microstructure related properties (hydration, porosity and sorptivity) of OPC concrete made with different contents of UEO.
3- To compare between the behaviors of concretes made with either UEO or traditional-chemical admixtures (namely, water-reducing and air-entraining) during their fresh and hardened state.

## 3. EXPRIMENTAL PROGRAM

Ten OPC concrete mixes and another ten OPC paste mixes were prepared. The variables in these mixes include admixture type and dosage of admixture. Two chemical admixtures were adopted in these mixes, namely, water-reducing admixture (WR) complies with ASTM C 494-81 Type A and BS 5075 Part 1 and air-entraining admixture (AE) complies with ASTM C 260- 81 and BS 5075 Part 2. Used engine oil (UEO) was also utilized in these mixes as an admixture. The used UEO was collected from different vehicles service station in Cairo. The chemical analysis of the used UEO is listed in Table 1. Four dosages for each used admixture were regarded (control, 0.15, 0.30 and 0.60, % by weight of cement). Constant water cement ratio of 0.50 was used for cement paste and concrete mixes.

Table 1 Chemical analysis of UEO.

| Sulfate, mg/g | Lead, mg/kg | pH value |
|---|---|---|
| 4.15 | o.45 | 7.10 |

For concrete mixes, constant weights of washed-natural desert sand of 700 kg/m$^3$ and natural gravel of 1070 kg/m$^3$, complying with ASTM C 33 and ESS 1109/2002 requirements, were used. Constant weight of Local OPC (400 kg/m$^3$), complying with BS 12 (1978), EN 197-1, ESS 5325 (2005) and ASTM C618 (1992), was used. The chemical composition of the used cement (OPC) and physical properties of the used aggregate are represented in Tables 2 and 3, respectively. The initial setting time of OPC mixes made with or without these above-mentioned admixtures were also measured, using Vicate apparatus, and the results will be demonstrated in the next section.

Mixing of concrete ingredients was performed in the laboratory (20 ± 2$^o$C and 65% RH), using a 100 liter capacity concrete mixer. Dry ingredients of concrete mix were initially mixed for one minute prior to adding the mixing water. Admixtures such as UEO, WR and AE were diluted in water before it was added to the dry ingredients in the mixer. Water was then added to dry mixture of cement and aggregate and mixed for another two minutes, which were enough periods for producing homogenous concrete.

Table 2 Chemical composition of OPC.

| $SiO_2$ | $AL_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ | LOI | Insoluble residue |
|---|---|---|---|---|---|---|---|---|---|
| 20.1 | 4.3 | 3.8 | 61.1 | 1.7 | 0.4 | 0.19 | 3.6 | 3.8 | 0.90 |

Table 3 Physical properties of gravel and sand.

| | Maximum aggregate size, mm | 24-hour water absorption, % | Specific gravity | Fineness modulus | Unit weight, kg/m$^3$ |
|---|---|---|---|---|---|
| Gravel | 20 | 0.50 | 2.50 | - | 1570 |
| Sand | - | 0.66 | 2.66 | 2.59 | 1590 |

Immediately after mixing, the initial slump values were measured for all concrete mixes in accordance with BS 1881: Part 102 (1983) and air content was quantified in accordance with the method B described in BS 1881: part 106: 1983 and ASTM- C 173. The values of instant slump at different elapsed times from the end of mixing process, 30, 60, 120 and 240 minutes, were also recorded, to assess the rate of slump loss of concrete (fluidity loss). Meanwhile, ten cube specimens (150 mm) were taken from each concrete mix, demolded, cured in water for 27 days. Five specimens were allocated for measuring the surface hardness, homogeneity, density and compressive strength of concrete, while, the other five specimens were designated for sorptivity test.

