

Properties of concrete containing used engine oil

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ABSTRACT

Since last few years cement replacement materials with industrial by-products and agricultural wastes in concrete production are widely used. It imparts positive environmental effect because the waste materials are not released to the environment. It was reported that the leakage of motor oil onto concrete surfaces in old grinding units increased the resistance such concrete to freezing and thawing, it made to understand that the effect is similar to adding an air-entraining chemical admixture to the concrete. This paper presents results of the experimental study conducted to investigate the effects of used engine oil on properties of fresh and hardened concrete. With the addition of used engine oil, concrete slump was increased by 18% to 38% and air content by 26% to 58% as compare to the slump of control concrete. Porosity and oxygen permeability of concrete containing used engine oil was also reduced and the compressive strength obtained was approximately same as that of the control mix.

Keywords: *Used engine oil, Oxygen permeability, Total porosity, Compressive strength, Concrete*

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1.0 INTRODUCTION

Lubricants are used for a wide range of applications, including: engine and transmission lubricants, hydraulic fluids, metal working fluids, insulating and process fluids and greases. During service in these applications, part or all of the lubricants may be consumed in the process. The balance tends to become contaminated with substances such as water, metal particles, rust, dirt, carbon and lead, and with other by-products of the combustion or the industrial process [1].

Waste motor oil poured into household drains, or directly onto the ground, can work its way into the waterways and ground waters. Illegally disposed of oil can pollute the groundwater with contaminants such as lead, magnesium, copper, zinc, chromium, arsenic, chlorides, cadmium and polychlorinated biphenyls. It was reported that one quart of oil can pollute up to 250,000 gallons of drinking water and/or approximately 40,730 square feet of soil, making it non-productive for farming or plant growth for up to 100 years¹. Although there is adequate campaign all over the world about the safe disposal of used engine oil, however, the reality is that about 40% of the used engine oil is illegally disposed of, which ultimately goes to rivers and seas [2].

It is reported in literature that the leakage of oil onto the concrete surfaces in old grinding units resulted concrete to offer greater resistance to freezing and thawing. This implies that adding used engine oil to the fresh concrete mix could be similar to adding an air-entraining chemical admixture, thus enhances the potential durability of concrete while serving as another technique of disposing the oil waste [3]. However, experimental data to support this hypothesis appear is very limited.

Principal objective of this research study was to investigate the effects of used engine oil on the properties of fresh concrete i.e. slump and air content and hardened concrete i.e. compressive strength, porosity and the coefficient of oxygen permeability. Concrete mixes were made of 100% cement (OPC) and OPC blended with fly ash, FA as partial replacement. The used engine oil dosage was kept 0.15% after various trial mixes. Properties of concrete containing used engine oil were compared with the properties of concrete containing new engine oil, commercially produced air entraining agent, superplasticiser and the plain concrete.

2.0 EXPERIMENTAL PROGRAMME

2.1 Materials and Mix Proportions

A detailed experimental programme was prepared to determine the slump value and air content of fresh concrete mixes. The properties of hardened concrete such as compressive strength and porosity at the ages of 3, 7, 28, and 90 days and oxygen permeability at the age of 28 days were investigated. A total of 13 different concrete mixes were prepared and the details of all the mixes are given in Table-1.

Ordinary Portland cement, OPC from Lafarge Cement Malaysia that complied with the requirements of BS 12 [4] was used throughout this experimental study. Sand and the gravels conforming to BS 882:1992 [5] were used as fine and coarse aggregates respectively. Used engine oil was collected from Proton Edar Service Station at Jalan Lahat, Ipoh Perak, Synthium 800 standard grade new engine oil and commercially

available air entraining agent SIKA AER 50/50 and superplasticiser supplied by SIKA Malaysia Sdn Bhd were used in this investigation. Concrete ingredients were batched by weight proportion of 1:2.33:2.5 for OPC or OPC/FA, sand and gravel. The mix proportion was adopted based on previous research [6] on concrete mix proportion. Water and admixture were measured in percentage by weight proportion of OPC or OPC/FA used. Fly ash was obtained from Manjung power station, Lumut, Perak, Malaysia, which was supplied complementary by YTL Cement Malaysia Sdn Bhd. Chemical composition and physical properties of fly ash as obtained from the supplier are given in Table-2

