Investigating Olive Waste Ash as a Sustainable Additive in Rigid Pavement Design

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Abstract: One of the effective solutions to help the environment, which is of great importance, is the possibility of reusing organic waste. Effective recycling of waste can contribute to environmental preservation. This study was conducted to examine the potential use of olive waste ash (OWA) as an additive to improve the performance of rigid pavements. In this research, olive waste ash was added to the concrete mix in quantities of 3, 6, 9, and 12 percent by weight of cement. The results of laboratory tests showed that adding 3 percent of OWA, despite an 8 percent reduction in compressive strength (which is less significant in concrete used for rigid pavements), led to an increase in tensile strength, which plays a key role in improving the performance of rigid concrete pavements. On the other hand, the use of this additive increased the air void percentage in the concrete mix, which improves the concrete surface's resistance to freeze-thaw cycles. Therefore, using small amounts of this waste, in addition to increasing the service life of rigid concrete pavements, plays a beneficial role in helping the environment and reducing the costs of disposal of organic and agricultural waste.

Keywords: Concrete, Olive waste ash, OWA, Rigid pavement, Aggregate.

1. Introduction

Tunisia, like other countries such as Spain, Italy, Greece, Turkey, and Jordan, has a long tradition of cultivating olive trees, primarily for olive oil production. With the growing global demand for olive oil, the expansion of olive plantations and mills is expected to increase. These mills, however, generate significant amounts of olive waste, including Olive Waste Ash (OWA) produced from burning for heating during winter. Currently, OWA is disposed of in landfills, posing environmental risks such as groundwater contamination. Recycling this waste into construction materials offers an eco-friendly disposal solution, reducing landfill use and supporting sustainable development. Concrete, one of the most widely used building materials globally, is essential in the construction of infrastructure such as pavements, roads, and buildings.

Traditional concrete used in modern construction industries has some inherent drawbacks, such as high porosity, which makes it vulnerable to liquid and chemical attacks, particularly from chloride-based substances.

Over the years, many researchers have explored the use of various additives to improve the strength and durability of concrete, aiming to reduce repair and maintenance costs. Among these additives are fly ash, a by-product of coal combustion, as well as rice husk and wheat straw, which have all been studied for their potential to enhance concrete properties and performance (Tayeh et al., 2021).

Previous studies have shown that adding fly ash to concrete improves its durability and strength, particularly for rigid pavements and building materials. However, research on the potential of OWA in concrete mixes remains limited (Zhang et al., 2022). Recent studies on olive oil waste ash have yielded promising results, enhancing properties in cement mortars, reducing alkali-silica reactions, and improving concrete performance at high temperatures (Al-Akhras and Abdulwahid, 2010). Despite its benefits, most OWA still ends up in landfills, creating an environmental burden. This paper explores the use of OWA as an additive in rigid pavement concrete, focusing on its impact on workability, strength, and durability. By repurposing this abundant waste material, OWA can help address environmental issues while contributing to sustainable construction practices.

Khedaywi et al. (2020) examined the effects of OWA on asphalt cement and concrete mixtures. Using varying OWA amounts (0%, 5%, 15%, and 20%) with asphalt cement, limestone, and valley gravel aggregates, they tested physical properties like penetration, ductility, softening point, and specific gravity. Marshall and dynamic creep tests were conducted at different temperatures and load frequencies. Results showed that higher OWA reduced penetration and ductility but increased softening point and specific gravity. While Marshall Stability improved up to 10% OWA, it decreased beyond that, and the dynamic modulus dropped with higher OWA, temperature, and load frequency.

Al Qadi et al. (2021) studied the effect of Olive Husk Ash (OHA) on asphalt concrete mixtures. They added OHA at levels of 0%, 5%, 10%, 15%, and 20% by volume to the asphalt binder and used the Marshall Test. The results showed that OHA improved Marshall Stability and voids in mineral aggregate, while reducing flow, retained stability, stiffness, and retained stiffness at 10%-15% OHA. The study suggests that OHA can be an effective material for pavement construction, offering benefits to the asphalt industry.