The surface hardness and homogeneity of specimens were then examined at age of 28 days, using Schmidt hammer of type N and ultra-sonic pulse velocity according to BS 1881 Part 201 and ASTM C 805, respectively. This was followed by determining the compressive strength, according to BS 1881: Part 116: 1983 and BS 1881: Part 121: 1883. An average of five measurement values for each tested property was then obtained. Prior to compressive strength test, the cubes were used to test the SSD density following BS 1881: Part 114: 1983.

For determining the sorptivity, the surfaces of designated concrete specimens were exposed capillary absorption test, as described earlier by McCarter et al [6]. The sorptivity of concrete specimens were then calculated using the data recorded from capillary absorption test, using the same test procedures and mathematical expression used by Hall [7] and Claisse et al [8]. Hall [7] has defined the sorptivity (S) as the slope of the cumulative volume of water absorbed per unit area (i) against the square root of time (t), using the following Equation. Each reported test data point is the mean of the results for five specimens.

$$i = a + St^{0.5} \qquad \text{……………(1)}$$

To determine the porosity and degree of hydration of OPC matrices containing the above-mentioned admixtures, % of evaporated water (EW) and % of non-evaporable water (NEW) of hardened OPC paste were assessed, respectively, following the same approach suggested in literature [9,10,11,12] . So, ten OPC paste mixes incorporating different dosages of UEO, WR and AE admixture (0, 0.15, 0.30 and 0.60 %) AE were prepared. Five disc samples of 25 mm thickness and 50 mm height were taken from each cement paste mix, and then cured in water till the age of testing (28 days). After curing, the saturated-surface dry weight of each disc specimen was weighted ($W_1$), followed by oven-drying the specimen at 105ºC and 950 ºC. Constant weights of each specimen at 105ºC ($W_2$) and 950 ºC ($W_3$) were recorded. % EW and NEW were then approximately estimated, using the following Equations 2 and 3, respectively. Each reported test data point is the mean of the results for five samples.

$$\%EW = 100\,(W_1-W_2)/W_2 \quad ........(2)$$

$$\%NEW = 100\,(W_2-W_3)/W_2 \quad ........(3)$$

The %EW represents the amount of free water (unbound water) existed in pores of OPC matrix, which in turn it can be considered in this study as an indicative measure for the amount of interconnected pores (porosity) in concrete [10]. While, %NEW was adopted to provide an indicative measure for the amount of bound water in OPC matrix, existed in OPC hydration products, where all hydration products approximately decompose when it is exposed to a high elevated temperature of 950 ºC [12].

## 4. RESULTS AND DISCUSSION

### 4.1. Fresh Properties

Effect of inducing used engine oil (UEO) into OPC mixes, as an admixture, on their initial slump and air content are illustrated in Figs. 1 and 2, respectively. A comparison between the effects of traditional chemical admixtures, namely, water reducer (WR) and air entraining (AE), and UEO on these parameters was also shown. As seen from Fig.1, the initial slump of OPC concrete increases with increasing the dosage of UEO induced in OPC mixes. The amount of increase reaches 25, 75 and 110%, compared to the corresponding of OPC made without admixture (control mix). The effect of UEO on initial slump seems to be nearly close to that obtained when a traditional chemical admixture (water-reducing admixture, WR) was used. Consequently, utilization of UEO has a beneficial role on enhancing the consistency of concrete. This confirms the findings reported earlier by Shafiq et al [5], whom found that the enhancement in slump value with the addition of used-engine oil was in the range of 15 to 54%.

