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Utilization of Olive Mill and Medical Waste Ash in Cementitious and Concrete Mixtures Reinforced with Natural and Synthetic Fibers

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Abstract

This study investigates the potential of incorporating olive waste ash (OWA), derived from the combustion of agricultural by-products in Jordan, as a supplementary cementitious material (SCM) in concrete and mortar mixes. In addition to OWA, medical waste ash was also evaluated to explore sustainable alternatives to Ordinary Portland Cement (OPC), a major contributor to global CO_2 emissions. The effects of different ash sources and replacement percentages (5%, 10%, 15%) on workability, pozzolanic activity, mechanical strength, and thermal conductivity were analyzed. Furthermore, the influence of natural (Date Palm Fibers) and synthetic (Polypropylene) fibers on the mechanical and thermal performance of the cementitious composites was examined. Results of mortar samples demonstrated that while higher ash content generally reduced compressive strength and workability, certain mixes—particularly those with 10% OWA—maintained competitive strength and exhibited improved thermal insulation. However, the addition of fibers in combination with OWA in a concrete mix showed no effect on the mechanical properties and thermal conductivity. This work highlights the viability of utilizing locally sourced agricultural and industrial waste materials to develop environmentally friendly and thermally efficient construction materials.

Keywords: Supplementary Cementitious Materials, Fiber Reinforced Concrete, Olive Waste Ash, Sustainability, Date Palm Fibers.

1. Introduction

Concrete is extensively utilized as the primary construction material for buildings and infrastructure due to its notable characteristics such as strength, versatility, and cost-effectiveness. However, in its current production state, concrete is currently regarded as a non-sustainable material because of its reliance on non-renewable resources in its production process [1]. Furthermore, most concrete mixtures include Ordinary Portland Cement (OPC) in their composition as the primary binder material. OPC is responsible for the emission of large amounts of CO_2 during its production and application phases which is detrimental to the environment. Estimates indicate that the cement industry is responsible for 5-7% of global CO_2 emissions [2–4]. CO_2 emissions from cement production processes can be divided into direct and indirect emissions [3]. Direct emissions are due to the fossil fuel combustion needed to burn the clinker as well as the CO_2 that results from the decomposition of $CaCO_3$. Whereas the indirect CO_2 emissions are generated by usage of electrical energy as well as the vehicles transporting the produced cement. Therefore, various measures utilizing alternative technologies in the cement production process are considered by the scientific community as well as the industry to reduce CO_2 emissions [5,6].

One of the measures taken to reduce CO_2 emissions from cement production process is the use of alternative materials as supplementary cementitious materials (SCM). The use of SCMs as a partial replacement of cement has been described as the most practical and economical measure, as well as having the highest potential to reduce the use of cement in concrete [3,4]. Furthermore, by-products of industrial and agricultural processes that can serve as SCMs such as Fly Ash (FA), Ground Granulated Blast-furnace Slag (GGBS), Silica Fume (SF), and biomass ash have an additional environmental advantage due to either recycling of waste materials or the use or renewable resources. Certain materials such as FA, GGBS, SF, and rice husk have been extensively used as partial replacement of cement in concrete [7–10]. The use of biomass ashes is a particularly attractive SCM option as the actual biomass serves as a renewable energy source and the resulting ashes of their combustion, which can be harmful to the environment, are utilized in cementitious mixes due to their pozzolanic activity.

Different types of biomass ash have been utilized in the development of concrete and cementitious materials such as date palm ash [11], bamboo leaf ash [12], rice husk ash [7], and palm oil fuel ash [13]. The choice of these materials is usually dependent on the type of biomass that is available locally in the region where the research originates from. Jordan is a large producer of olive oil, with an estimated 15-20% of all land planted with olive trees. The production of

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these trees is estimated to be around 154,000 tons where 22% are produced in the form of table olives and 78% as olive oil [14]. The process of extracting olive oil results in large amounts of waste material often referred to as olive mill waste (OMW). This waste can make up to 80% of the initial weight of the harvested olive fruit and is divided into pomace, which is a combination of husk and pulp, and olive mill wastewater that results from the extraction process [15,16].

One way to restore some of the waste is by incinerating the solid OMW to be used as fuel in the olive mill or households to obtain thermal or electric energy through combustion [17,18]. This process results in olive waste ash that can have a harmful effect on human health in the form of respiratory problems due to inhalation of this ash or contamination of ground water by leaching heavy metal contents of ash [19,20]. The ash produced as a result of biomass combustion can be incorporated into concrete mixtures as a partial replacement of cement.