Dahim et al. (2022) investigated the use of olive oil waste fly ash in concrete to create a sustainable material for pavements and construction. They replaced cement with olive ash at levels ranging from 0% to 12.5%. The results showed that while olive ash reduced workability, concrete strength and durability improved up to 7.5% replacement, beyond which strength declined. The optimal replacement was found to be 7.5%, which enhanced concrete by lowering the water-cement ratio and filling voids. This study highlights the potential to reduce costs, recycle waste, and improve concrete performance.

Haddad and Khedaywi (2023) studied the impact of OHA on the dynamic creep behavior of asphalt concrete. They added OHA at 5%, 10%, 15%, and 20% by volume to the asphalt binder and conducted creep tests at different loading frequencies (1, 4, and 8 Hz) and temperatures (5°C, 25°C, and 40°C). The results showed that 10-15% OHA improved the asphalt concrete's resilient modulus, creep stiffness, and reduced accumulated strain, making it a cost-effective and sustainable additive for asphalt production.

Burned olive waste was added by Attom et al. (1998) to improve the qualities of the subgrade. The impact of adding this trash at a replacement ratio of 2.5% by weight to four different types of black cotton soil was assessed by looking at changes in mechanical properties, compaction energy, water content, and physical qualities. The study's findings demonstrated that adding garbage improved the workability of all soil samples by lowering their plasticity index (PI). Fine burnt olive waste particles filled the porous structure of black cotton soil at a 2.5% replacement ratio, increasing the maximum dry density (MDD) and improving the unconfined compressive strength (UCS). The density decreased with additional replacement. The low specific gravity of the trash was blamed for this behavior.

A study by Khedaywi et al. (2021) sought to assess how Olive Husk Ash (OHA) affected the asphalt binder's ductility, penetration, softening point, fire and flashpoint, and specific gravity. OHA was added to asphalt-cement at different concentrations (0%, 5%, 10%, 15%, and 20%)

in their investigation. Tests were conducted to determine how OHA affected the asphalt-cement binder, and the findings showed that a higher OHA content increased the binder's specific gravity, softening point, fire and flashpoints, and decreased penetration and ductility.

The function of fly ash, a byproduct of burning coal to generate electricity, as an addition for asphalt concrete mixes is examined by Abdul Rahman et al. (1991). They investigated how the robust modulus and rut depth properties of asphalt concrete mixes were impacted by the fly ash particle size, aggregate gradation, and binder concentration. They came to the conclusion that the medium size (1 to 44) was the ideal extender because it gives the mix the right amount of stiffness and air spaces.

Al-Massaid et al. (1994) assessed the impact of the asphalt concrete mixture and olive husk asphalt binder. distinct amounts of olive husk (OH) were mixed with three distinct kinds of aggregate (granite, limestone, and basalt). According to the results, adding OH up to 10% of the total weight of the binder would decrease penetration at low temperatures and improve penetration at high ones. It was determined that the olive husk lowers the ideal binder content while increasing workability, stability, durability, and resistance to stripping.

The testing of hot mix asphalt (HMA) with fly ash in place of 10% asphalt-ash binder was investigated by Sobolev et al. (2013). Presenting ASHphalt as a sustainable solution is a significant step. strategy for constructing infrastructure in the future. The findings demonstrated that the inclusion of fly ash enhanced the asphalt mastics' and mixes' rheological characteristics, as well as the mastics' resilience to aging and thermal relaxation.

The impact of replacing conventional filler in hot mix asphalt with fly ash (FA) was examined by Mistry and Roy (2016). Comparing the combination with 4% FA as the ideal filler content to a conventional mix and standard standards, the results showed a greater stability value with a lower optimal asphalt cement percentage.

Wood ash's physical, chemical, and morphological characteristics were examined by Naik (1999), who discovered that it may be utilized as a chemical activator and pozzolanic mineral additive in cement-based materials. Additionally, he stated that wood ash has a great deal of potential for usage in the manufacturing of roller compacted concrete pavement (RCCP), controlled low strength material (CLSM), and other building materials.