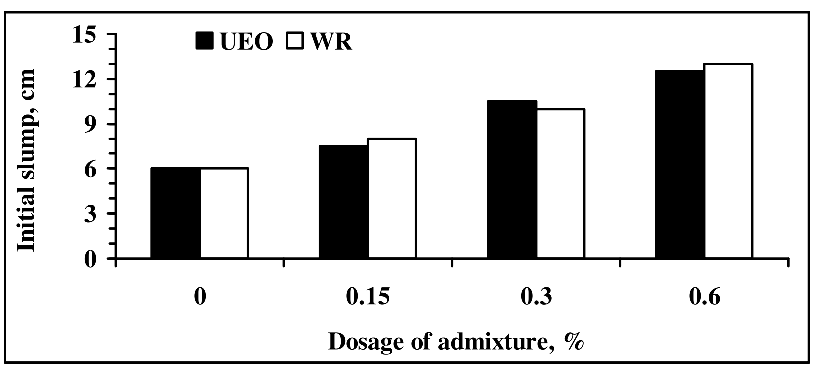


**Fig.1: Initial slump of OPC mixes made with either UEO or WR.**

As noted from the results in Fig. 2, UEO can also alter the air content of fresh concrete, where, the % of air content increased by about 5, 10 and 25% as a result of inclusion 0.15, 0.30 and 0.60% UEO in OPC mix, respectively, compared to that of control mix. However, this effect is not comparable with that noted when OPC mixes were admixed with air-entraining admixture (AE), where, the air content of concrete was significantly increased with adding AE to OPC mix by amounts reach 30, 65 and 80%, as a result of utilizing 0.15, 0.30 and 0.60% AE, respectively.

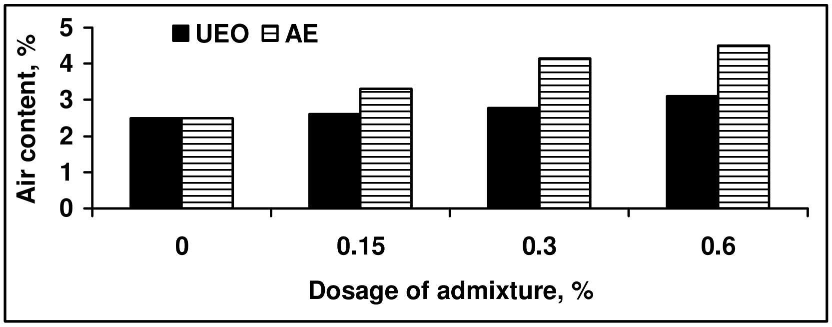


**Fig. 2: Air content of OPC mixes made with either UEO or AE.**

Moreover, the effects of UEO and traditional-chemical admixtures (WR or AE) on the initial setting time of OPC mixes were also investigated, and the results are plotted in Fig. 3. The results affirms that UEO has a significant effect on reducing the value of setting time, where the initial setting time of OPC mixes made with 0.15, 0.30 and 0.60% UEO reach 120, 110 and 90 minutes, respectively, while the corresponding of that mix made without admixture reaches 150 minutes. It also seems from the results plotted in Fig. 3 that the values of initial setting time of OPC mixes made with WR and AE are fairly close to each other, and not comparable with those made with UEO. So, it can be stated that utilizing of UEO in OPC concrete mixes can reasonably alter their consistency, compactability and rate of setting, as verified from the results established in Figs. 1 to 3.