Table-1: Details of concrete mix proportion

Mix Type	OPC(kg/m ³)	FA	Cagg (kg/m ³)	FAgg (kg/m ³)	W/C (kg/m ³)	UEO	NEO	SP	AER
CM	325	0	1137.5	757.3	178.8	0	0	0	0
OPC/UEO	325	0	1137.5	757.3	178.8	0.15%	0	0	0
OPC/NEO	325	0	1137.5	757.3	178.8	0	0.15%	0	0
OPC/SP	325	0	1137.5	757.3	178.8	0	0	0.15%	0
OPC/AER	325	0	1137.5	757.3	178.8	0	0	0	0.15%
40FA	195	130	1137.5	757.3	178.8	0	0	0	0
40FA/UEO	195	130	1137.5	757.3	178.8	0.15%	0	0	0
40FA/NEO	195	130	1137.5	757.3	178.8	0	0.15%	0	0
40FA/SP	195	130	1137.5	757.3	178.8	0	0	0.15%	0
50FA	162.5	162.5	1137.5	757.3	178.8	0	0	0	0
50FA/UEO	162.5	162.5	1137.5	757.3	178.8	0.15%	0	0	0
50FA/NEO	162.5	162.5	1137.5	757.3	178.8	0	0.15%	0	0
50FA/SP	162.5	162.5	1137.5	757.3	178.8	0	0	0.15%	0

Note: OPC- Ordinary Portland Cement, CM- control Mix, UEO- Used Engine Oil, NEO- New Engine Oil, SP- Superplasticiser, AER- Air Entraining Admixture, FA- fly Ash, CAgg- Coarse Aggregates, FAagg- Fine Aggregates.

Table-2: Chemical composition of fly ash obtained from Manjung Power Station Malaysia

Oxide Composition	Percentage (%)
SiO ₂	56.39
Al ₂ O ₃	17.57
Fe ₂ O ₃	9.07
CaO	11.47
MgO	0.98
SO ₃	0.55
K ₂ O	1.98
Na ₂ O	1.91
Specific Gravity	2.37
Fineness, m ² /kg	243

2.2 Mixing, casting and curing

Mixing of concrete ingredients was done in the laboratory using a 100-liter capacity concrete mixer. Dry ingredients; cement, sand and gravel were first mixed for 1 minute in

the mixture prior to water addition. Admixtures such as used oil, new oil and Sika AER and superplasticizer were mixed in water before it was added to the dry ingredients in the mixer. After addition of water to the dry ingredients, it was mixed for 2 minutes in order to achieve homogenous concrete. After homogeneous mixing of fresh concrete, it was tested for determination of slump and air content. Slump value was measured in accordance with the British standard BS 1881 part 102, 1983 [7] and air content was measured in accordance with ASTM C231 [13].

Concrete cubes were cast in standard steel mould of dimensions 150 mm x 150 mm x 150 mm according to the specifications defined in BS 8110 1997 [8]. Similarly plain concrete prisms were cast in steel mould of dimensions 100 mm x 100 mm x 500 mm. Plain concrete planks of 40 mm x 400 mm x 400 mm dimensions were cast in wooden moulds and 50mm diameter cores were drilled out for porosity measurement from the planks.

After casting the specimens in the moulds, they were covered with black plastic sheets and left for 24 hours. Subsequently, all specimens were stripped-out and transferred into the water-bath at room temperature for curing until the desired age of testing.

3.0 TESTING OF SPECIMENS

3.1 Compressive Strength

Concrete cubes at ages 3, 7, 28, and 90 days were tested in accordance with the procedure defined in BS 1881: Part 116, 1983 [9-10]. A universal hydraulic testing machine with a maximum capacity of 500 kN was used to test the specimens.