In order to enhance the qualities of rammed earth blocks, Ghanem et al. (2024) investigated the application of OWA. They added cement at 2%, 4%, 6%, and 8% and substituted OWA for soil at 10%, 20%, 30%, and 40% by weight. Proctor, California Bearing Ratio (CBR), and unconfined compressive strength (UCS) tests were performed over 7, 28, and 56 days. According to the findings, cement enhanced dry density whereas OWA decreased dry density and raised moisture content. OWA increased strength up to 30% replacement, according to UCS experiments, after which strength sharply decreased. It was suggested to use a mathematical model to forecast strength over time. According to the study's findings, OWA can enhance the characteristics of cement-stabilized rammed earth blocks, providing a sustainable building option.

Using waste materials as partial substitutes for natural aggregates is one promising strategy to improve the sustainability of concrete. One possible substitute for fine aggregate in concrete is bottom ash (BA), a byproduct of burning coal in thermal power plants (Singh and Siddique, 2014). In addition to reducing the use of natural resources, using BA in concrete offers a workable way to get rid of this waste, which is usually dumped in landfills and has a negative impact on the environment.

The impacts of employing natural rubber latex (NRL) as a modifier in concrete and basalt aggregates (BA) in place of river sand for sustainable stiff pavements were examined by Kantatham et al. in (2024). According to the study, adding more BA decreased compressive strength, suggesting that although BA may take the role of river sand, overuse could jeopardize structural integrity. However, the study highlighted that the use of BA and NRL encourages high-performance, environmentally friendly concrete, providing a viable option for rigid pavement construction. In order to improve the long-term sustainability of rigid pavements, Samingthong et al. (2023) investigated the synergistic use of NRL and recycled materials (PET and crumb rubber) in concrete.

This research aims to examine the effects of Olive Waste Ash on asphalt and flexible pavements.

2. Methods

2.1. Materials

The obtained OWA that is shown in Figure 1 had a specific gravity of 2.05, and the particles ranged in size from 1-10 µm.

Figure 1. Olive Waste Ash

The wastes of olives were combusted in an oven at a controlled temperature for two hours until they were fully converted into ash (see Figure 2).

Figure 2. Olive Waste Ash

The chemical composition of OWA is given in Table 2. It was high in silica (SiO_2) and other useful oxides for concrete.

Table 1. Chemical composition of cement and olive oil waste ash (OWA).

Chemical Composition	Percentage of Cement	Percentage of OWA
SiO_2	22.84	21
Fe_2O_3	2.62	2.5
Al_2O_3	3.84	4.5
CaO	48.87	30.1
K_2O	-	30
Na_2O	-	0.4
SO_3	-	0
MgO	2.79	5.4
P_2O_5	-	6
LOI	-	2.81

Ordinary Portland cement (OPC) was used to make the concrete for producing grade 30 rigid pavement concrete. The specific gravity of the OPC used in this study was 3.15, and its chemical composition is provided in Table 1. Limestone aggregate, with a maximum aggregate size of 14 mm, was used as the coarse aggregate (Figure 3) for the mix proportion. A control concrete mix was prepared with a water-cement ratio of 0.40. The fine aggregate (Figure 4) used was natural sand, and the gradation of both types of aggregates conformed to ASTM C33-93 (Standard Specification for Concrete Aggregates).

Figure 3. Coarse aggregate used for the mix design

Figure 4. Fine aggregates used for the mix design

Figure 5 represents the particle size distribution of the aggregates. The mixture was prepared in accordance with the standard procedures of ASTM C192 (Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory) for laboratory batching and mixing.