Al-Akhras et. al. (2010) studied both the physical and mechanical characteristics of mortars containing different percentages of Olive Biomass Bottom Ash (OBBA)[21]. The study showed that physical attributes such as workability and setting time decrease with increasing OBBA percentage. While the compressive and flexural strength increases when OBBA is used as a replacement of sand and decreases when used as a replacement of cement. Furthermore, Alkheder et. al. (2016) showed that increasing the amount of OBBA used in a cement paste decreases both the compressive and flexural strengths. This was attributed to the retarding effect that the waste has on the hydration process as well as the decrease in bond between the surfaces of the waste and the cement paste [16]. Similar conclusions were reached by Ghazzawi et. al. (2024) and Belaidi et. al. (2025) where the increase in OWA percentage as OPA replacement led to deterioration in mechanical properties of the resulting mortar paste [22,23]. Moreover, Tayeh et. al. (2021) showed that both workability and compressive strength of concrete decrease when OBBA percentage increase in the mix [24].In more recent developments, OWA has been utilized to produce high-strength geopolymer concrete by partially replacing FA and GGBS. The study showed that at certain replacement percentages, a denser microstructure of the geopolymer can be obtained which leads to higher compressive strengths [25]. Furthermore, OWA has been utilized in geopolymer cements as an activator instead of typical commercial activators such as KOH[26]. This use of OWA enhances the sustainability of geopolymer concretes by eliminating the usage of activators with hazardous impact on the environment.

Crushed Olive Kernels (COK) have been used as sand replacement for mortar and concrete production[2,27]. It was shown that mechanical properties generally decline while thermal properties are improved. The thermal properties of OBBA as an additive has been shown to strongly influence the thermal isolation in building bricks [28]. It was shown that thermalconductivity drops due to the porosity and bulk density of building blocks incorporating OBBA. Although bricks incorporating OWA show improved thermal conductivity, Lebaied (2025) showed that they suffer from declining compressive strength as the percentage of OWA increases [29].Thermal conductivity in self-compacting mortars was improved through using crushed olive kernels as fine aggregate [27]. This work will investigate thermal conductivity of concrete and mortar mixtures containing Olive Waste Ash (OWA) as a SCM.

Natural fibers have been employed as reinforcement in Fiber Reinforced Concretes (FRC) instead of conventional fibers because of its renewable and recyclable nature. Thus, the environmental cost in terms of CO_2 emissions can be reduced. For example, 3.7 tons of CO_2 are generated to produce 1 ton of polypropyelene (PP) fibers, whereas jute fibers absorbs CO_2[30]. Additionally, natural fibers provide excellent mechanical properties such as high yield at a lower processing cost [31,32]. Coconut and basalt fibers have been utilized in lightweight concrete to produce thermally efficient buildings [33]. It was observed that thermal conductivity decreased as the fiber percentage increases. In a study conducted by Shah et. al. (2022), it was noticed that natural FRCs are influenced by various factors such as length, treatment, structure, and hybridization of the fibers integrated within the cementitious matrix [32]. In general, the compressive strength of natural FRC tends to decrease when fiber percentage is increased when compared to unreinforced concrete [33–35]. Flexural strength, on the other hand, tends to increase up to a certain optimal value when natural fibers are added to concrete. However, exceeding this optimum fiber content can result in a decline in flexural strength [36–38]. Moreover, the addition of pozzolanic materials such fly ash and silica fume can improve the compressive strength of natural FRCs [9,35,39]. However, several concerns are associated with the use of natural fibers in FRC. The long-term durability due its organic nature, lower workability, and the weak bond at the fiber-cement paste interface [37–40].

This work intends on utilizing natural and sustainable materials as SCM's to develop environmentally friendly concrete and mortar mixtures. The SCM's will be sourced from agricultural, OWA, and industrial, medical waste, by-products. They will be used to partially replace cement thereby eliminating the detrimental effects of these airborne materials. OWA will be sourced from different geographic locations within Jordan to examine whether that influences the characteristics of the developed cementitious mixtures. Additionally, natural, Date Palm Fibers (DF),and synthetic fibers, PP fibers, will be used as reinforcement to concrete containing OWA to study their effect on mechanical and thermal properties. The pozzolanic activity of the SCM's used in this study will be assessed both mechanically and chemically. The workability of the developed mortars will be assessed. Mechanical characterization will be carried out in the form of compressive and flexural strength tests. The thermal characteristics of the developed cementitious mixtures will be studied by examining their thermal conductivity.

2. Materials

2.1. Materials

2.1.1. Cement

A concrete mix was prepared using CEM I (Ordinary Portland Cement), which was sourced from a local manufacturer in Amman, Jordan. The cement conformed to ASTM C150 specifications and had a specific gravity of 3.14. The chemical composition is shown in Table 1.