3.2 Total Porosity

Total porosity of concrete was determined by vacuum saturation method that was developed by RILEM [11]. At the age of 3, 7, 28, and 90 days, three 50mm diameter discs were cored-out from concrete planks. Total porosity of the samples was determined using equation (1) as below:

$$P(\%) = \frac{W_s - W_d}{W_s - W_w} \times 100 \quad (1)$$

Where, P is the total porosity in percentage, W_s is the weight of saturated samples measured in the air; W_d is the weight of oven-dried samples measured in the air, and W_w weight of saturated samples measured in water. All weight measurements are in grams, g.

3.3 Measurement of Oxygen Permeability

The permeameter (UTP Permeameter) installed in Concrete Technology Laboratory at, University Technology PETRONAS, UTP were fabricated according to the design of the Leeds permeameter. Cylindrical concrete samples 50 mm diameter and 40 mm thick samples that were oven dried were used to determine the total porosity and for measurement of oxygen permeability. The coefficient of oxygen permeability was calculated by modified Darcy's equation (2) as follows [6]:

$$K_o = \frac{2\mu p_{out} QL}{A(p_{in}^2 - p_{out}^2)} \quad (2)$$

where:-

- K_o = the intrinsic permeability of concrete in m^2
- μ = dynamic viscosity of flowing fluid; for oxygen at $20^\circ C$, μ is 2.02×10^{-16} N.s/ m^2 ,
- p_{out} = the outlet pressure, that is equal to 1 bar at standard temperature and pressure
- p_{in} = the inlet pressure, which was kept between 1 to 4 bars⁶.
- Q = Flowrate in m^2/s
- A = Sample area in m^2
- L = Sample thickness, m

4.0 RESULTS AND DISCUSSION

Experimental results obtained on fresh concrete mixes in terms of slump and air content are presented. The properties of hardened concrete in terms of compressive strength, porosity and permeability are illustrated in the following section.

4.1 Fresh concrete properties

i) Slump

Figure-1 shows the slump values of 13 different concrete mixes used in this experimental investigation; for control mix it was obtained as 20 mm. When used engine oil was added to 100% OPC concrete, the slump value increased to 35 mm. Similarly the slump of new oil with 100% OPC concrete was obtained as 59 mm. SIKA superplasticiser which is commercially produced to increase the fluidity of concrete, increased the slump value of 100% OPC concrete to 49 mm.

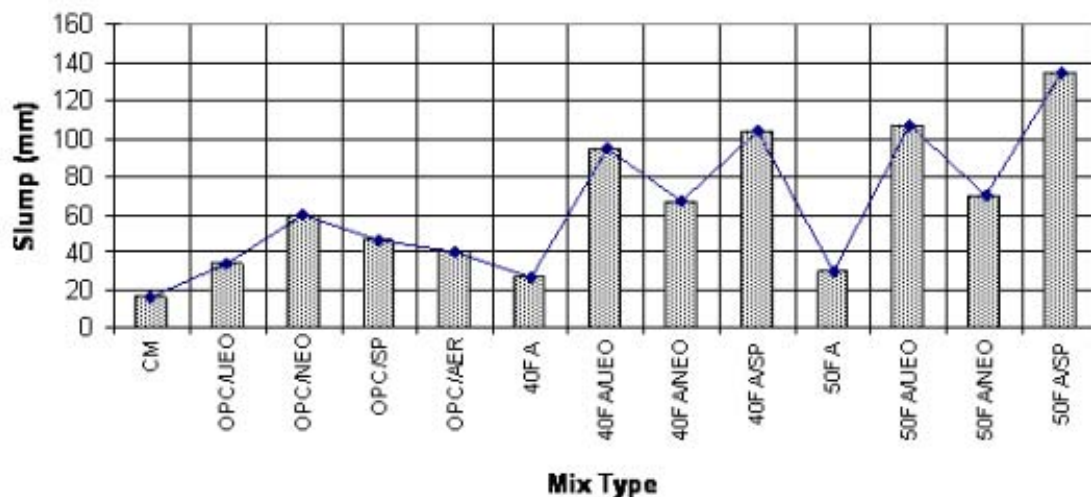


Figure-1: Variation of slump of concrete mixes containing different admixtures

Usually fly ash when used as a partial replacement of OPC in concrete will increase the slump of concrete and this hypothesis is found to be true in this experimental investigation. Concrete mixes 40FA and 50FA made of 40% and 50% fly ash, yielded higher value of slump i.e. 26 mm and 28 mm respectively. Used and new engine oils and

superplasticiser significantly increased the slump value of fly ash based concrete by 1.5 to 2 times of the respective fly ash mix.