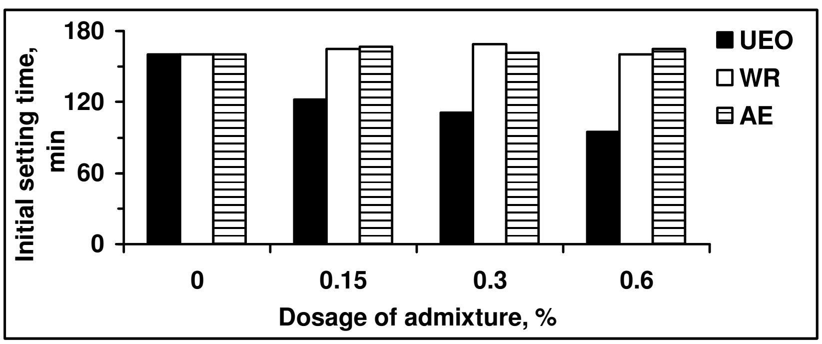


**Fig. 3: Initial setting time of OPC mixes made with various admixtures.**

The question arises from the above discussion is; would such beneficial effect of UEO on the consistency of concrete remain at later elapsed periods? The answer to this arisen question would provide a good understanding to the properties of OPC concrete during its casting and placement state. Determining the rate of loss in fresh properties of concrete is imperative for concrete technologists and engineers on site in order to specify the suitable period between mixing and casting. So, the instant slump of OPC concrete containing different dosages of UEO (0.0, 0.15, 0.30 and 0.6%) were studied at different elapsed periods from mixing (EP), 0, 30, 60, 120 and 240 minutes. The results of this investigation are shown in Fig. 4, where the % values of relative slump (instant slump/initial slump) were plotted against EP. As seen, % of relative slump dramatically decreases with increasing EP for all investigated mixes. Rate of decrease in the % of relative slump increased with increasing the dosage of UEO. In other words, inclusion of UEO into OPC mix can lead to increase its rate of slump loss (fluidity loss). These results agree with those reported in Fig. 3, where the setting time was noted to be decreased with increasing UEO content, thus leading to increase the rate of slump loss (fluidity loss).

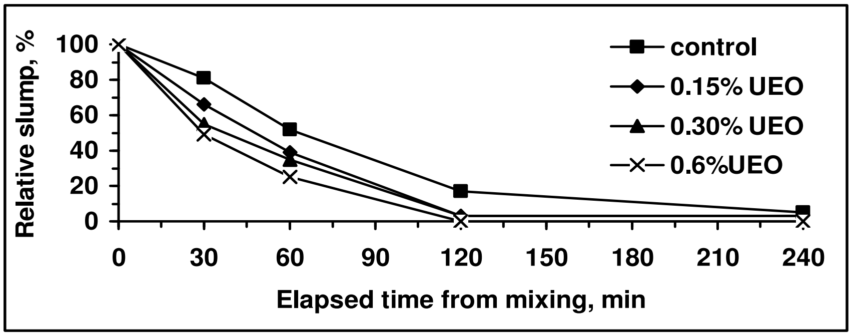


**Fig. 4: Rate of slump loss of OPC concrete mixes made with different contents of UEO.**

The rate of slump loss of mixes containing 0.30% UEO was compared with that of mixes made with either 0.30% WR or 0.30% AE, as illustrated in Fig. 5. It can be seen that, at one hour from mixing, the % of relative slump for all considered mixes containing UEO and traditional-chemical admixtures are almost similar, and lower than that of control mix, where the % of slump loss reach 65 and 45%, for mixes made with admixtures and without admixtures, respectively. After an hour from mixing, the mixes containing UEO started to loose its fluidity more rapidly than that for mixes admixed with WR and AE. However, the rate of slump loses of mixes incorporated with traditional-chemical admixtures (WR and AE) appeared to be comparable with that of control mix.

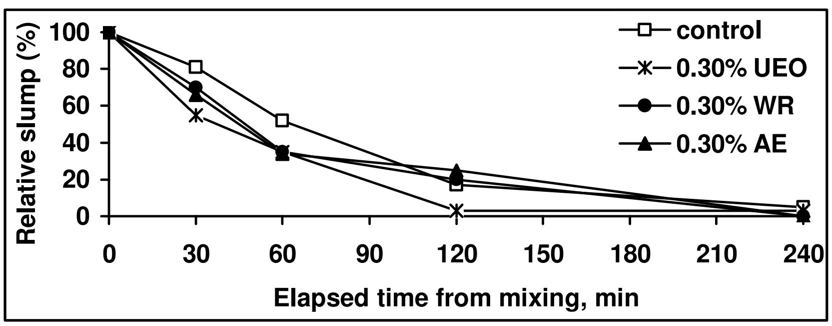


**Fig. 5: Rate of slump loss of OPC mixes made with different admixture types.**

To sum up, utilization of used-engine oil (UEO) resulted in a significant alteration in the performance of OPC concrete during its fresh state. UEO decreases the initial setting time and increases the consistency, air content and rate of fluidity loss of OPC concrete. These effects increased with increasing the dosage of UEO in OPC mixes. Therefore, UEO behaved as a chemical admixture and its uses would provide the dual action for plasticizer and air-entraining admixtures. However, a further rhyeology study is required to understand the mechanism of such waste material on fresh parameters of OPC concrete and then clarifying this phenomenon.

