Evaluation of the effect of the mechanical properties on the performance of interlocking concrete block pavement under the influence of petroleum products

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Abstract. Recently, there has been an upsurge in the use of interlocking concrete block pavement (ICBP), though large scale and extensive use of the blocks is not commonplace. In some residential districts, the current trend which is seen as a new fad is concrete-block paving of driveways and courtyards of private homes. There is also a gradual increase in the use of concrete blocks for paving pedestrian walkways in recent constructions in the cities, and in rehabilitating old walkways in urban activity centers. The aim of this study is to investigate the effect of three types of petroleum products: Fuel oil (FO), Kerosene (K) and Engine oil waste (EO), on the mechanical and physical properties of interlocking concrete block pavement (ICBP) manufactured from two Iraqi factories, where two types of (ICBP) were chosen one from each factory. 66 specimens were submerged in the petroleum products for 30, 60, and 90 days, then the compressive strength, ultrasonic pulse velocity, density and absorption values were determined and compared with non-submerged specimens. In general, the results showed that ICBP-2 has good resistance to the effect of kerosene and fuel oil.

Key words
Interlocking Concrete Block Pavement, petroleum products, kerosene, black oil, compressive strength.

1. Introduction
The recent re-emergence of the use of interlocking concrete block pavement (ICBP) in Iraq, particularly for paving the driveways and courtyards of private homes and some public precincts, has created a sudden upsurge in the use of and demand for concrete paving blocks. This has led to the proliferation of construction of concrete blocks and pavements of all shades and sizes. Associated with these developments are the problems and issues related to the structure and design of interlocking concrete block pavements, product and construction quality, construction guides, and customer support services.

Interlocking concrete block pavements (ICBP) have been and are being used to construct structurally sound pavements for pedestrian and vehicular traffic including aircraft landings, and have become a major construction material in heavy-duty industrial paving as well. They are also appropriate for paving surfaces subjected to oil spillage, and offer easy maintenance access to underground utility lines.
There were, however, some problems that affected ICBP when it was used in refuelling places and adjacent sidewalks of a long-term repair shop, in appearance, color, smoothness of edges and overall performance which is caused by the misuse and neglect.

Despite their enormous potential as surfacing materials, concrete paving blocks have not received sufficient attention and support from the road sector and allied industries in Iraq. Because of this, there does not appear to be any sustained or systematic research efforts at the present aimed at providing the necessary technical guidelines for concrete block paving. Like any pavement, the design and construction of interlocking concrete block pavements must not compromise sound engineering principles if construction durability, longevity and proper performance are to be assured.

In Iraq, due to the re-emergence of the use of ICBP and the accompanying growing demand, many companies both small and large have proliferated on the market to satisfy demand or have added production of concrete paving blocks to their line of products [1].

Interlocking concrete block pavements (ICBP) are manufactured from concrete, which is a mixture of cement, water, fine aggregate and coarse aggregate. The compressive high strength, ease of production, low cost, good compatibility with other materials especially with steel, durability under aggressive conditions are some benefits of this material. But there are factors that affect the compressive strength, behaviors and performance of concrete water/cement ratio, mix ratio, degree of compaction, type of cement, aggregate grade, design constituent, mixing method, placement, curing method and the presence of contaminates [2]. When petroleum products are spilled on concrete and reinforced concrete elements of structures pavements, they gradually impregnate them, causing cracks in their structure, which can have a negative impact on their reliability and mechanical safety. The influence of oil derivations with different viscosities, like fuel oil (FO) Kerosene (K) and Engine oil waste (EO), affects concrete in varying manners due to the ability of the fluid to be absorbed by concrete [3].

Durable concrete has the ability to withstand the effects of environmental conditions to which it will be subjected, such as weathering, chemical attack, and abrasion. The migration of water, petroleum products, and other liquids through properly designed, placed, consolidated, and un-cracked concrete is minute [4].

Petroleum products, especially light ones, are known to have the ability to penetrate the concrete through cracks due to shrinkage, voids as well as joints, which causes major problems that restrict the success of concrete as a construction material used in structures that store and transport oil products, or those that are in contact with it, such as floors in warehouses, refineries, factories, and fuel stations. Hewlett and Liska (2019) [5] explained that hydrocarbon products fill the pores of anhydrous cement particles, which impedes the process of hydration, leading to the decrease in the strength of concrete and its development over time. Calabrese et.al (1992) [6] found that regardless of the type of sand and the high percentage of polluted petroleum, it leads to a decrease in the strength of concrete in the early and late ages [7]. AL-Zaidi (2001) [8] studied the influence of oil products (gas oil and kerosene) on the physical properties of concrete, and revealed that specimens cured in gas oil and kerosene showed higher compressive strength for all ages, compared with their water counterparts. The effect of state of concrete (wet or dry) before exposure to oil products doesn’t produce significant effect on the compressive strength.

