Sustainable Asphalt Concrete for Road Construction and Building Material

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Abstract. In this study, the possibility of producing new geopolymer concrete from olive oil waste in Jordan is presented. Olive oil residues in Jordan and many Mediterranean countries constitute a major environmental and health problem. So far, the waste is disposed of by means of sanitary landfill, and this poses an environmental risk and pollutes the groundwater, the main source of water in Jordan. The ash remaining from burning olive oil residues was used to produce geopolymer concrete by adding sodium hydroxide and without using any Portland cement. Mixtures were prepared using the central composite design. The focus was on the two most important factors affecting the properties of geopolymer concrete, which is the amount of ash and the amount of alkaline solution. After curing the concrete and passing 28 days, the compressive strength, slump, absorption, and porosity were measured. The results of compressive strength, absorption and porosity were excellent in comparison with the results obtained from conventional concrete. Despite the promising results the slump of the proposed concrete is low, and the slump loss was very fast. Further studies are needed to improve the workability of geopolymer concrete from olive oil waste. This concrete allows to recycle a large amount of olive waste in Jordan and many other countries which reduce the impact on health and environment.

1. Introduction
During the last century, concrete was one of the most widely used construction materials in the world. In view of the steady increase in population and the development of infrastructure in most countries of the world, the demand and production of concrete will continue to increase significantly. Despite this, this huge amount of concrete production has a great impact on the environment and the need to produce environmentally friendly and sustainable concrete has become on the agenda of many researchers in many international research centres. Many institutions have presented this problem and called for scientific research to produce green concrete and reduce its impact on the environment and people's lives [1]. The production of a ton of cement used in concrete, such as Portland cement, is accompanied by the release of a ton of carbon dioxide. The contribution of the construction industry, especially the production of concrete for buildings, roads, and infrastructure, is estimated at 8 percent of carbon dioxide globally [2]. The shift to produce environmentally friendly concrete and the reduction of carbon dioxide emissions can be done in two ways. The first is to search for cement materials that are used as a bond other than the current cement, whose production constitutes a high energy that emits carbon dioxide and the method of manufacturing in which the raw materials are burned at a temperature of about 1500°C,
which also produces huge quantities of CO$_2$. The second method by which researchers try to replace percentages of cement in concrete with other materials that work with cement as a binder well, which reduces the percentages of using cement to produce concrete [1]. Intensive research conducted to reduce the use of cement in concrete by partially replacement of cement using several alternative binders and pozzolanic materials. Among these replacement material fly and bottom ash from various sources such as ash for coal produced from power generation plants [1, fly ash from sloid waste incineration, fly ash from burning heavy and crude oil, and ash from burning rice husk [3-8]. In addition, other researchers used ground granulated blast furnace slag (GGBFS), silica fume and limestone powder [9-10].

In the last decade, several studies try to produce new concrete called geopolymer concrete. This concrete use 100% new binder mixed with alkaline material such as sodium hydroxide, potassium hydroxide and silicate hydroxide [11-15]. This alkaline could react with industrial byproduct such as fly ash, slag, and clay to form a binder for the filler fine and coarse aggregate. This new type of concrete produce by polymerization of the waste material used instead of hydration process of ordinary cement with water. This new type of concrete is promising since it is recycling large amount of waste mostly toxic and harsh to environment. In addition, this new type of concrete eliminates or reduce the CO$_2$ emission during manufacturing Portland cement [8, 16-19].

Jordan like several other Mediterranean countries has large number of olive mills to produce olive oil. Olive oil mills contribute a large amount of agricultural waste. This waste is utilized in winter to produce heat and the by-product is olive waste ash. This ash is disposed in sanitary landfills causing environmental problems. Recycle these wastes may reduce these environmental problems and may also contribute to sustainable development of other construction materials such as concrete. Example of these waste is given in Figure 1. The olive waste in Figure was from Irbid-Qumaym olive oil mill located in north of Jordan as stated in the map in Figure 2.