## 4.2. Hardened Properties

It is comprehensible from the above discussion that, utilizing UEO as an admixture has reasonable impacts on the various characteristics of concrete during its fresh state. Consequently, an imperative question may be arisen, would these impacts accompany with alterations in the various properties of concrete during its hardened state? As a result, the experimental program was conducted to investigate the mechanical, homogeneity and microstructure-related characteristics of OPC concrete made with different dosages of UEO. The mechanical property was examined as a function of compressive strength and surface hardness of concrete. While, microstructure-related characteristics of concrete were assessed by studying their porosity (EW), degree of hydration (NEW) and rate of water flow into cover zone using sorptivity approach. These above-mentioned properties were also evaluated for OPC concrete made with traditional-chemical admixtures (WR and AE) and were then compared with those of OPC concrete made with UEO.

### 4.2.1. Mechanical characteristics

Figs. 6 and 7 show 28-day compressive strength and surface hardness of OPC concrete incorporated with various dosages of UEO, WR and AE (0, 0.15, 0.30 and 0.60, % by cement mass. As seemed from the results reported in Fig. 6 that inducing of UEO into OPC could slightly decrease the 28-day compressive strength. The amount of decrease reaches about 5, 8 and 15%, when a dosage of 0.15, 0.30 and 0.60% UEO was utilized, respectively, compared with that of control specimens. Similar effect but with a slight extent was noted when AE was utilized, where the amount of reduction in the compressive strength attained 5 to 10%. Whilst, an opposite effect was not found when WR was used, where the compressive strength was slightly enhanced as a result of adding WR to OPC mix.