ii) Air Content

The amount of entrapped air in the control mix (CM) was measured as 1.9%. When the chemical air-entraining admixture AER, was added in 100% OPC mix, (OPC/AER) the entrained air content increased to 3.3% whilst the superplasticiser mix OPC/SP recorded 3.4%. The amount of entrained air in 100% OPC concrete containing used and new engine oil were measured as 3.0% and 3.1% respectively. The amount of entrained air for all 13 mixes used in this investigation is shown in Figure-2. However, for concrete mixes containing 40% and 50% fly ash, the air content more than the air content for mixes containing used engine oil, new engine oil and superplasticiser.

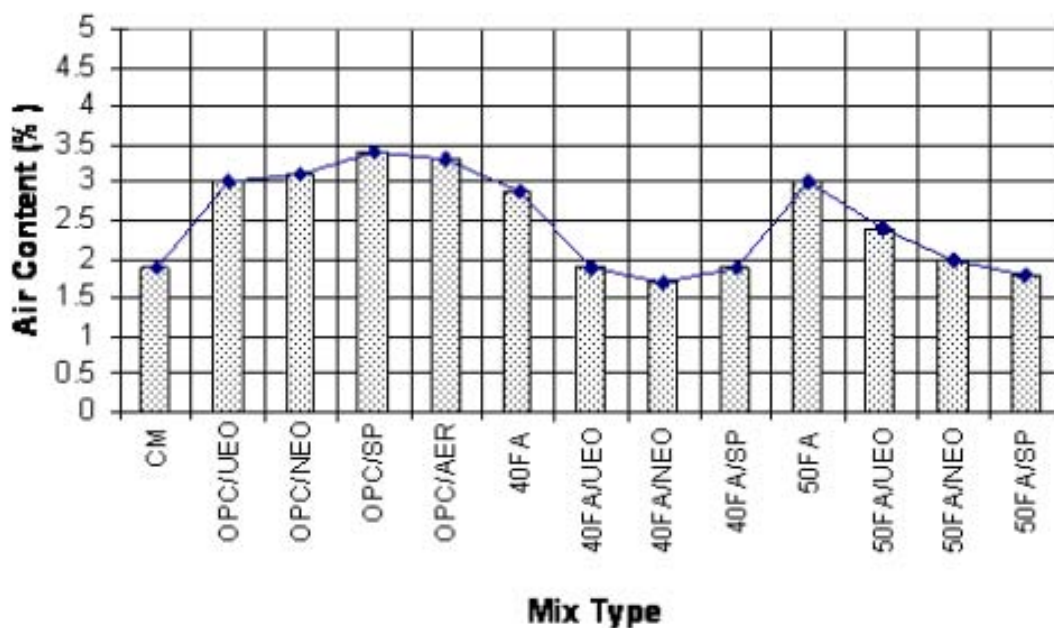


Figure-2: Variation in air content in concrete mixes containing different admixtures

4.2 Hardened Concrete Properties

i) Total Porosity of Concrete

Total porosity of hardened concrete is an important property, which is an indicator of quality, strength and durability; it reduces with respect to the age as hydration progresses. At the age of 3 days total porosity, P of all concrete mixes was measured within the range of 9.9% to 12.6%, which is an indicator of better performance of concrete to be exhibited in the long term. At 28 days, the control mix, (CM) achieved 10.6% porosity whilst the total porosity of the mixes OPC/UEO, OPC/NEO, OPC/SP and OPC/AER concrete were 8.7%, 9.1%, 9.7% and 9.8% respectively. It shows that at the age of 28 days OPC/UEO concrete yielded the lowest porosity (8.7%). The same trend was observed at the age of 90 days where the porosity of concrete mix OPC/UEO was reduced to 8.3% whereas for CM it was measured as 9.7%. Figure-3 depicts the complete test data of total porosity, P of all 13 concrete mixes with respect to age.