Many researchers including Hewlett and Liska (2019) [5], Alexander and Svetlana (2018) [9] reported that mineral oil has no effect on the quality of concrete.
The damage of the oils depends on their viscosity; the higher viscosity of the oil, the less it is likely to impregnate the concrete Alexander P. (2019) [10]. Therefore, the viscosity of oil is a very important property for oil store tanks, according to Spamer (1994) [11].

Although many studies have been conducted on the behavior of hardened concrete exposed to petroleum products, the interpretation of their behavior is still unclear and needs to be studied. This research is an attempt to provide additional information on the effect of some petroleum products on the ICBP from two factories in Baghdad city. The specimens (ICBP) from the first factory were different in shape and dimension from those taken from the second factory. The effect of (ICBP) specimens soaked in fuel oil (FO) Kerosene (K) and Engine oil waste (EO) was investigated at soaking ages of 30, 60, and 90 days.

2. Experimental work

The 66 specimens of (ICBP), 33 specimens for each factory, were soaked in three types of petroleum products (fuel oil (FO), Kerosene (K), and Engine oil waste (EO)) for 30, 60, and 90 days, to determine the effect of soaking the specimens in the aforementioned products. The compressive strength, ultrasonic pulse velocity, density, and absorption were determined and compared with dry (un-soaked) specimens.

2.1. Materials

2.1.1. Interlocking concrete block Type 1 (ICBP-1). The specimens used were obtained from AL-Jabery factory. The concrete mixture of the (ICBP) Type 1 was (1:1:2) for cement, fine aggregates and coarse aggregate, respectively, and water to cement ratio w/c was (0.42). The physical properties are shown in Table 1.

2.1.2. Interlocking concrete block Type 2 (ICBP-2). The specimens used were obtained from AL-Qaisar factory. The concrete mixture of the (ICBP) Type 2 was (1:2.5:1:8% pozzolanic material) for cement, fine aggregates, coarse aggregate and pozzolanic material, respectively, and water to cement ratio w/c was (0.45). The physical properties are shown in Table 1.

| Table 1. properties of (ICBP) |
|-------------------------------|
| **Compressive strength, MPa** | (ICBP-1) | (ICBP-2) |
| Absorption, %                 | *30-25   | *50-45   |
| Weight, kg                    | 3.30-3.40| 2.85-2.95|
| Shape                         | 'I'      | Hexagonal shape |
| Area, mm                      | 25475    | 35337    |
| Thickness, mm^2               | 60       | 40       |
| Max. Size of coarse aggregate, mm | *10-20 | *6-9     |
| Density, kg/m^3               | 2200     | 2140     |
| Prices ,ID/m^2                | *10000 (35 pieces) | *17000 (25 pieces) |

*values supplied by the manufacturer.

2.1.3 Petroleum products. Fuel oil (FO), Kerosene (K) and Engine oil waste (EO) with specifications are shown in Table 2. They were brought from the local market and stored in plastic containers to avoid any losses.
Table 2. Properties of Oil Products

| Oil Inspection Data | Fuel oil (FO) | Kerosene (K) | Engine oil-waste (EO) |
|---------------------|--------------|--------------|-----------------------|
| Viscosity (Centipoises) | 135 at (60 °C) | 1.64 at (20 °C) | 111.32 at (40 °C) |
|                     | 51 at (80 °C) | 1.00 at (40 °C) | 17.83 at (100 °C) |
|                     | 24 at (100 °C) |               |                       |
| Color               | Yellow       | Light yellow  | Dark black            |
| Specific gravity (gm/cm³) at: 20°C | 0.95 - 0.985 | 0.77-0.820 | 1.39 |
| Moisture content, % by volume | 0.05 - 0.1 | 0.05 - 0.1 | 1.34 |
| Sulfur content, % by weight | 4-5 | 0.2-0.3 | |

*Given by the manufacture.

2.2. Specimen preparation
A total number of 66 ICBP specimens were brought from two factories and soaked in three types of petroleum products in plastic containers at 20 °C (laboratory environment), the samples used for the compressive strength and Ultrasonic Pulse Velocity tests were wiped with dry cloth and left to dry in air for 24 hr before the test.