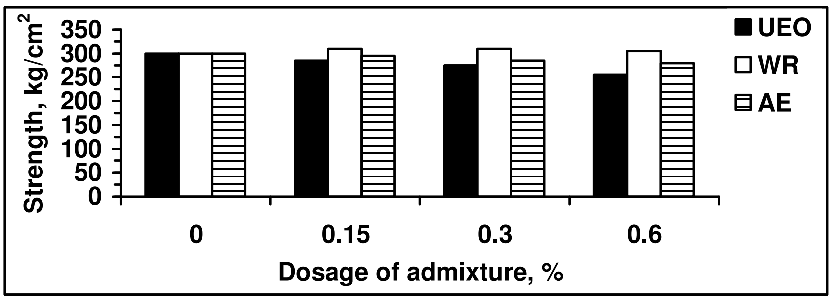


**Fig. 6: 28-day compressive strength of OPC concrete made with various admixtures.**

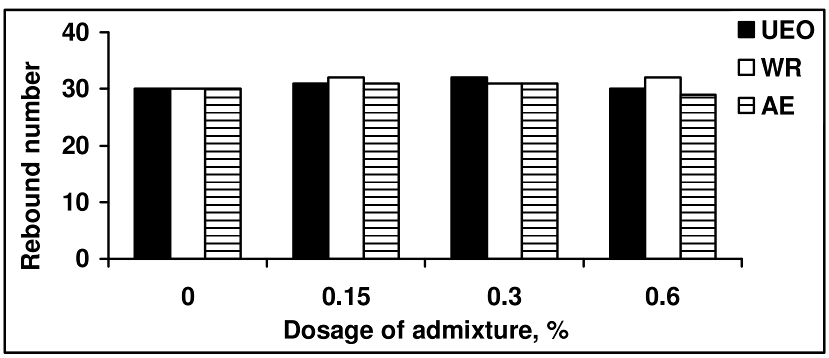


**Fig. 7: Hardness of OPC concrete made with various admixtures.**

These results however, disagree with the findings obtained by Hamad et al [1] and Shafiq et al [5], whom revealed that UEO maintained the compressive strength whereas the chemical air-entraining admixture caused approximately 50% loss in compressive strength. Despite of this contradictory, they reported that the other mechanical properties were significantly adversely affected by utilization UEO or AE in OPC mixes, where they found UEO resulted in average losses of 21, 17 and 6% in the values of flexural strength, splitting tensile strength and modulus of elasticity. The corresponding losses when AE was used 33, 42 and 35%, respectively [1].

On the other hand, the results illustrated in Fig. 7 emphasize that the UEO insignificantly affected the surface hardness of concrete, where, the rebound number measurements (taken by Schmidt Hammer apparatus at age of 28 days) vary from 30 to 32. Similar effects were noted when traditional-chemical admixtures was utilized. However, there is a contradiction between the impacts of UEO on surface hardness and compressive strength. This may be arisen from the difference between the sensitivity of both approaches used in this study for tracing such impacts.

### 4.2.2. Homogeneity and density

The homogeneity of concrete containing such waste material (UEO) or traditional chemical-admixtures was investigated using ultra-sonic pulse velocity (UPV) approach, and the results of such investigated are shown in Fig. 8. As shown, the homogeneity of concrete is slightly reduced as a result of inducing UEO into OPC mix. The amount of reduction reaches 5, 10 and 15%, when 0.15%, 0.30 and 0.60% UEO were used, respectively. These reductions are nearly similar with that produced for specimens made with AE. An opposite effect was produced when WR was used, where the value of UPV of OPC concrete was enhanced by about 5 to 10%, compared to control specimen. These behaviors are generally close to that obtained earlier when the compressive strength of specimens made with such admixtures was regarded, see Fig. 6.

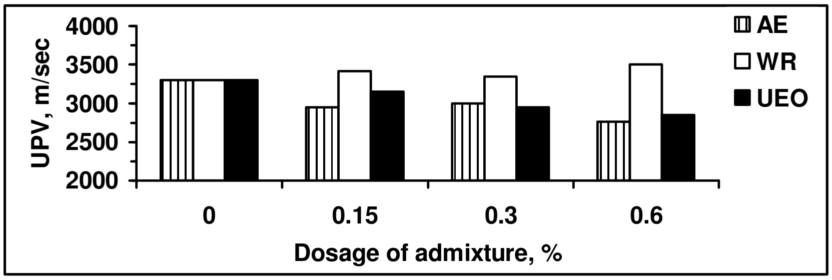


**Fig. 8: Ultrasonic-pulse velocity of OPC concrete made with various admixtures.**

Fig. 9 demonstrates the saturated unit weight of OPC concrete made with different admixture types (UEO, WR and AE). Slight reduction in the density of OPC concrete was noted when OPC concrete was admixed with either UEO or AE. These reductions are in concurrent with that noted reductions in the compressive strength and homogeneity characteristics see the results reported in Figs. 7 and 8. On the other hand, the density of OPC maintained unvaried when WR admixture was induced into its mix. These above-mentioned effects may be attributed to the significant role of UEO and AE on altering the % air content, which in turn would affect the hardened properties of concrete [13].