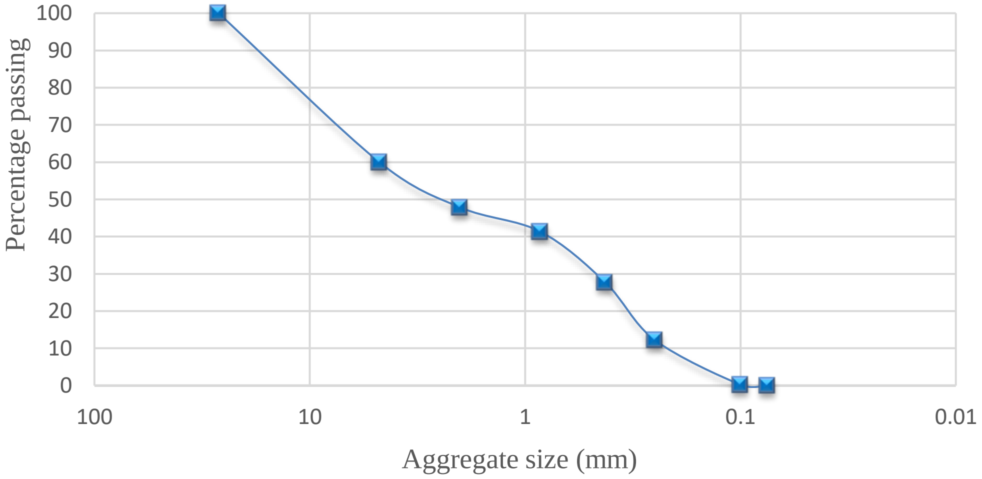

Figure 5. Gradation of limestone aggregate used in this study.

2.2. Design method

To test the effect of adding OWA, twenty-six different concrete mixes were prepared by partially replacing cement in the control mix. The replacement of OWA ranged from 3% to 12%, with an increase of 3%.

The concrete specimens were cured in water (Figure 6) until the day of testing (ASTM C511-21 - Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes). At 28 days of curing, for the Compressive Strength test and Freezing-Thawing test, twenty cube specimens were prepared in the laboratory according to the standards (BS EN 12390-3:2019 - TC | 31 Jul 2019 | BSI Knowledge) and (Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing). For the Splitting Tensile Strength test and Air Voids test, six cylinder specimens were prepared in the laboratory according to the standards (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens) and (Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete).

Figure 6. Concrete specimens cured in water

Table 2. Mix design for a 10x20cm cylindrical mold

Olive Waste Ash (%)	Portland Cement (gr)	Olive Waste Ash (gr)	Fine Aggregate (gr)	Coarse Aggregate (gr)	Water (gr)
0	1131	0	1508	1131	509
3	1097	34	1508	1131	395.85
6	1063	68	1508	1131	395.85
9	1030	101	1508	1131	395.85
12	995	136	1508	1131	395.85

Table 3. Mix design for a 15x15 x15cm cubic mold

Olive Waste Ash (%)	Portland Cement (gr)	Olive Waste Ash (gr)	Fine Aggregate (gr)	Coarse Aggregate (gr)	Water (gr)
0	2430	0	3240	2430	1093.5
3	2357.1	72.9	3240	2430	850.5
6	2284.2	145.8	3240	2430	850.5
9	2211.3	218.7	3240	2430	850.5
12	2138.4	291.6	3240	2430	850.5

2.3 Concrete compressive strength test

The concrete compressive strength test involves casting concrete samples in the shape of cylinders or cubes and curing them for a specific period, typically 28 days. After curing, the samples are placed in a testing machine where they are subjected to a gradually increasing compressive load until they fail. The maximum load at which failure occurs is recorded, and the compressive strength is calculated by dividing this load by the cross-sectional area of the sample (ASTM C39/C39M). The compressive strength test is shown in Figure 7.

Figure 7. Compressive strength test

2.4 Tensile strength test

The Brazilian tensile strength test measures the tensile strength of concrete by applying a diametral compressive load to a cylindrical specimen. The cylinder is positioned horizontally in the testing machine, and a compressive load is applied across its diameter until the specimen fails. The tensile strength is then calculated using the applied load and the dimensions of the specimen (ASTM C496/C496). The tensile strength test is shown in Figure 8.

Figure 8. The tensile strength test

2.5 Concrete air content test

The air content in hardened concrete is measured using the pressure method. In this process, a sample of hardened concrete is placed inside a pressure chamber. The air content is then calculated based on the change in pressure that occurs due to the air voids present in the sample (ASTM C231/C231). The Air content test is shown in Figure 9.

Figure 9. The Air content test

2.6 Concrete freezing and thawing test

The freeze-thaw test for hardened concrete consists of exposing concrete samples to cycles of freezing and thawing in a controlled environment. During this process, the changes in mass and strength of the concrete are measured periodically. Before freezing, the concrete specimens are immersed in water. Each cycle involves freezing the sample and then thawing it under specific conditions (ASTM C666/C666M). The freezing and thawing test is shown in Figure 10.