2.3. Laboratory tests
A total number of 66 ICBP specimens were brought from two factories and soaked in three types of petroleum products in plastic containers at 20 °C (laboratory environment), the samples used for the compressive strength and Ultrasonic Pulse Velocity tests were wiped with dry cloth and left to dry in air for 24 hr before the test.

2.3.1 Absorption test. According to the ASTM C20 - 00(2015) [12], this test is performed by drying the cubes in the oven at a temperature of 105°C for 24 hours, and then measuring their weight to give the dry weight. The specimens were then soaked in water for (24) hours, then taken out and weighed. The absorption ratio was calculated using the following formula:

\[
\text{Absorption ratio} = \frac{(\text{wet weight} - \text{dry weight})}{\text{dry weight}} \times 100 \quad (1)
\]

2.3.2 Compressive strength test. The compressive strength test was carried out on ICBP-1 and ICBP-2 using a digital compression machine of 2000 kN capacity. The load was applied at a rate of 1.5 kN/sec, in accordance with (ASTMC936/C936M−13 [13]. The average value of three separate test results was adopted at each soaking time (0, 30, 60 and 90 day ages).

2.3.3 Ultrasonic Pulse Velocity test. The Ultrasonic Pulse Velocity test consists of measuring the time of travel of an ultrasonic wave passing through the concrete. The time of travel between the initial onset and reception of the pulse are measured electronically. The path between transducers, divided by the time of travel, gives the average velocity of wave propagation. The test was performed according to ASTM C597-02 [14]. The average value of three tested ICBP was adopted at each soaking time (0, 30, 60 and 90 day ages).

3. Results and Discussion

3.1 Density
The result of density of ICBP-1 and ICBP-2 for dry specimens (2200 and 2140, kg/m³, respectively) and at various times of soaking in petroleum products is shown in Figure 1 and Figure 2. The density of the ICBP exposed to K and FO in 30, 60, and 90 day ages decreased (0.63, 0.95, 1.67 %) and (0.18, 0.36, 1.2%) respectively, for ICBP-1, (0.23, 0.55, 0.79) % and (0.046, 0.41, 0.60) % for K and FO respectively for (ICBP-2). Due to the harmful effect of petroleum product on the bond between
aggregate and cement paste, this led to the increase in porosity and decrease in strength and density, according to Nada and Sara (2013) [15] and Rajab (2016) [16]. While the EO in 30, 60, and 90 were increased in 90 days age to 1.36 and 1.07 % for ICBP-1 and ICBP-2, respectively, due to the existence of inside pores which were partially filled with EO that have high viscosity because of increase in density. The increase or decrease in density for the ICBP-1 was higher than the density for ICBP-2.

![Graph ICBP-1](image1)

**Figure 1.** Relationship between density and soaking time for all the types of petroleum products for ICBP-1

![Graph ICBP-2](image2)

**Figure 2.** Relationship between density and soaking time for all the types of petroleum products for ICBP-2

### 3.2 Absorption

Figure 3 shows the results of the absorption of ICBP-1 and ICBP-2, soaked in the three petroleum products. As shown, the absorption increased for the two type of ICBP with soaking time, with ICBP-1 having higher absorption than ICBP-2 ranging in value between (1.45 to 4.68) % for ICBP-1 and (0.39 to 3.2) % for ICBP-2. The results show that the FO and K have the highest values due to the lower viscosity as compared to EO. The penetration of FO in 30 day ages reaches 10-15 mm from the edge to the core of the specimens, and 30-35 mm for 60 day ages, then the specimens were saturated for 90 days. Both the K and EO specimens show the same behavior, except for the EO the specimen soaked for 90 days, in which the core remained dry due to the high viscosity.
3.3 Compressive Strength

The change in compressive strength of ICBP due to petroleum products relative to dry specimens are plotted in Figure 4 and Figure 5. The results show that there was a decrease in the compressive strength of ICBP due to exposure to the oil products, and that this decrease was proportional to the increase in the soaking time and the loss in mechanical properties (compressive and splitting tensile strengths). The effect of exposure to petroleum products was relatively smaller for high strength concrete (HPC) compared with normal strength concrete (NSC), as shown from the compressive strength values for the dry specimens (25 MPa for ICBP-1 and 50 for ICBP-2), which was due to many factors such as mix design, water content, grading of aggregates, used machinery, skill of workers, additive materials and experimental conditions.