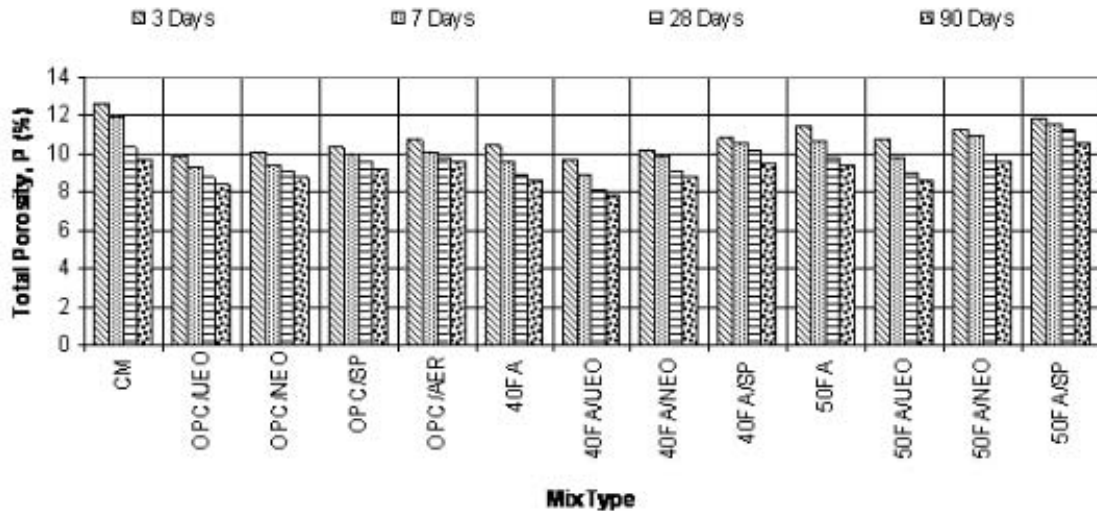


Figure-3: Porosity of concrete mixes containing different admixtures at different ages

The same trend in porosity measurement was observed with concrete mixes containing 40% and 50% fly ash. At the age of 3 days the porosity of mixes 40FA and 50FA were 10.4% and 11.4% respectively whilst the porosity of 100% OPC mix, CM was 12.6%. This is due to the fact that the fine grain size of fly ash made it possible to fill up the voids in the concrete matrix and consequently its pozzolanic reaction produced more calcium silicate hydrates gel to reduce the porosity. It was found that the concrete containing fly ash depicted about 10% lower porosity than the 100% OPC concrete. When the used engine oil was added to fly ash based concrete, the total porosity further reduced. At the age of 28 days, the porosity of concrete mixes 40FA and 50FA were 8.9% and 9.8% respectively whilst the total porosity of the mixes 40FA/UEO and 50FA/UEO were 8.1% and 8.9%. However, the total porosity of fly ash mixes containing new engine oil, NEO and superplasticiser, SP was higher than their counterpart for mixes 40FA and 50FA. It can be concluded that with 40% fly ash and 0.15% dosage of used engine oil, the least porosity of concrete was achieved almost at all ages of testing.

ii) Compressive strength

Compressive strength for each of the 13 mixes was measured at four different ages: 3, 7, 28 and 90 days. At all the ages, compressive strength of control mix, CM containing 100% OPC was found to have higher strength than the rest of the mixes. There was not much reduction in compressive strength observed for concrete mixes containing 0.15% dosage used engine oil with respect to the corresponding control mix, i.e. CM, 40FA and 50FA. At the age of 28 days, the compressive strength of control mix, CM obtained as 42 N/mm² and for concrete mix OPC/UEO it was 39 N/mm². Similarly for 40FA, it was measured as 33 N/mm² and for 40FA/UEO it was 31 N/mm². Compressive strength of all concrete mixes at different ages is plotted in Figure-4