Figure 10. The Concrete freezing and thawing test

3. Results and Discussion

A series of tests, including compressive strength, tensile strength, durability, and freezing and thawing tests, were performed to assess the effect of OWA on the fresh and hardened properties of concrete. The results of these tests are presented below. These tests aimed to evaluate the impact of this additive on the performance of rigid concrete pavements.

3.1. Effect of OWA on compressive strength

The compressive strength of various concrete mixes was evaluated over different curing periods to determine the impact of adding OWA over time. Figure 11 illustrates the relationship between compressive strength and curing time for different levels of OWA addition. The findings suggest that incorporating OWA into the concrete mix has both advantages and disadvantages. At a 3% replacement level, OWA serves as an effective filler, enhancing the density of the concrete matrix. The fine particles of Olive Waste Ash fill the voids in the mix, which reduces porosity. This improvement supports hydration and the formation of calcium silicate hydrate (C-H-S), the primary binder responsible for strength development in concrete. As indicated, the concrete with 3% OWA achieves a compressive strength nearly equivalent to the control mix after 28 days of curing, demonstrating a balance between mechanical performance and stability. However, at higher amounts of OWA (6% and above), reduced formation of C-H-S, increased porosity, and weaker bonding within the matrix, resulting in a significant decrease in compressive strength. These results align with studies on other agricultural waste ashes, such as fly ash and rice husk ash, which exhibit similar behavior at elevated replacement levels. (e.g., Alyami et al., 2023).

At replacement levels of 9% and 12%, a decrease in microstructural integrity is observed. Although these mixes show lower strength, they offer environmental benefits, as they help reduce carbon emissions and recycle agricultural waste. Therefore, higher OWA replacement levels may be suitable for non-structural applications where lower strength is acceptable, but they are not recommended for structural or load-bearing applications. These findings confirm that adding 3% OWA is an optimal amount for achieving compressive strength close to that of the control mix, which is acceptable for concrete used in rigid concrete pavements and also provides environmental benefits in terms of agricultural waste recycling.

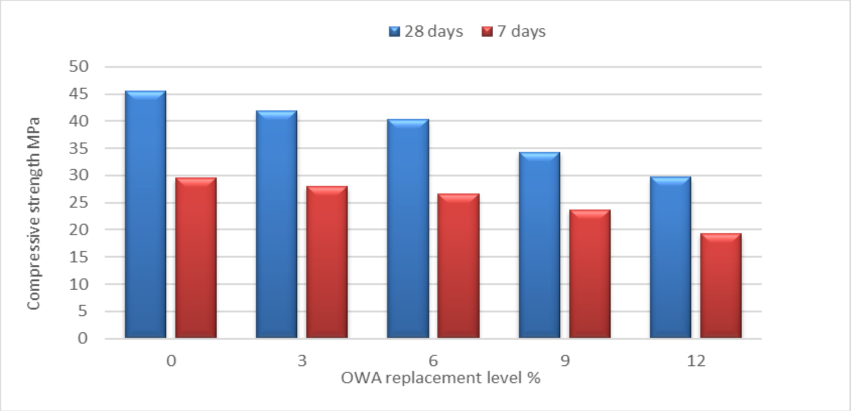

Figure 11: Compressive strength of concrete containing OWA at different curing times.

3.2. Effect of OWA on splitting tensile strength

The splitting tensile strength of concrete mixes with varying percentages of OWA (Oil Well Ash) was evaluated after 28 days of curing. The results illustrate the impact of OWA inclusion on the development of tensile strength over time, as shown in Figure 10. Beyond a 3% replacement level, there is a gradual decline in tensile strength, particularly at 6% and higher replacement levels. This reduction can be attributed to increased porosity, reduced cement content, and weaker Interfacial Transition Zone (ITZ) development. At higher replacement levels, there is insufficient formation of calcium silicate hydrate (C-S-H), which compromises the tensile performance of the concrete, making it more susceptible to crack propagation and tensile stresses (Mohamed et al., 2023).