Table 1. The chemical composition

Chemical compositions (wt. % of cement)	OPC
SiO_2	17.6
$Al2O_3$	4.3
Fe_2O_3	2.97
CaO	61.0
MgO	0.87
SO_3	4.14
Na_2O	0.34
K_2O	0.26
Blaine surface area (cm2/g)	3765

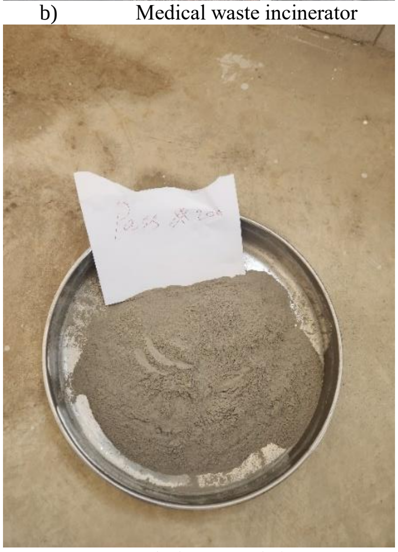
2.1.2. Mineral admixtures

The ash collected from agricultural and industrial by-products were used as cement replacements in mortar and concrete mixtures. Agricultural by-products were acquired from olive mills in various locations within Jordan, whereas industrial by-product was collected from the medical waste incinerator at Jordan University of Science and Technology (JUST). The OWA was acquired in the form of both fly and bottom ash from boilers of local olive mills in Irbid and Tafila governates in Jordan. Olive cake (pomace) from the previous harvest season is used as the primary fuel for the combustion boiler in order to provide hot water for the processes that take place in the olive mill as shown in Figure 1a. The OWA was grinded using LA abrasion machine to produce a finer material shown in Figure 1c. The LA abrasion machine is filled with steel balls and as the drum rotates the balls collide simulating wear and tear to aggregates.It was then sieved and only the particulate materials that passed sieve #200, shown in Figure 1d, were used. Figure 1b shows the Hoval pyrolysis incinerator at JUST which incinerates medical waste collected from health establishments across Jordan. Fly ash was collected from this incinerator and the same process of grinding and sieving was applied to it. Table 2 shows a summary of waste ash used in this work.

a) Olive cake in a boiler

b) Medical waste incinerator

c) LA abrasion machine



d) Ash that passed sieve #200

Figure 1. Waste ash used in the work during the incineration process in a) the olive cake boiler and b) pyrolysis incinerator. The resulting ash was grinded in c) LA abrasion machine, and then it was sieved so that only d) ash that passed sieve #200 remained.

Table 2. summary of waste ash used in this work.

Material	Waste type	Location	Picture
Fly ash	Industrial	JUST	
Fly ash	Agricultural	Irbid	
Bottom ash	Agricultural	Irbid	
Bottom ash	Agricultural	Tafila	

2.1.3. Aggregates

Crushed limestone with a maximum particle size of 12.5 mm, a specific gravity of 2.62, and a water absorption of 2.59% was used as the coarse aggregate. Well-graded natural river sand with a maximum particle size of 5 mm, a specific gravity of 2.62, and a water absorption of 1.9% was utilized as the fine aggregate.

2.1.4. Fibers

Natural and synthetic fibers were used in this work. Date palm fibers (DF) are the natural fibers and were attained from locally grown palm trees around Amman, Jordan. DF grows in a mesh form around the trunk of the tree from where it was collected and varied in length and diameter. They were then treated with a 3% sodium hydroxide aqueous solution to eliminate any traces of remaining organic matter such as lignin, pectin, and wax among other substances. This fiber treatment is meant to enhance the bond between the fiber and the surrounding matrix [41]. The fibers were then rinsed multiple times with deionized water and dried in the oven at 60 ºC for 24 hours. Next, the fibers were manually cut to lengths between 50 – 60 mm approximately. Figure 2 shows the date palm fibers prior to chemical treatment Fig. 2a and after the treatment Fig. 2b.

(a) (b)

Figure 2. Date palm fibers a) prior to treatment and b) after treatment

Polypropylene (PP) fibers were supplied from Fosroc®, Jordan. They are 12 mm long with tensile strength and elastic modulus of 350 MPa and 3,500 – 4,800 MPa, respectively, and excellent cement compatibility. The primary goal of fiber addition to the cementitious mixture is to investigate whether there is a synergistic effect that results from combining fibers with mineral admixtures.

2.1.5. Chemical admixture

Master Glenium 51, a high range water reducer, also known as superplasticizer (SP), that is polycarboxylic ether based with specific gravity of 1.1 g/cm^3, was used in the concrete mix in this work.

2.1.6. Cementitious mixtures

The mortars were prepared using a 1:2.75binder to silica sand ratio following ASTM C305 with a constant water: binder (w/b) ratio of 0.7. The binder consists of the cement and the mineral admixtures shown in Table 1 as they were used as cement replacement at three different percentages by mass: 5%, 10%, and 15%. Therefore, a total of 13 mixes including the control mix were produced as shown in Table 2.

Table 2. Mortar mix proportions

Mix	Cement (g)	Sand (g)	Water (mL)	Ash (g)
Reference	298	819.5	209	0
5%	283.1	819.5	209	14.9
10%	268.2	819.5	209	29.8
15%	253.3	819.5	209	44.7

The mineral admixtures used in concrete mix design, however, consisted of mixing all the OWA together and utilizing them as a cement replacement by mass. This was done to test the feasibility of this replacement if done at a large-scale production, in addition to the abundance of olive cake in Jordan which is incinerated to produce the OWA. Eight concrete mixes were created to study the effect of OWA as a cement replacement and also to study the combined effect of using both fibers in addition to the mineral admixture. More details regarding the mix design can be found in Table 3. The subscript next to OWA in mix name signifies the percentage of cement replacement by OWA. The addition of fibers is identified by using PP to indicate the use of polypropylene fibers, whereas DF indicates the use of date palm fibers.