Total porosity plays an important role for strength development in concrete. To analyze this relation, compressive strength of all concrete mixes is plotted against their corresponding porosity value (refer Figure-5). Both compressive strength and total porosity of concrete developed non-linearly with respect to age. Upon concrete maturity, i.e. after 28 days, both compressive strength and total porosity vary very slowly, therefore

an exponential correlation as equation (3) was obtained as the best representative of the relationship between compressive strength and total porosity.

$$f_{cu} = 350.8e^{-0.256P} \quad (3)$$

$$R^2 = 0.705$$

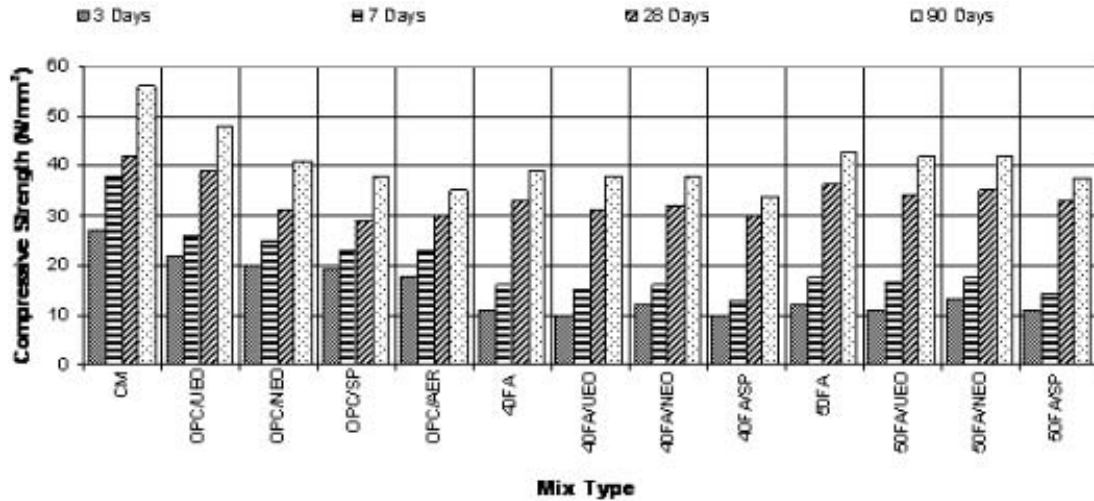


Figure-4: Variation of compressive strength, f_{cu} of concrete mixes at different ages

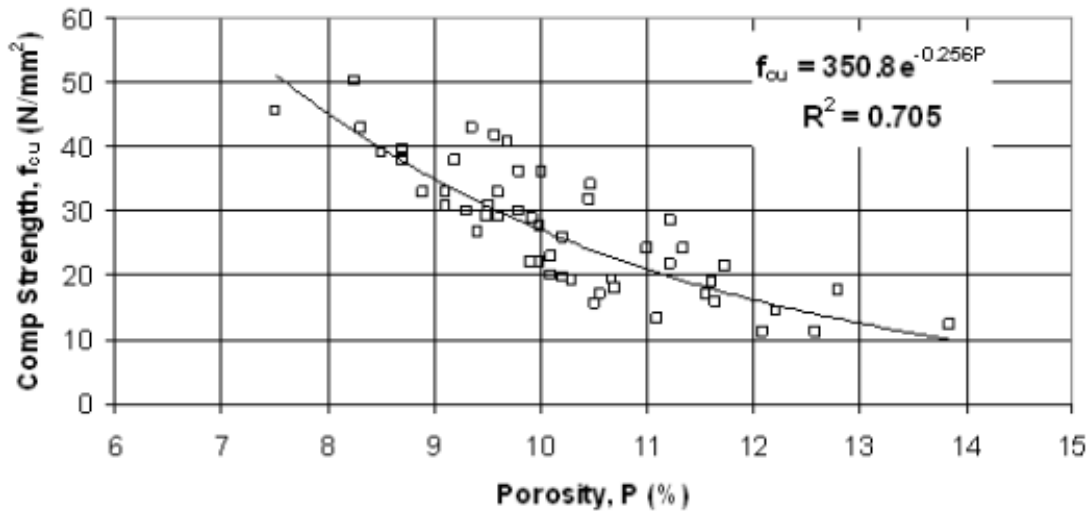


Figure-5: Statistical Correlation between Compressive Strength, f_{cu} and Total Porosity, P