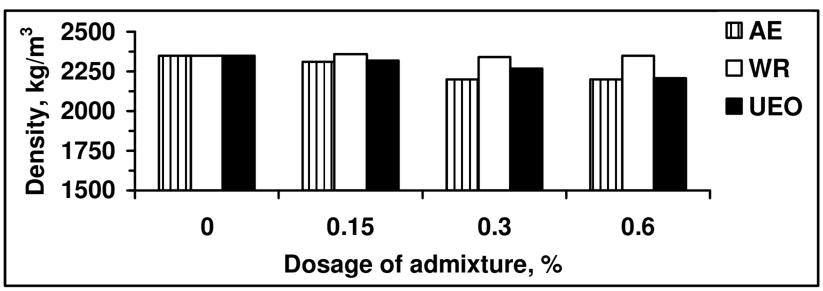


**Fig. 9: Saturated unit weight of OPC concrete made with various admixtures.**

### 4.2.3 Microstructure-related characteristics

It is clear from the above discussion that, incorporating UOE in OPC mixes can alter most of investigated engineering properties, strength, homogeneity and density. However, there is no available scientific explanation in literature to understand this phenomenon. Therefore, the % of evaporable water (EW) and % of non-evaporable water (NEW) of OPC matrix was investigated to clarify the impacts of UEO on its microstructure-related characteristics, porosity and degree of hydration, respectively. The rate of water inflow into the cover zone was also elucidated to determine the absorptivity of such concrete, which is mainly dependent on the pore structure of surface zone of concrete. Investigating these characteristics could provide a clear image to the influences of UEO on microstructure of concrete, which in turn, have an effect on concrete properties during its hardened state.

Therefore, effects of UEO on %EW and %NEW of hardened cement paste, using thermo-gravimetric analysis approach, were examined, and the results are plotted in Figs. 10 and 11, respectively. A comparison between the effects of UEO and the other traditional-chemical admixtures (WR and AE) on these properties was also presented. As seen, the porosity of OPC matrix (represented by % EW) significantly increases with increasing the dosage of UEO in OPC matrix, and the amount of increase in porosity vary from 20 to 25%. This means that the inclusion of UEO into OPC matrix can alter its microstructure to a more porous structure, hence leading to reduce its mechanical, homogeneity and density characteristics, as verified from the results illustrated shown in Figs. 6, 8 and 9.

A similar effect but with slight extent was noted when the impact of UEO on the degree of hydration (characterized by % NEW) was determined, see Fig. 11. The amount of reduction in % NEW attained about 10%, when 0.60% UEO was used, which resulted in an increase in the amount of pores in OPC matrix and consequently an increase in its porosity, thus affecting the hardened properties of concrete. The results reported in Figs. 11 and 12 also emphasize that the role of UEO and AE on the micro structural-related characteristics (porosity and degree of hydration) are fairly comparable. Where, % EW increases and % NEW decreases with inducing AE into OPC mixes. These impacts however, disagree with that produced when WR admixture was utilized, where; %EW and %NEW approximately remain unvaried as a result of using WR.