2.3 Sample preparation and curing

Mortar samples were prepared using a stand mixer. The water and cement were added to the mixing bowl and were mixed at a slow speed for 30 seconds. Sand was then added over a period of 30 seconds. The mixing speed was then changed to medium, and the mortar was mixed for another 30 seconds. The mix was then left at rest for 90 seconds and the contents were scraped of the sides of the bowl. Finally, the mixing was resumed at medium speed for another 60 seconds. Mortar was then cast in two layers according to ASTM C109/109M-16a in 5 cm cubes and in 5x10 cm cylinders.

Table 3. Proportion of concrete mixtures (Kg/m3)

Mix	OWA (Kg)	Cement (Kg)	Water (Kg)	w/b	CA (Kg)	FA (Kg)	SP (%)	Fibers (%)
OWA_0	0	390.4	182	0.46	931.5	739.1		0
OWA_5	19.52	370.8	182	0.49	931.5	739.1		0
OWA_{10}	39.04	351.3	182	0.52	931.5	739.1		0
OWA_{15}	58.56	331.8	182	0.55	931.5	739.1		0
$OWA_{0\text{-}PP}$	0	390.4	182	0.46	931.5	739.1		2
$OWA_{10\text{-}PP}$	39.04	351.3	182	0.52	931.5	739.1		2
$OWA_{0\text{-}DF}$	0	390.4	182	0.46	931.5	739.1		2
$OWA_{10\text{-}DF}$	39.04	351.3	182	0.52	931.5	739.1		2

A rotary drum was used to prepare the concrete mixture. First, fine and coarse aggregates were added to the mixer with a part of the water and were left for 2 minutes. Then the cement was added along with the pozzolanic materials and were mixed for an additional two minutes. Finally, the SP with the remaining amount of water were added to the mix and left for another minute. Concrete samples were poured into 10x30 cm cylinders and 15x15 cm cubes. Both types of samples were cast in three layers and were compacted using a tamping rod. All samples, mortar and concrete, were left for a day at room temperature before demolding. The samples were then submerged in water for the duration of their curing as shown in Fig. 3a and 3b. Mortar samples were cured for 28 days, whereas concrete samples were cured for 7, 28, and 90 days. Concrete cylinders were sulfur capped after their curing was over for compressive testing as shown in Fig. 3c.

3. Methods

3.1. Pozzolanic activity

The strength activity index (SAI) was calculated based on the control mortar mix. It is the percentage ratio of the strength of specimen with OWA to that of control mortar mix.

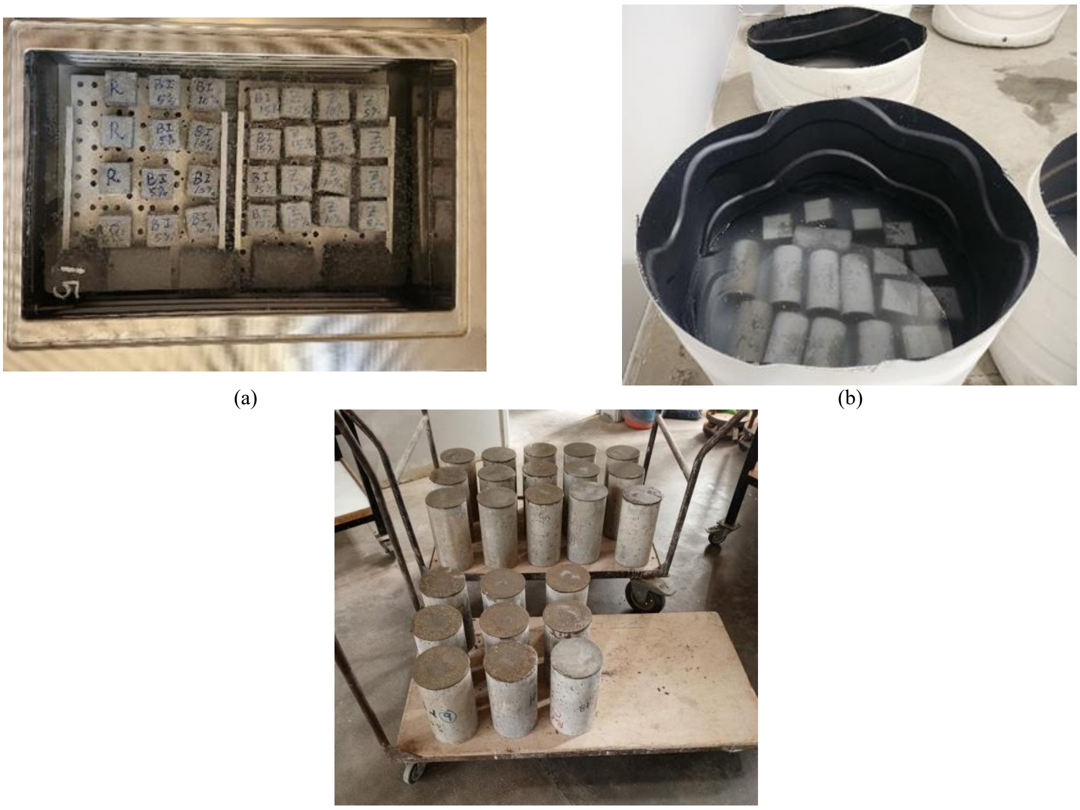
$$SAI = \frac{Compressivestrengthofmineraladmixturemortar}{Compressivestrengthofreferencemortar} X\ 100$$