iii) Oxygen Permeability

Figure-6 shows the logarithmic values of the coefficient of oxygen permeability, $\log(K_o)$ of different concrete mixes measured at the age of 28 days. Amongst the 3 sets of concrete mixes i.e. 100% OPC, 40FA and 50FA, concrete mix containing 0.15% of used engine oil measured the lowest value of oxygen permeability. For 100% OPC concrete, control mix, CM showed 1.69 times higher coefficient of oxygen permeability than that of the concrete mix OPC/UEO. Similarly OPC/NEO mix showed 1.59 times more permeability than the OPC/UEO mix. Coefficient of oxygen permeability for mixes

OPC/SP and OPC/AER were 4.6 and 5.65 times the permeability of OPC/UEO respectively.

Same trend was observed with the other sets of concrete mixes namely 40FA and 50FA. Coefficient of permeability for concrete mixes, 40FA, 40FA/NEO and 40FA/SP were 1.21, 1.16 and 2.77 times respectively higher than the coefficient of oxygen permeability of the concrete mix 40FA/UEO respectively. Similarly the ratios for 50FA series were 1.07, 1.27 and 2.07 (over those of OPC/UEA. From the above discussion it can be concluded that the used engine oil in concrete reduces the permeability hence the deterioration may be delayed.

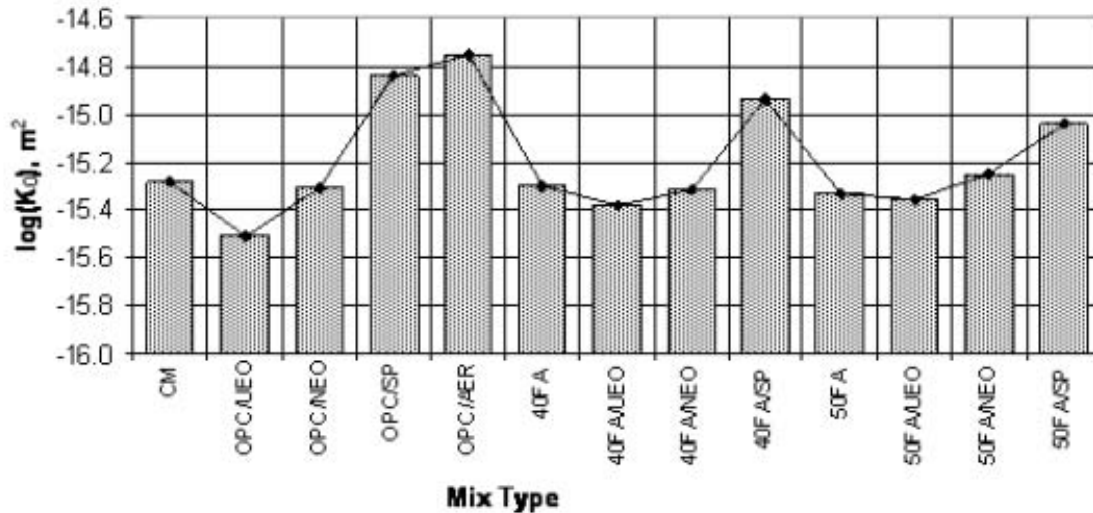


Figure-6: Coefficient of Oxygen Permeability, log(K_o) of different Concrete Mixes

Oxygen Permeability versus Compressive Strength and Total Porosity
 Porosity, compressive strength and permeability of concrete are three important parameters that address performance characteristics of concrete. A best fit for permeability against porosity and strength obtained using statistical analysis of the data is shown in Figure-7.