This study tries to explore the use of ash extracted from the waste of olive mills to produce a new type of sustainable concrete. This new concrete could be an alternative to concrete made from Portland cement, which is known to be unsustainable and has an impact on the environment. In addition to the above, the study also aims to find an effective way to get rid of large quantities of olive oil waste, which is a major environmental and health problem in Jordan.

2. Sustainable concrete
Portland cement concrete is the most synthetic material used worldwide but also one of the most environmentally unfriendly. Ordinary concrete is considered to have a great impact on the environment, and it can affect sustainability and the environment in several aspects that can be classified into four areas (see Figure 3). The first area that makes concrete not environmentally friendly and unsustainable is the raw materials that are used to produce concrete. The consumption of
large quantities of raw materials causes an unsustainable depletion of natural resources. The second area of influence is during the manufacture of cement. Manufacturing cement consumes large amounts of energy and emits huge amounts of carbon dioxide. The third area is the life of the concrete materials used in the construction industry. Concrete has a relatively short service life, and if it is increased, it may become another method of sustainability. The fourth area is the demolition of concrete material when it reaches its design period. Mostly breakdown old concrete will produce large amounts of waste that are often not reused.

![Figure 3. Areas related to sustainability of concrete.](image)

Below are some trends and methods that can convert concrete into a sustainable material and reduce its great impact on health and the environment:

- Find new raw material to produce cement and concrete such as waste from industrial activities.
- Partially replace Portland cement by other binder material such as ash, GGBFS, silica fume and limestone powder.
- Find new binder material instead of Portland cement.
- Enhance the manufacturing technology of cement to reduce energy used and CO$_2$ emission.
- Enhance the mix design for proportion of concrete components which may lead to lower the cement content and achieved required performance.
- Develop new types of concrete such as geopolymer concrete which utilize waste ash or clay with alkali material as new binder.
- Enhance the concrete performance to extend its life cycle and reduce the need for new concrete to replace existing concrete structure.
- Utilize the demolition concrete material in producing new concrete.
- Improve the repair techniques and methods to extend the service life of existing concrete structures.

3. Materials and methods

This section presents the properties of all materials used to prepare concrete. In addition, the subsection presents the centre composite design used to develop mix proportions of sustainable concrete. The test conducted to characterize concrete produced in this study are also presented.

3.1. Fine and coarse aggregate

The aggregate used in this study to prepare geopolymer concrete were fine and coarse limestone aggregate. The properties and particle size distribution are presented in Figure 4 and Table 1.

| Properties         | Fine aggregate | Coarse aggregate |
|--------------------|----------------|------------------|
| Bulk specific gravity | 2.46           | 2.61             |
| Absorption         | 1.41           | 0.73             |
| Fineness Modulus   | 2.93           | -                |
3.2. Olive oil ash and alkali solution
Fly ash used in this study was produced from olive oil waste collected from Irbid-Qumaym olive oil mill in north of Jordan. The waste was burned for several hours. The ash was sieved using sieve number 200 with opening 0.075 mm. The fine particles of fly ash with particle size less than 0.075 mm is used to mix with alkali material, fine and coarse aggregate to produce agricultural geopolymer concrete. The specific gravity of the ash was 2.1. Ash particle size reduce using ball milling apparatus for 2 hours. SEM of the olive waste ash before and after ball milling are presented in Figures 5 and 6, respectively. The chemistry of fly ash and Portland cement is given in Table 2. The ash is classified according ASTM standard as class F.

The alkali solution used in this study was sodium silicate solution (NSS) and sodium hydroxide solution (NHS). Sodium solutions were used due its potential to dissolve fly ash particles [13-17,20-23], and its low cost compared to other activators.