3.2. Flowability

The workability of the mortars used in this work were studied through the flow table test according to ASTM C230. Two samples of each category were tested leading to a total of 26 samples.

3.3. Mechanical testing

Mortar samples were tested at 28 days in compression to evaluate their strength following ASTM C109.Compression and split tension tests were used to characterize the mechanical properties of concrete samples shown in Figure 4a and 4b following ASTM C39 and ASTM C496, respectively. The compression samples were tested at 7, 28, and 90 days, whereas the split tension samples were tested at 90 days. Controls model 50-C4632 with a capacity of 2000 kN was used in testing the samples in a force-controlled manner at a rate of 1600 N/s. Three samples were tested for each mechanical test conducted in this work in all categories. A total of 39 tested samples for compressive strength of mortar, 48 samples for compressive strength of concrete, and 24 samples for the splitting strength of concrete.



(a) (b) (c)

Figure 3. (a) curing of mortar samples (b) curing of concrete samples (c) sulfur capped concrete cylinders

(a) (b)

Figure 4. (a) Compression test (b) Split tension test

3.4. Thermal conductivity

Thermal conductivity coefficient of both mortar and concrete samples was evaluated using Thermtest Transient Line Source TLS-50 which employs a needle probe method. This portable thermal conductivity meter simplifies the testing process, enabling efficient evaluation of thermal conductivity in accordance with ASTM D5334-14. Concrete and mortar cylinders measured 100 X 300 mm and 50 X 100 mm, respectively, were used to measure thermal conductivity. Mortar samples were evaluated at 28 days while concrete samples were evaluated at 7, 28, and 90 days. Three samples were tested for each category leading to a total of 72 samples for concrete and 39 samples for mortar. A hole was drilled at the top of the samples in order to insert the probe to take measurements of the temperature history vs. logarithmic time from which the coefficient k was calculated. Figure 5 shows the testing of thermal conductivity of a mortar sample.

4. Results and discussion

Figure 6 shows that the flowability of mortar samples decreases as the percentage of mineral admixture increases. At 5% cement replacement, it can be seen that T, FI, and BI exhibited better or similar flowability to the reference sample at 5%, 10%, and 15% cement replacement. This can be ascribed to the lower surface area of these mineral admixtures when compared to cement which lowers the water demand. On the other hand, JF showed overall lower levels of flowability which indicates higher water absorption caused by higher surface area, and high internal friction between the particles of the mixture.

Figure 7 shows the compressive strength of the different mortar samples as well as the strength activity index (SAI) of each sample. The compressive strength tends to decrease as the percentage of mineral admixture increases in JF, FI, and BI. On the other hand, for mortar T, there seems to be an optimum amount that achieves the highest compressive strength for these mortars at 10% cement replacement. JF mortar exhibited the highest compressive strength at 5% cement replacement achieving almost the same strength as the reference sample. Further increment in JF replacement of cement caused durability issues which can be seen in Figure 8 and that is reflected in its compressive strength. This visible deterioration confirms that higher percentages compromise the matrix integrity and long-term durability of JF mortar. BI achieved consistently higher compressive strength when compared to FI mortars at all cement replacement percentages. Moreover, the drop in strength from one percentage to another in BI mortars was less pronounced than in FI mortars. The SAI values of the different mortar samples are indicated on top of each bar in Figure 7.