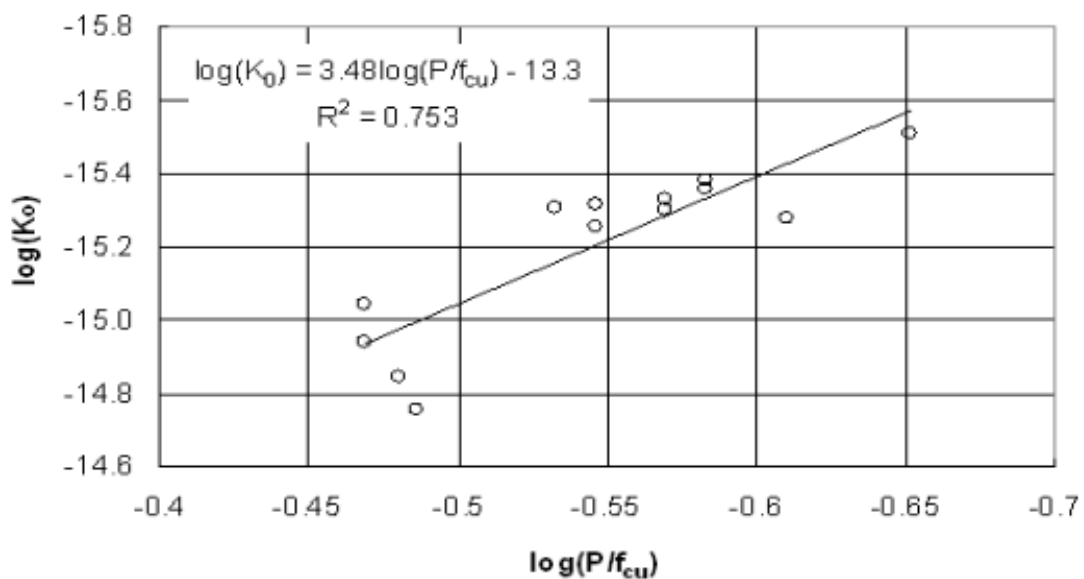


Figure-7: Oxygen Permeability, log(K_o) versus Porosity to Strength Ratio log(P/f_{cu})

The equation obtained is:

$$\log(K_o) = 3.48 \log\left(\frac{P}{f_{cu}}\right) - 13.3 \quad (4)$$

Cabrera *et al.* in 1989 [11] and Shafiq and Nuruddin [12] (determined the similar equation as:

$$\log(K_o) = 1.01 \log\left(\frac{P}{f_{cu}}\right) - 15.95 \quad (5)$$

Equation (4) as obtained in this experimental investigation is comparable with equation (5) that was developed by Cabrera *et al* [11] and widely accepted by concrete researchers all over the world. This also indicates the reliability of UTP permeameter in measuring the permeability of concrete.

5.0 CONCLUSIONS

Based on the results and discussion the following conclusions were drawn:

1. Effects of the used engine oil and the new engine oil in concrete mixes were more or less similar. Dosage of engine oil in concrete acted as a chemical plasticizer, which enhanced the fluidity of fresh concrete and increased the slump value to twice the slump value of the control mix. Concrete mixes containing 40% and 50% fly ash followed this trend.
2. Dosage of engine oil in 100% OPC concrete increased the air content of the fresh concrete to about 30 to 50% as compared to the air content of the control mix. Whereas the commercial chemical air-entraining admixture, SIK AER almost doubled the air content.
3. A 0.15% dosage of engine oil reduced the total porosity of concrete between 14% and 27%, whilst the dosage of SIK AER and superplasticiser reduced the porosity within a range of 7% to 11%.
4. Effects of engine oil on the concrete compressive strength were negative with respect to the control/reference mixes. However, engine oil based concrete yielded higher compressive strength than the corresponding concrete mixes containing dosage of superplasticiser or air entraining agent.
5. A 0.15% dosage of used engine oil had the lowest value of the coefficient of oxygen permeability. In control mix with 100% OPC, used engine oil reduced the permeability to about 65% of the coefficient of oxygen permeability of the control mix. In fly ash based mixes, used engine oil reduced the coefficient of permeability to approximately half of the reference mix.
6. A valid statistical correlation between oxygen permeability and porosity to compressive strength ratio was obtained that is comparable with the widely accepted equation presented by Cabrera *et al* [11].

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