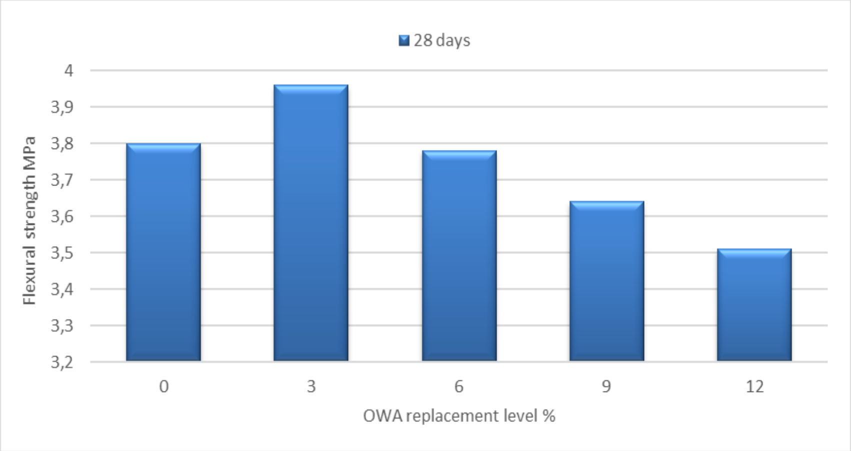

Figure 10: Tensile strength test results

However, the reduced tensile strength at higher replacement levels makes these mixes less suitable for structural applications that require high tensile performance. These findings confirm that a 3% replacement level is optimal for balancing tensile strength with enhanced sustainability. Beyond this threshold, although the environmental benefits are significant, the reduced tensile performance limits the use of OWA in high-performance or load-bearing concretes. Therefore, lower replacement levels of OWA are recommended for rigid pavements to ensure both durability and sustainability without compromising structural integrity (Mehta & Monteiro, 2006).

3.3. Air content

The incorporation of OWA in rigid concrete pavement has a significant impact on its air-void structure, which is essential for freeze-thaw durability. At a lower replacement level of 3% (Figure 11), OWA serves as a filler. It enhances the concrete matrix by reducing microvoids and promoting a more optimal distribution of air voids.

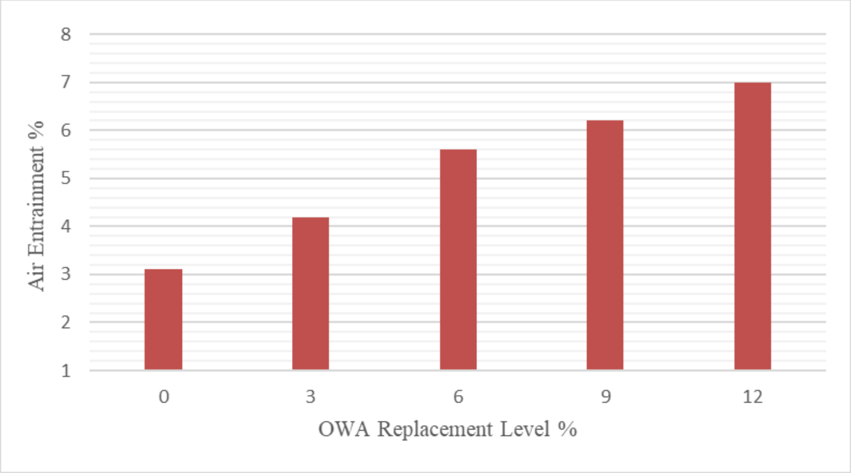

Figure 11: Air content test results

This results in improved resistance and strength, as the controlled air void structure effectively accommodates water expansion during freezing, minimizing freeze-thaw damage. However, when the OWA replacement exceeds 6%, the air void content increases due to reduced hydration efficiency and the agglomeration or clustering of OWA particles. This, combined with increased porosity, leads to a loss in compressive strength and durability. These findings highlight OWA as a sustainable material that recycles agricultural waste. However, the replacement level must be carefully optimized to balance durability, strength, and environmental benefits. (Siddique, 2014).