Figure 5. Testing of thermal conductivity of mortar sample

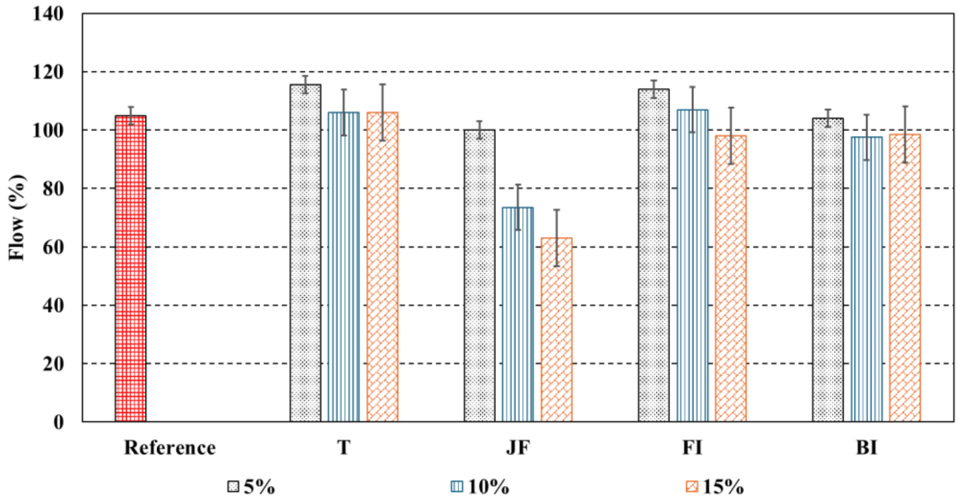


Figure 6. Flowability of mortar samples

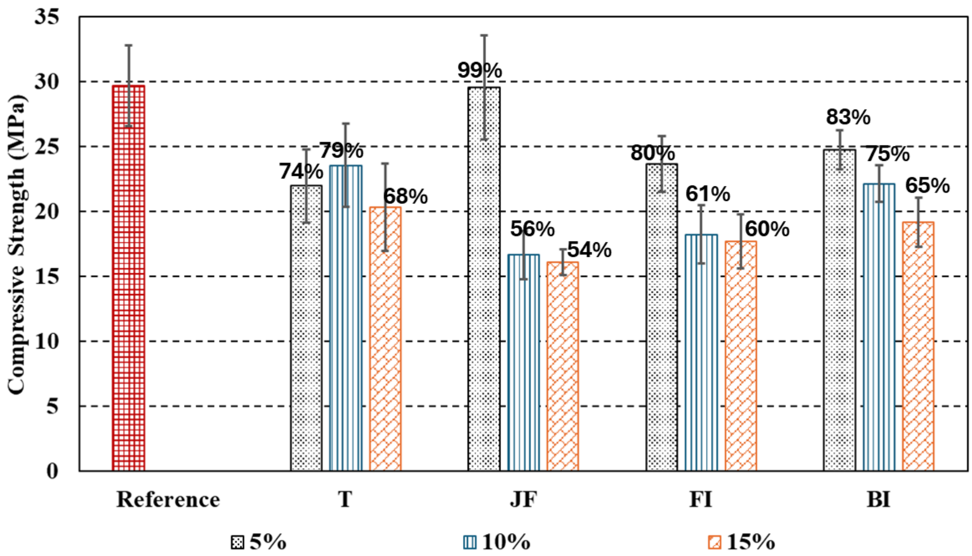


Figure 7. Compressive strength of mortar samples at different cement replacement percentages at 28 days

Figure 8. Deterioration of samples as the percentage of JF increases

Figure 9 shows the compressive strength of the different concrete samples. As the concrete curing age increases, the compressive strength increases for all samples. Additionally, as the replacement percentage of cement increases, the compressive strength decreases. The addition of fibers, PP and DF, to OWA_0 achieves similar compressive strength to that of OWA_0 at 7 days. However, as the concrete cures, the strength increases, and at 28 days, it can be seen that the compressive strength of $OWA_{0\text{-}PP}$ and $OWA_{0\text{-}DF}$ exceeds OWA_0. On the other hand, when fibers are added to 10% cement replacement mixtures (OWA_{10}), the early-age strength (7 days) is slightly improved while the 28-days strength decreases. The reduction in the 28-days strength of these samples indicates that fibers are affecting the curing process through interfering with the hydration of the cementitious mix. Consequently, this leads to bonding issues between the fibrous medium and the surrounding cementitious matrix.

Figure 10 shows the splitting tensile strength of the concrete samples at 90 days. The results show that increasing the percentage of olive waste ash results in lower splitting strength of concrete samples. Furthermore, the addition of fibers to the reference sample (OWA0) improved the splitting strength, with date palm fibers (DF) outperforming polypropylene (PP). On the other hand,OWA10 achieved similar splitting strength when PP and DF fibers were used in the mix. This suggests bonding issues between the fibrous materials and the surrounding matrix when OWA is present in the cementitious mixture.

A scanning electron microscope (SEM) was not employed because the primary objective of the paper was to evaluate the mechanical performance of the cementitious mixtures developed in this work. Although SEM would have provided valuable details regarding the microstructure of the cementitious matrix and the fiber-cement interface specifically, it did not limit the validity of the findings and the observations of the authors. Furthermore, the use of SEM would prove valuable in future work where a more detailed analysis of the microstructure will be considered.