Table 2. Chemical composition of waste fly ash.

| Composition in fly ash | SiO$_2$ | Fe$_2$O$_3$ | Al$_2$O$_3$ | CaO | K$_2$O | Na$_2$O | SO$_3$ | MgO | LOI |
|------------------------|---------|------------|------------|-----|-------|--------|-------|-----|-----|
| Olive Fly Ash (OFA)    | 28.52   | 29.32      | 12.34      | 17.91 | 1.31  | 0.69   | 0.73  | 1.30 | 3.62|
| Portland cement        | 20.99   | 3.86       | 6.19       | 65.96 | 0.6   | 0.17   | -     | 0.2 | 1.53|

3.3. Central composite design
Response surface methodology using central composite design was performed to prepare geopolymer concrete using olive oil waste ash. This methodology use to evaluate the effect of the most two factors affecting geopolymer performance. The two factors consider in this study is the amount of olive oil fly ash (OFA) used and the amount of alkali solution (AS). Five levels were used for each variable OFA
and AS. The central composite design reduces the 25 mixes needed as full factorial to 9 mixes which can cover the feasible range of mixes. The strength of sustainable geopolymer chosen in this study was grade 30 concrete. This concrete will have minimum design strength equal to 30 MPa. This grade of concrete was chosen because it is the most grade used in the construction industry for structural concrete. Since other concrete constituents such as fine aggregate, coarse aggregate are filler not binding material it kept constant and equal to about 0.65 percent.

The centre of fly ash value was 450 kg/m$^3$ and the centre alkali solution was 200 kg/m$^3$. The alpha of the centre composite was 1.41 to form a rotating central design. The value of the two variables and the coded of the centre composite design is given in Figure 7 and Table 3. The proportions of sustainable geopolymer concrete mix are 450 kg/m$^3$ olive ash, 200 kg/m$^3$ alkali solution, 1100 kg/m$^3$ coarse aggregate, 456 kg/m$^3$ fine aggregate and 43 kg/m$^3$ water.

![Figure 7. Central composite design for ash and alkali.](image)

The performance properties $Y$ using central composite could relate to the two factors $x_1$ and $x_2$ by full quadratic formula given in equation 1.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2$$

(1)

Where $Y$ the performance of SGC such as compressive strength, workability (slump), porosity and absorption. $\beta_0$, $\beta_1$, $\beta_2$, $\beta_{12}$, $\beta_{11}$, and $\beta_{22}$ are constant parameters of the quadratic model. $X_1$ is the first factor or concrete mix variable such as olive fly ash (OFA) and $X_2$ is the second concrete mix variable alkali solution (AS).

**Table 3. Properties of sustainable asphalt concrete pavement.**

| Concrete Mix Code | Actual value | Coded value | Note       |
|-------------------|--------------|-------------|------------|
|                   | Olive oil ash (kg/m$^3$) | Alkali solution (kg/m$^3$) | Olive oil ash | Alkali solution |
| OWA1              | 540          | 200         | 0          | 0          | Center-Axial |
| OWA2              | 421          | 178         | -1         | -1         | Corner       |
| OWA3              | 421          | 222         | -1         | +1         | Corner       |
| OWA4              | 479          | 178         | +1         | -1         | Corner       |
| OWA5              | 479          | 222         | +1         | +1         | Corner       |
| OWA6              | 409          | 200         | -1.41      | 0          | Axial        |
| OWA7              | 491          | 200         | +1.41      | 0          | Axial        |
| OWA8              | 450          | 169         | 0          | -1.41      | Axial        |
| OWA9              | 450          | 231         | 0          | +1.41      | Axial        |
3.4. Testing regimes
The Sustainable geopolymer concrete (SGC) was produced by mixing the required proportion of each material followed the procedures described by ASTM C305 [24]. The fresh mixes were cast into the required moulds and vibrated for 1 min using to exclude any entrapped air. The SGC 150 mm cube specimens were cured at a controlled laboratory room temperature of 25°C and relative humidity 80%. Slump test was performed on fresh concrete and compressive strength was measured at 28 day of curing according to ASTM standard. Porosity and absorption also measured at 28 days of curing.

