The use of olive waste for development sustainable rigid pavement concrete material

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Abstract. Recycle and reuse of agriculture and industrial wastes becomes a big challenge in different parts of the world. The success in the waste recycle could lead to conserve the environment, reduce the use of cement, and improve health environment. This paper presents the potential use of fly ash from olive oil waste in Jordan to improve concrete material which could be used as a sustainable material for rigid pavement and building construction material. Olive oil ash was collected from olive oil mill and replace cement in producing concrete material. The range of cement replacement was 0% to 12.5% with increment 2.5%. The results indicate that olive oil reduces the workability of concrete material. The reduction of the slump of concrete increases with increasing olive ash content. Strength and durability of concrete improved and increased with increasing olive ash content in concrete up to 7.5 percent then the strength reduced. The results in this study show that the use of 7.5% was the optimum replacement of cement. This percent could produce concrete with higher strength and higher durability in comparison with the control concrete mix. Olive waste ash enhances both strength and durability because it reduces the effective water-cement ratio in concrete mix and filling the pore and void structure in concrete material. The benefits of this study could reduce the cost of concrete and recycle waste material and enhance concrete properties.

1. Introduction

Jordan is one of Mediterranean countries such as Spain, Italy, France Greece, Turkey, Tunisia, Syria, Lebanon. These countries have a vast olive tree plantation used to produce olive oil. The high demand for olive oil will continue to increase in the future leads to an increase in olive tree plantation. Jordan has large number of olive mills to produce olive oil. These mills produce a large amount of olive waste materials. Most of these wastes used in winter to produce heat and the by-product is olive oil waste fly ash. This ash is disposed in sanitary landfills. This may cause several environmental problems and pollute the ground water. Recycle these wastes may reduce these environmental problems and may also contribute to sustainable development of other construction materials such as concrete.

The concrete material is the most construction material used in the world. Concrete material mainly used in rigid pavement, road construction and as a building material. This material suffers from weak strength and very porous structure make it deteriorate due to inclusion of liquids and chemical
containing chloride. Several researchers investigate the use of additive to enhance its strength and durability. Fly ash used by many researchers to investigate its effect in improvement to the performance of concrete. If strength and durability of concrete enhanced using fly ash this could save a large amount of money in repair cost and rehabilitation of rigid payment and building constructed from concrete.

Fly ash is a by-product waste material produced from combustion of waste or combustion of materials to produce energy. Fly ash could be produced from coal combustion [1], municipal solid waste, burning of rice husk [2] and wheat straw ash [3] burning heavy oil [4]. Fly ash waste used to enhanced rigid pavement concrete material and building cement concrete material [5-7]. Fly ash waste used to enhance concrete durability [8]. In addition, fly ash waste used to enhanced asphalt flexible pavement material [9-18]. Limited studies were conducted to evaluate the effect of olive oil waste fly ash on the concrete properties. Olive oil waste fly ash used to improve properties of cement mortars [5,19], enhance alkali-Silica reaction of concrete material [20], and improve the performance of concrete exposed to elevated temperatures [21]. In addition, fly ash from industrial wastes was used to enhance properties of several types of concrete such as self-compacting concrete [22-24], light weight concrete [25-28] and geopolymer concrete [29-30].

To date, olive oil waste fly ash is dumped in sanitary land fill. This toxic fly ash is disposed of in landfills may leading to environmental problems. This study conducted to investigate the use of olive oil fly ash in rigid pavement concrete material on concrete performance such as workability, strength, and durability.

2. Materials and Methods
Olive oil waste was collected from Qumaym olive oil mill in Irbid, Jordan. The olive waste was burned in oven for two hours to ensure all wastes were converted to olive oil waste ash (OWA). The location of the olive wastes and the waste are shown in Figure 1. The OWA specific gravity was 2.05 and the diameter of the ash ranges from 1 to 10 µm. The chemical composition of the OWA is given in Table 1. Ordinary Portland cement was used to produced rigid pavement concrete material grade 30. The specific gravity of cement was 3.15. The chemical composition of cement is given in Table 1. Limestone aggregate with maximum aggregate size equal to 14 mm was used in this concrete. A control concrete mix was prepared with water cement ratio 0.5. Concrete control mix proportions were 360 kg/m³ cement, 180 kg/m³ water, 722 kg/m³ fine aggregate and 1098 kg/m³ coarse aggregate. The gradation of the aggregate is given in Figure 2. This particle size distribution of the aggregate meets the specification of ASTM 33-93.

![Figure 1. Source of olive oil waste; (a) Jordan map shows the location of olive waste in Irbid; (b) Olive waste before combustion.](image-url)
Table 1. Chemical composition of cement and olive oil waste ash (OWA).

| Chemical Composition | Percentage in OWA (%) | Percentage in Cement (%) |
|----------------------|-----------------------|--------------------------|
| SiO$_2$              | 21.0                  | 20.5                     |
| Fe$_2$O$_3$          | 2.5                   | 4.3                      |
| Al$_2$O$_3$          | 4.5                   | 5.4                      |
| CaO                  | 30.1                  | 65.5                     |
| K$_2$O               | 30.0                  | -                        |
| Na$_2$O              | 0.4                   | -                        |
| SO$_3$               | 0.0                   | 3.0                      |
| MgO                  | 5.4                   | 2.16                     |
| P$_2$O$_5$           | 6.0                   | -                        |
| LOI                  | 2.81                  | 3.0                      |

Figure 2. Gradation of limestone aggregate used in this study.