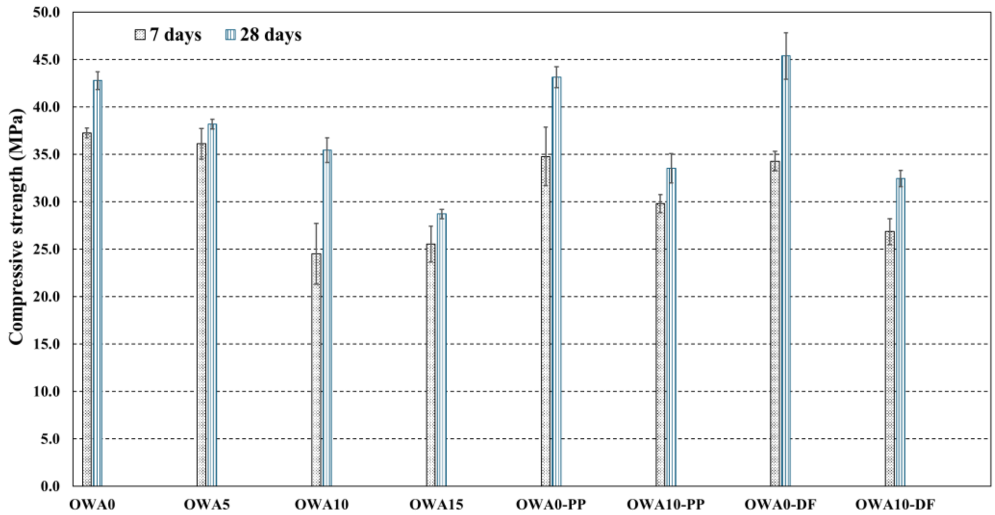


Figure 9. Compressive strength of concrete samples at both 7 and 28 days

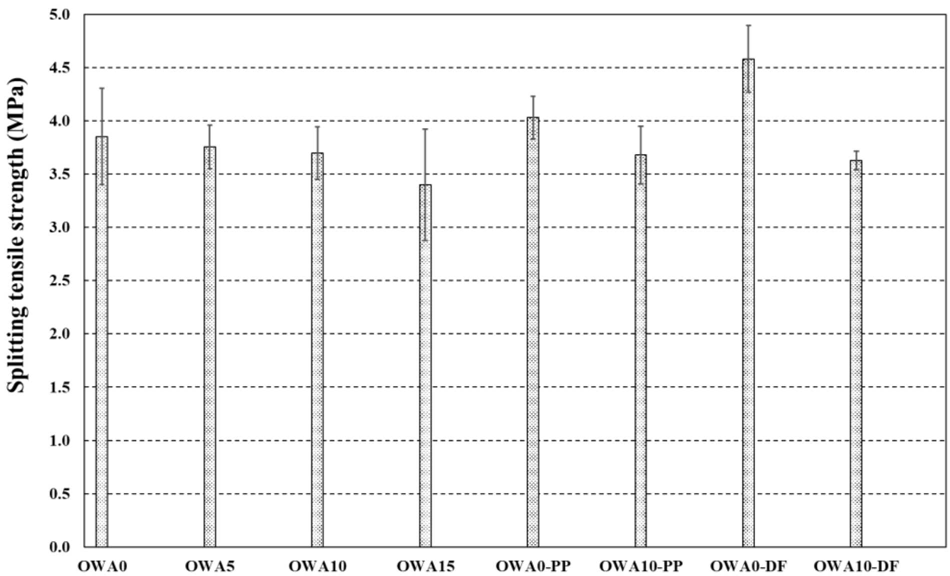


Figure 10. Splitting tensile strength of concrete samples at 90 days

The values of thermal conductivity for mortar samples are shown in Figure 11. The addition of agricultural waste lowers the thermal conductivity as opposed to medical waste which causes the thermal conductivity to increase when compared to the reference sample. For medical waste (JF), as the percentage of ash increases the thermal conductivity decreases. This trend is also noticed in T. Conversely, in FI and BI samples, which have the same origin, the thermal conductivity is either maintained or slightly increases as the cement replacement percentage increases.

Figure 12 shows the thermal conductivity of concrete samples at 7, 28, and 90 days of age. Thermal conductivity increases as the age of concrete increases for all samples. Furthermore, increasing the mineral admixture to the reference sample does not have a significant effect on thermal conductivity at 7 and 28 days. However, at 90 days the thermal conductivity of reference sample is noticeably higher than samples with OWA as cement replacement. The addition of polypropylene fibers seems to increase the thermal conductivity at 90 days of age when added to the reference mix while it remains the same at 7 and 28 days. Conversely, the addition of date palm fibers lowers the thermal conductivity at 90 days while slightly increasing thermal conductivity at 7 days. Furthermore, date palm fibers addition to 10% cement replacement mix had no effect on thermal conductivity. On the other hand, the addition of PP fibers to 10% cement replacement mix showed lower thermal conductivity at 7 days. However, at 90 days of age the thermal conductivity increased when compared to the OWA_{10} and $OWA_{10\text{-}DF}$ concrete mixes.