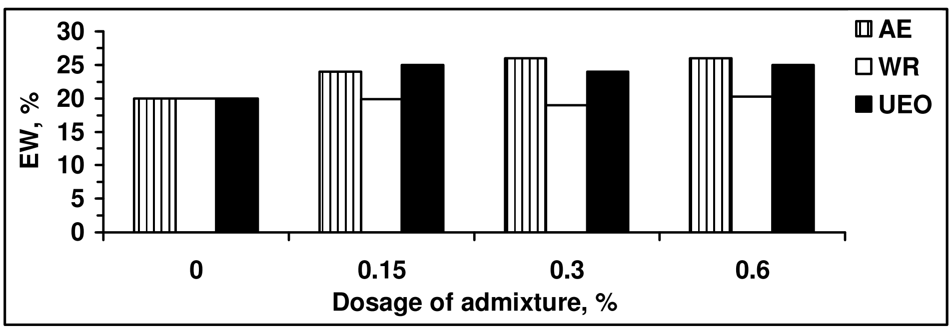


**Fig. 1:· Amount of evaporable water in of OPC hardened cement paste made with various admixtures.**

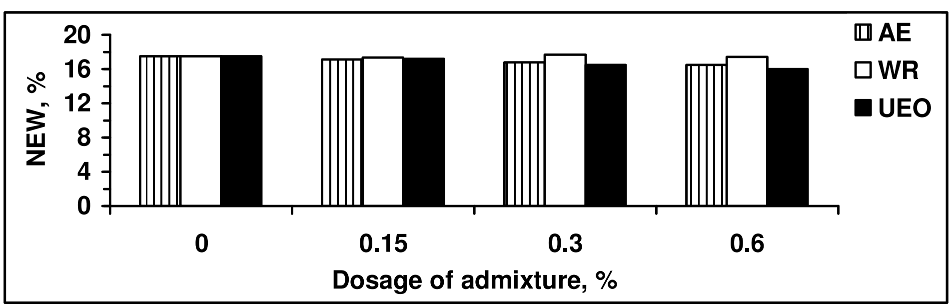


**Fig. 11: Amount of non-evaporable water in of OPC hardened cement paste made with various admixtures.**

The rate of water inflow into cover zone of OPC concrete containing such admixture types was investigated as a function of its sorptivity to assess its mass transport property and hence microstructure characteristics. The results of this investigation are shown in Fig. 12. As seen, the sorptivity of OPC concrete proportionally increases with utilizing either UEO or AE. On the other hand, the sorptivity of OPC concrete was reduced with the addition of WR admixture, and the amount of reduction increases with increasing the dosage of WR. This may be attributed to the enhancements occur to porosity and degree of hydration of OPC matrix, as indicated from the results shown in Figs. 10 and 11.

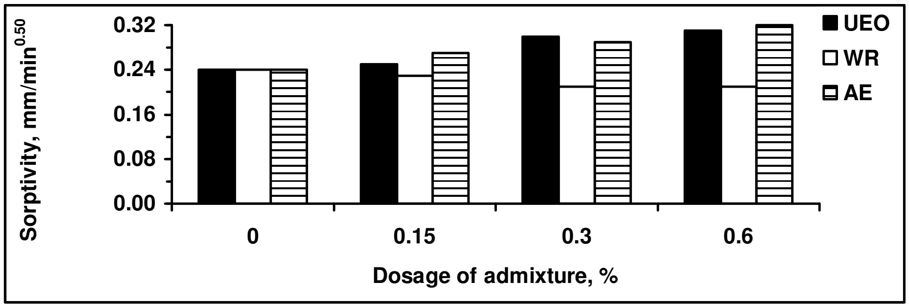


**Fig. 12: Sorptivity of OPC concrete made with various admixtures.**

The results reported in Fig. 12 verify that inclusion of either UEO or AE into OPC mixes may lead to increase the amounts of fluid pathways and interconnected pores in cover zone, which resulted in an increase in their sorptivity values. In other words, utilization of UEO in concrete industry may influence micro structural- related characteristics. However, a further microstructure analysis study has to be performed to confirm such explanation and to provide more information about pore size distribution, capillary pores and nature and amount of hydration of OPC matrix containing such waste material (UEO). The impacts of UEO on the various hardened properties of concrete would be then simply clarified and understood.

## 5. CONCLUSIONS

Based on the results and discussion, the following conclusions were made:

i- Utilization of used-engine oil (UEO) resulted in a significant alteration in the performance of OPC concrete during its fresh state. UEO decreases the initial setting time and increases the consistency, air content and rate of fluidity loss of OPC concrete. These effects increase with increasing the dosage of UEO in OPC mixes. Therefore, UEO behaved as a chemical admixture and its impacts would provide the dual action of both plasticizer and air-entraining admixtures.

ii- Inducing UEO into OPC mixes has a reasonable influence on the microstructure-related characteristics of hardened OPC matrix. Where, increasing the dosage of UEO resulted in an increase in porosity and sorptivity and a slight reducing in the degree of hydration.

iii- 28-day compressive strength, homogeneity and density of OPC concrete can be slightly degraded due to the adoption of UEO. However, the surface hardness of concrete has not adversely affected due to the use of UEO.

iv- Impacts of UEO and air-entraining admixture on the various investigated characteristics of OPC concrete during its hardened seem to be more or less similar.

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