3.5. Conventional concrete
To compare the Sustainable geopolymer concrete (SGC) with Portland cement concrete, conventional concrete mix with the same grade 30 MPa was prepared using the same fine and coarse aggregate. The mix proportion was according to ACI211 concrete mix design. The water cement ration was 0.5. The strength, slump and durability of this mix were determined like SGC mixes. The mix proportion and results of the conventional concrete performance is given in Table 4.

| Mix proportion and performance test | Water cement ratio | Ratio of Cement to Aggregate | Ratio of fine to coarse aggregate | Strength (σ) (MPA) | Slump (S) (mm) | Absorption (A) (%) | Porosity (n) (%) |
|------------------------------------|-------------------|-----------------------------|-------------------------------|-------------------|----------------|-------------------|----------------|
| Conventional concrete              | 0.5               | 1:5                         | 2:3                           | 32.1              | 120            | 3.1               | 7.21            |

4. Results and discussion
The results of development and performance of conventional concrete and SGC using response surface methodology and central composite design are presented in the following subsections.

4.1. Strength, Slump and Durability of SGC
The results of testing SGC such as compressive strength (σ), slump (S), Absorption (A) and porosity (n) are summarized in Table 5.

| Concrete Mix Code | Strength and Workability | Durability | Note |
|-------------------|--------------------------|------------|------|
|                   | Compressive strength (σ) (MPA) | Slump (S) (mm) | Absorption (A) (%) | Porosity (n) (%) |
| OWA1              | 33.2                      | 22         | 1.9   | 5.38                          | -                 |
| OWA2              | 31.3                      | 27         | 2.6   | 6.13                          | -                 |
| OWA3              | 32.4                      | 22         | 2.7   | 5.91                          | -                 |
| OWA4              | 31.8                      | 28         | 2.4   | 6.44                          | -                 |
| OWA5              | 37.1                      | 15         | 1.6   | 3.56                          | High slump loss  |
| OWA6              | 29.5                      | 35         | 3.2   | 8.22                          | Very harsh       |
| OWA7              | 34.2                      | 25         | 2.1   | 5.41                          | -                 |
| OWA8              | 30.7                      | 30         | 2.3   | 6.31                          | -                 |
| OWA9              | 35.5                      | 20         | 1.7   | 5.12                          | High slump loss  |

The result of compressive strength (σ) is presented in Figure 8 for all 9 mixes of SGC concrete. The strength of all mixes has achieved the design and required strength at 28 days of curing. It is noticed that the strength after 24 hours of production the central mix (OWA1) exceeds 20 MPa. This strength for conventional concrete needs about 3 weeks after production. The results of slump of SGC
presented in Figure 9 indicate small slump value which may make it difficult for use in the site specially for mix OWA5 where slump loss very fast. The results of durability of all SGC mixes which is presented in Figures 10 and 11 indicate high durable concrete with lower porosity (n) and absorption (A). This concrete could possess a high resistance to deterioration conditions and will protect reinforced concrete from corrosion problems which is major cause of defects in concrete structures such as rigid pavement in roads, bridges, and building. The high alkali environment of SGC also make it superior to resist corrosion problems.

4.2. Response surface methodology
The response surface developed using central composite with the most two variables affecting geopolymer concrete namely olive oil ash (OFA) and alkali solution (AS) was conducted. The results of the full quadratic model equation to relate the performance of SGC such as \( \sigma \), S, A and n to the factors OFA and AS are given in Table 6. The results show high significant correlation coefficients and low mean square error. This indicate that these models could predict and estimate the performance of design concrete parameters such as strength, slump, absorption, and porosity. These models could help engineers to design and adjust the proportion of the factors to meet the required SGC performance. To better visualize these models given in equations 2 through 5, the response surface of the four model were presented in Figures 12, 13, 14 and 15. The response surface shows how \( \sigma \), S, A and n changes by changing OFA and AS in the feasible region.