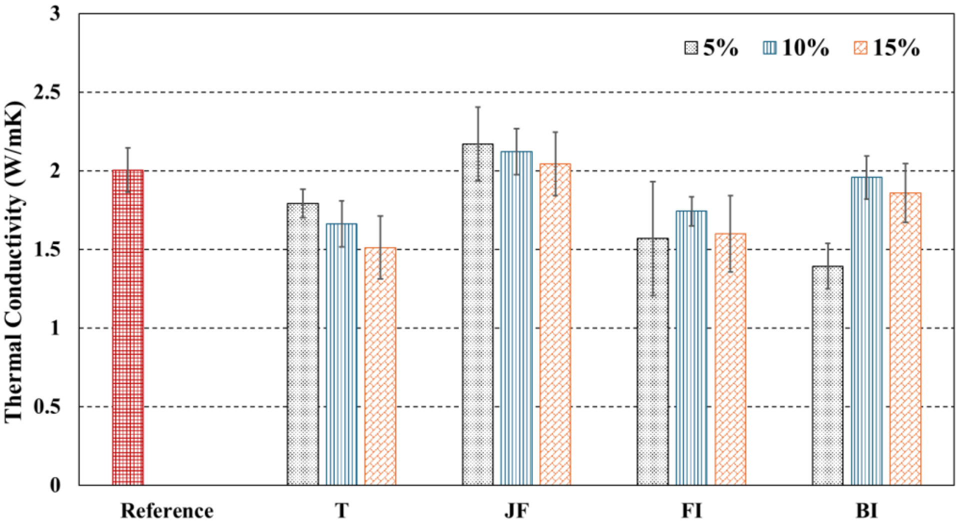


Figure 11. Thermal conductivity of mortar samples at 28 days

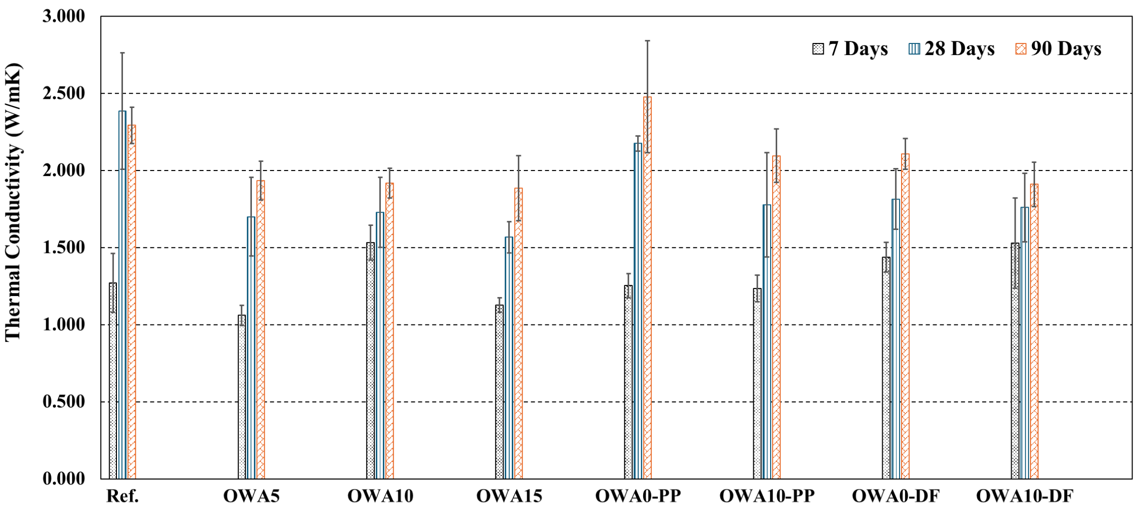


Figure 12. Thermal conductivity of concrete samples at 7, 28, and 90 days

5. Conclusions

This study explored the use of olive waste ash (OWA), derived from agricultural by-products, and selected fiber reinforcements, natural (date palm fibers) and synthetic (polypropylene), as partial substitutes for cement in mortar and concrete mixtures. The findings demonstrate that increasing the percentage of OWA generally leads to reduced workability and compressive strength. However, agricultural OWA, particularly from Tafila, maintained acceptable flowability and exhibited optimal mechanical performance at a 10% replacement level. This suggests that moderate replacement levels can achieve a balance between sustainability and structural integrity.

The incorporation of fibers into concrete mixtures had a notable impact on mechanical properties. Date palm fibers significantly enhanced the splitting tensile strength of the control mix, outperforming polypropylene fibers. Nevertheless, this reinforcing effect diminished when fibers were combined with concrete mixtures containing 10% OWA, indicating potential interactions between the ash content and fiber-matrix bond characteristics.

Thermal conductivity measurements revealed that the addition of agricultural OWA contributes to a reduction in heat transfer, particularly at later curing ages. The inclusion of date palm fibers further improved thermal insulation properties, whereas polypropylene fibers had a minor opposite effect, slightly increasing thermal conductivity due to their material density.

In conclusion, the results support the viability of using locally sourced agricultural waste, specifically OWA at a 10% cement replacement rate, in combination with date palm fibers to develop environmentally friendly, thermally efficient, and structurally sound construction materials. This approach offers a practical pathway toward more sustainable concrete technologies by simultaneously reducing CO_2 emissions and utilizing abundant waste materials in Jordan.

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