To evaluate the effect of adding OWA, five concrete mixes were prepared by partially replacement of cement in the control mix. The replacement or OWA content range from 2.5 kg to 12.5 kg with increment 2.5 kg.

Six concrete mix proportioning were produced with different percentages of OWA using ACI method [31]. For each mix cube specimens were prepared in the laboratory according to the standard [32]. Slump of the fresh concrete for all mixes were measured according to appropriate standard [33]. The concrete specimens were cured in water until the day of testing [34]. At 28 days of curing the concrete cubes tested for compressive strength and water absorption according standard test [35-36].

3. Results and discussion

To evaluate the effect of OWA on fresh properties and hardened properties of concrete material, slump, compressive strength and absorption of concrete mixes were tested and analyzed. The results of these properties are presented in the following subsections.

3.1. Effect of OWA on slump
The slump test was performed for all mixes with OWA content from 0% to 12.5%. Samples of slump test are given in Figure 3. The results of slump of all mixes are presented in Figure 4. The results indicate that slump and workability of fresh concrete decreases with increasing OWA content. This may attribute to the smaller size of OWA and larger surface area. In addition, the specific gravity of OWA is less than specific gravity of cement. Replacement of cement by weight will lead to larger volume OWA which will consume more water from the mix. This will significantly reduce the workability as the slump reduced. Larger OWA content will cause a larger reduction in slump. The relationship between slump and OWA content could be modeled as a linear relationship and took the form:

\[
\text{Slump} = \beta_0 + \beta_1 x
\]

Where \(\beta_0\) and \(\beta_1\) are model parameters. \(X\) is the OWA content. The model parameters and correlation coefficients are given in Figure 4. The square correlation coefficient was 0.9844. This indicate a good fit of the results using linear regression model.

3.2. Effect of OWA on compressive strength
The compressive strength at different time of curing for all concrete mixes was evaluated. The results of compressive strength versus curing time at all OWA content are given in Figure 5. The results indicate that compressive strength increases with increasing OWA content up to 7.5 percent.
Compressive strength decreases when the OWA content above 7.5 percent. These trends were observed over all curing time. The result show that compressive strength reaches higher value at OWA content 7.5 percent. The improvement in compressive strength because OWA has specific gravity less than cement therefore, the volume of OWA is larger than the same weight of cement. In addition, OWA has a smaller particle size and these reasons could reduce the effective water cement ratio of concrete containing OWA. Water cement ratio (w/c) is the most factors affecting strength of concrete and OWA reduce w/c leads to increase compressive strength according to Abraham laws.

To better visualize the effect of OWA content on concrete compressive strength, the relationship between compressive strength of concrete and the OWA content was established using regression analysis. The results are shown in Figure 6. The best model to fit the result was quadratic formula given in equation 2.

\[
\text{Compressive Strength} = \beta_0 + \beta_1 x + \beta_2 x^2
\]  

(2)

Where $\beta_0$, $\beta_1$, and $\beta_2$ are model parameters equal to 31.807, 1.3957, and -0.1309 respectively. X is the OWA content. The square correlation coefficients $R^2=0.8937$.
3.3. Effect of OWA on durability
The durability of concrete was measured using concrete absorption. The absorption of concrete incorporated OWA is presented in Figure 7. The results indicate that absorption of concrete decreases with increasing OWA content until 7.5% then the trend reverse. This is because the fine particle of OWA could fill the voids and porous structure of concrete specially the interfacial zone. Also, OWA reduces effective w/c ratio which reduces the pore structure of concrete. This lead to enhance the durability of concrete.

To better visualize the effect of OWA content on concrete absorption, the relationship between absorption of concrete and the OWA content was established using regression analysis. The best model to fit the result was quadratic formula given in equation 3.

\[
Absorption = \beta_0 + \beta_1 x + \beta_2 x^2
\]

Where \(\beta_0\), \(\beta_1\), and \(\beta_2\) are the model parameters equal to 1.5432, -0.0691 and 0.0059, respectively. \(x\) is the OWA content. The square correlation coefficients \(R^2=0.8261\). It is clear from the result that 7.5% of OWA is the optimum replacement content to enhance concrete durability.

4. Conclusions
The result in this study indicate the feasibility of using and recycling olive oil waste ash in concrete industry. Replacement of cement in concrete material used for rigid pavement and building construction could improve strength of concrete and enhance concrete durability. The results also indicate that 7.5 percent of olive waste ash is the optimum replacement of cement in concrete to achieve the best strength and durability. Olive waste ash enhance both strength and durability because it reduces the effective water cement ratio in concrete mix and filling the pore and void structure in concrete material. Olive oil waste ash content decrease the workability of concrete this problem could be solved by addition of superplasticizer to achieve the same concrete slump.

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Conflicts of interest
The authors declare that there is no conflict of interest regarding the publication of this paper.
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