\[
\sigma = 36.2 + 0.239(\text{OFA}) - 0.759(\text{AS}) + 0.00165(\text{OFA})(\text{AS}) - 0.00057(\text{OFA})^2 + 0.000234(\text{AS})^2
\]

\[
S = -30 - 0.317(\text{OFA}) + 1.67(\text{AS}) - 0.00313(\text{OFA})(\text{AS}) + 0.000937(\text{OFA})^2 - 0.0011(\text{AS})^2
\]

\[
A = 4.0 - 0.0713(\text{OFA}) + 0.183(\text{AS}) - 0.000353(\text{OFA})(\text{AS}) + 0.000142(\text{OFA})^2 - 0.000082(\text{AS})^2
\]

\[
n = -24.9 - 0.075(\text{OFA}) + 0.564(\text{AS}) - 0.001(\text{OFA})(\text{AS}) + 0.00028(\text{OFA})^2 - 0.00031(\text{AS})^2
\]
Table 6. Properties of coarse and fine aggregate.

| Regression Model Parameters | Strength $(\sigma)$ | Slump $(S)$ | Absorption $(A)$ | Porosity $(n)$ |
|-----------------------------|---------------------|-------------|------------------|---------------|
| Mean square error           | 0.5386              | 4.02        | 0.295            | 0.69          |
| R (correlation coefficients)| 98.45%              | 85.62%      | 90.58%           | 90.11%        |
| $R^2$                       | 96.92%              | 73.3%       | 82.04%           | 81.2%         |
| F-test value                | 31.45               | 5.32        | 6.57             | 5.3           |
| Significance                | 0.001               | 0.05        | 0.04             | 0.5           |
| $\beta_0$                  | 36.2                | -30         | 4.0              | -24.9         |
| $\beta_1$                  | 0.239               | -0.317      | -0.0713          | -0.075        |
| $\beta_2$                  | -0.759              | 1.67        | +0.183           | +0.564        |
| $\beta_{12}$               | 0.00165             | -0.00313    | -0.000353        | -0.001        |
| $\beta_{11}$               | -0.00057            | +0.000937   | +0.000142        | +0.00028      |
| $\beta_{22}$               | 0.000234            | -0.0011     | -0.000082        | -0.00031      |

Figure 12. Variation of compressive strength with ash and alkali content (Quadratic model).

Figure 13. Variation of slump with ash and alkali content (Quadratic model).

Figure 14. Variation of absorption with ash and alkali content (Quadratic model).

Figure 15. Variation of porosity with ash and alkali content (Quadratic model).
4.3. SGC versus conventional concrete
In this study, two types of concrete were designed to have minimum concrete strength 30 MPA. All test of concrete performance such as $\sigma$, S, A and n were measured for both concrete. The results indicate that proposed sustainable concrete (SGC) have strength higher than the conventional concrete. The results also indicate that the absorption and porosity of SGC are lower than that of conventional concrete. This new proposed concrete could replace conventional concrete and provide additional advantages by recycling a large amount of olive oil waste and solve several environmental problems associated with this waste in Jordan as well as in many other Mediterranean countries. Despite all these advantages, SGC shows lower slump in compare with conventional concrete. In addition, the loss of slump with time is very high this will make difficulties in construction sites. This problem could not allow enough time for workers to cast concrete. Also, this short time in fresh condition will not be enough for ready mix industry to transport concrete from factory to construction site. Further research is needed to solve the problem of low slump and slump loss in future will be necessary.

5. Conclusion
In this paper new sustainable concrete was produced from olive oil waste ash. This new type of concrete recycles olive waste ash which form an environment and health problems in Jordan. The new SGC concrete possess a superior performance in terms of compressive strength and durability in compare with conventional Portland cement. In addition, this SGC concrete does not emit CO$_2$ in production like conventional cement binder. Despite all these benefits SGC concrete has low sump and workability. SGC also lose the workability and slump very fast and in short time. This is a desirable property for construction industry. Further research is needed to solve this problem is necessary.

6. References
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