3.4. freezing and thawing test

The freeze-thaw test, illustrated in Figure 12, demonstrates that OWA (Oil Well Ash) can be a sustainable and effective additive in concrete pavements, provided its use is optimized appropriately. At lower replacement levels, particularly at 3%, OWA significantly improves the freeze-thaw durability of concrete. One of the primary reasons for this enhancement is the increased number and stability of air bubbles within the concrete. These air bubbles create adequate space for water expansion during freezing, which prevents cracks and structural damage, effectively mitigating the adverse effects of freeze-thaw cycles. Consequently, there is a reduction in mass loss and an improvement in durability factors after cyclic freeze-thaw testing. In contrast, when the OWA replacement level exceeds 6%, a noticeable decline in freeze-thaw resistance occurs. This decline is attributed to increased porosity and reduced hydration efficiency, which compromise the interfacial transition zone (ITZ) and overall matrix integrity. The degree of cracking and spalling becomes more pronounced at higher OWA levels, leading to accelerated material degradation as indicated by mass loss measurements. These findings suggest that a 3% OWA replacement strikes an optimal balance between durability and sustainability, enhancing freeze-thaw resistance while providing environmental benefits to waste recycling. However, higher replacement levels should be restricted to non-critical applications due to their detrimental impact on freeze-thaw durability (Mehta & Monteiro, 2006; Siddique et al., 2014).

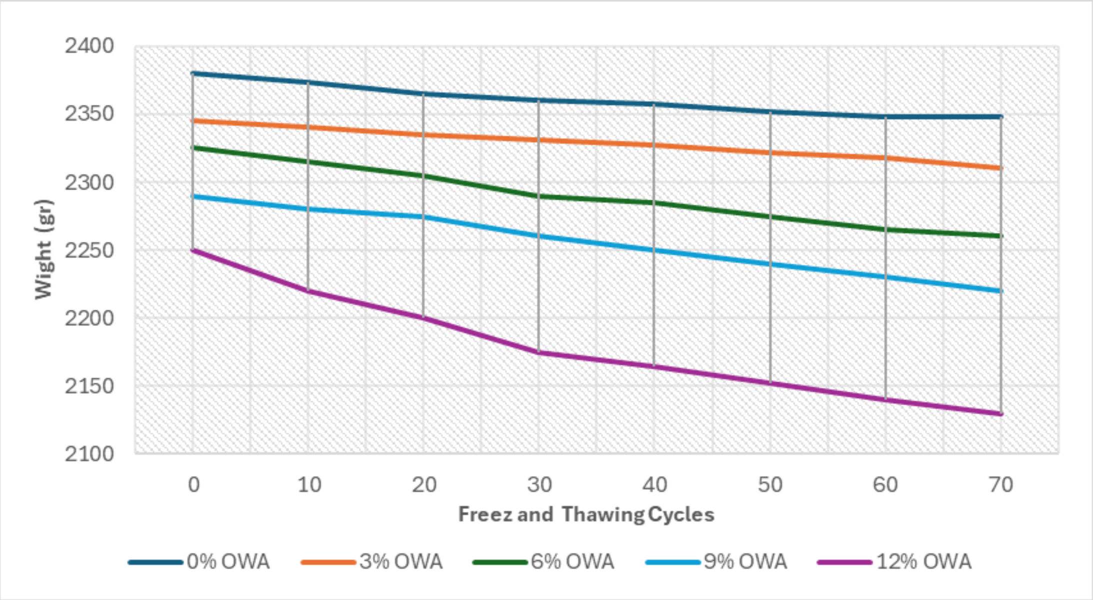

Figure 6: Mean mass loss

4. Conclusion

The outcomes of this study highlight the potential of Olive Waste Ash (OWA) as a partial cement replacement in concrete for rigid pavements, with varying effects depending on the replacement level.

- The results demonstrate that OWA can be effectively used as additive materials rigid pavements, with 3% being the optimal replacement level.
- Higher levels (≥6%) result in a significant reduction in tensile strength due to increased porosity and decreased cement hydration.
- The 3% OWA mix shows satisfactory freeze-thaw durability, whereas higher levels (≥6%) lead to substantial mass loss, restricting their use in regions with harsh climates.
- levels exceeding 6% should be avoided in rigid pavements in freeze-thaw-prone areas due to marked decreases in strength and durability.
- The air void test indicates that incorporating OWA at lower levels, particularly 3%, strikes a balance between durability and strength.
- OWA improves the pore structure by reducing micro-voids and controlling total porosity, making it a viable option for rigid pavements.
- Higher levels, such as 9% and 12%, increase air void content, negatively affecting compressive strength and freeze-thaw resistance.

AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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