The compressive strength of the two types of ICBP decreased with soaking time, except for 30 days age of the ICBP-1, where the results showed increased in value of compressive strength (14%, 4% and 3.52% for K, FO and EO, respectively) as compared with the dry specimen. This was due to continuous hydration of the cement paste, which increases the bond between cement paste and aggregate. Shetty (2000) [17] and Neville (2012) [18]. But in 90 days there was a decrease in compressive strength values (39.48%, 61% and 57% for FO, K and EO, respectively). Although the ICBP-2 shows a decrease in the compressive strength with soaking-time, it was less affected by the petroleum products compared with (ICBP-1), due to the high absorption, the mix design, fine material (and higher cement content in ICBP-1 than in ICBP-2). The decrease in compressive strength of ICBP-2 in 90 days was 14.46%, 12.57% and 12.56% for K, FO and EO, respectively.

The penetration of petroleum products into the specimens may cause an expansion in the voids of concrete mixtures and the separation of the particles from each other, which leads to weak bonds between them, reducing the cohesion forces on the surface of concrete as a result of the absorption of these petroleum products.

Figure 3. Relationship between Absorption and soaking time for all the types of petroleum products
The ultrasonic pulse velocity method consists of measuring the travel time of a pulse of longitudinal ultrasonic waves passing through the concrete. Ultrasonic pulse velocity values are useful for checking the homogeneity of concrete and for detecting cracks and voids in the concrete element, and in some cases, to monitor the strength development of concrete. It is very useful in this study, to investigate the effect of petroleum products inclusion on the ultrasonic pulse velocity of ICBP-1 and ICBP-2 in different ages. Figure 6 shows the Ultrasonic Pulse Velocity test. Table 3 shows the ICBP-1 and ICBP-2 average test results of ultrasonic pulse velocity measurements at different soaking time.

The results indicated that there is a similar behavior between the compressive strength and ultrasonic pulse velocity with the increase in the soaking time for all oil derivatives, except the behavior of 60 days age for ICBP-1, for which the ultrasonic pulse velocity receiver recorded low pulse but the compressive strength increased in value.

**Table 3.** Results of Ultrasonic Pulse Velocity test (km/sec) with soaking age, for all types of Petroleum product.

| Petroleum      | ICBP-1         |
|----------------|----------------|
| Soaking time   | fule oil       |
|                | Kerosene       |
|                | Engine oil waste |
| 0 day          | 25             |
| 30 day         | 25             |
| 60 day         | 28.5           |
| 90 day         | 26             |
| 0 day          | 50             |
| 30 day         | 50             |
| 60 day         | 48.5           |
| 90 day         | 46.8           |
| 0 day          | 50             |
| 30 day         | 50             |
| 60 day         | 47             |
| 90 day         | 45.73          |

![Figure 4. Relationship between compressive strength of ICBP-1 and soaking time](image)

![Figure 5. Relationship between compressive strength of ICBP-2 and soaking time](image)
| product              | 0 day | 30 day | 60 day | 90 day |
|----------------------|-------|--------|--------|--------|
| Fuel oil             | 3.08  | 2.89   | 2.88   | 2.85   |
| Kerosene             | 2.97  | 2.95   | 2.91   | 2.9    |
| Engine oil waste     | 2.93  | 2.84   | 2.82   | 2.72   |

**ICBP-2**

| Petroleum product    | Soaking time |
|----------------------|--------------|
|                      | 0 day | 30 day | 60 day | 90 day |
| Fuel oil             | 2.81  | 2.68   | 2.6    | 2.46   |
| Kerosene             | 2.83  | 2.75   | 2.67   | 2.65   |
| Engine oil waste     | 2.8   | 2.71   | 2.73   | 2.66   |

**Figure 6. Ultrasonic Pulse Velocity test**

**4. Conclusions**

Based on the experimental results in this research, the following conclusions can be drawn:

1. The reduction in compressive strengths of ICBP-1 and ICBP-2 increases with the decrease in the viscosity of the petroleum products in the entire period of exposure.
2. The maximum decrease percentage in the specimens’ compressive strength in 90 day age was caused by kerosene (61% for ICBP-1 and 16.18% for ICBP-2).
3. EO increased the density of specimens due to the ability of EO to fill the voids and capillary cracks and that returned to high viscosity while FO and K decreased the density due to low viscosity and this gave it the ability to pass through the porosity.
4. Ultrasonic pulse velocity test gives good indications about the effect of petroleum products on compressive strength of concrete with time but at the same time did not give the approximate value of the compressive strength.
5. The quality of products depends on the mixture of concrete (mix design, water content, additives material, grading of aggregates, chemical admixture) in addition to skills of workers and laboratory conditions (moulds, equipment …etc.) at the same time considering the economic cost and that depends on availability of raw marital, factory location, skilled workers ….etc.

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