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Utilization of Olive and Pumice Stones to Improve the Thermal Properties of Cement Mortar

Mais A. Abdulkarem[1*], Dalia Adil Rasool[1] and Baydaa Jaber Nabhan[1]

[1]*Materials Engineering Department, College of Engineering, Al-Mustansiriayah University, Baghdad, Iraq.*

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ABSTRACT

One of the main goals of sustainable solid waste management is recycling the waste as modified materials. This study aims to investigate the effect of using mixed waste materials (olive and pumice stones) on the properties of cement mortar. Different proportions of olive and pumice stones (i.e., between 10% and 30%) were added to replace the fine aggregates of cement mortar partially. In addition, a superplasticizer was used to increase the compressive strength and workability of cement mortar. The compressive strength, thermal conductance, density, and water absorption for each proportion of the mortar mixtures before and after the treatment of olive and pumice stones were measured. Results show that compared with normal mortar, the cement mortar mixed with 30% olive and pumice stones remarkably improved in terms of thermal insulation and compressive strength.

Keywords: Materials Wastes, Cement Mortar, Olive Stones, Pumice Stones, Compressive Strength, Thermal Conductivity, Density, Water Absorption.

1. INTRODUCTION

In general, concrete has been used as part of infrastructure development worldwide. However, the consumption of natural resources for concrete production has become a problem, especially with the rising costs of construction materials due to the increased demand. One solution to this problem is reducing the natural resources used for concrete production and substituting such resources with recycled materials. This procedure can alleviate construction cost and reduce the amount of waste material in landfills. Waste materials such as glass, recycled plastic, wood ash, rice husk ash, and olive waste, can be used as concrete materials. In addition, some recyclable waste materials such as vehicles' tires can be detrimental to the environment [1].

Pumice stones are lightweight rock materials which possess desirable physical, chemical, and mechanical properties. It can be combined with Portland cement and water to produce lightweight, thermal, sound, and insulating mortar cement [2].

Hossain [3] reported that the addition of 20% pumice powder as a coarse aggregate and cement additive to lightweight concrete showed that the mixture satisfied the required criteria of good concrete material. Rashiddadash *et al.* [4] studied the properties of the mortar cement when pumice stones were added to mortar cement. The pumice stones were used to prevent porosity in concrete that caused weak zones. Parhizkar *et al.* [5] reported the properties of concrete with pumice aggregates where lightweight concrete (i.e., coarse with natural fine aggregates and lightweight coarse and fine aggregates) were prepared, and their physical and

*Corresponding Author: *maisb58@gmail.com*

mechanical properties were examined. The results indicated that the mixture satisfied the requirements of lightweight concrete in terms of compressive and tensile strength and drying shrinkage.

Sivalinga and Rao [6] focused on concrete with lightweight aggregates, namely M20. Findings showed that the M20 concrete achieved considerable strength by replacing coarse aggregates with pumice aggregates at a proportion of 20%. Mixtures with 40% pumice and 0.5% fibre also yield positive results.

Olive waste is a by-product from the olive oil industry. Large amounts of solid olive waste, which contains organic minerals, accumulate and cause major damage to the environment due to its interaction with heat and humidity resulting in chemical hazards. For instance, carbolic acid and other strong life-threatening odours emanate from its decomposition. Such waste accumulation has increased at an alarming rate due to the lack of waste management techniques such as recycling or reusing waste in a positive or productive and environmentally friendly manner with the view of reducing the risks for environmental pollution and problems [7].

Al-Akhras [8] demonstrated that olive waste ash increased the resistance of concrete to the alkali-silica reaction. Al-Akhras and Wahid [9] used different proportions of olive waste ash to investigate the compressive strength, workability, flexural strength, and setting time of concrete. The results showed that the setting time and workability of the mortar cement decreased. Conversely, compressive and flexural strength decreased when the proportion of olive waste ash was increased. Leiva *et al.* [10] substituted a part of Portland cement with olive waste ash mortar. The findings illustrated that compressive and flexural strength were reduced with the increase in the percentage of olive waste ash due to the low siliceous content.

2. EXPERIMENTAL DETAILS

2.1 Materials

i. Ordinary cement was supplied by the United Cements Company, Tasluja Bazian, Sulaymaniyah. Tables 1 and 2 provide the chemical structure and physical properties of the cement used, respectively. Testing was conducted in the National Centre for Construction Laboratories in accordance with Iraq Specification No. 5 (1984) [11].
ii. Fine aggregates were derived from the Al-Ekadir region in Iraq in compliance with standard Iraqi No. 45 (1984) [12]. Tables 3 and 4 present the properties and grading of the fine aggregates, respectively.
iii. Pumice stones were cut and crushed into different sizes and treated with sodium hypochlorite ($NaOCl$) at 0.1 M and pH = 12, replacement from sand. Table 1 shows the chemical structure of pumice stones, replacement from sand. Table 4 displays the grading of the pumice aggregates.
iv. Olive stones are important materials produced from olive oil extraction and pitted olives from the table olive industries. Olives are air-dried for a few days to facilitate the separation of shells before crushing into different sizes. The olives were immersed in water for 24 hours, dried, replacement from sand. Table 4 illustrates the grading of olive stones.
v. Superplasticizer from Sikament FFN was used for 3% of the weight of cement and for all mixtures. It reduced water content in the mixture and maintained operability, thus increasing compression resistance.
vi. Clean water was used for all mixing and curing procedures.

Table 1 Chemical composition of ordinary Portland cement and pumice stone

Oxides composition	Content of cement (wt%)	Content of pumice (wt%)
SiO_2	18.81	74.2
AL_2O_3	5.26	12.52
Fe_2O_3	3.87	1.62
CaO	62.85	-
MgO	2.84	0.17
SO_3	2.70	-
I.R.	1.07	-
L.S.F.	0.80	-
L.O.I.	1.84	-

Table 2 Physical properties of ordinary Portland cement

Physical Properties	Test result	Specification limits
Soundness (Autoclave Method), %	0.09	≤ 0.8
Specific surface area (Blaine Method), m2/kg	330	≥ 230
Compressive strength, MPa		
3 days	25.13	≥ 15.00
7 days	34.6	≥ 23.00
Setting time (Vicat Apparatus),		
Initial setting, hr:min	1:15	00:45≥
Final setting, hr:min	3:08	≤ 10:00

Table 3 The properties of fine aggregate

Properties	Test results	Limited to the Iraqi specification
Sulphate content	0.12%	-
Specific gravity	2.65	≤ 0.5%
Chloride content	0.02	-
Absorption%	2.32	≤ 0.1

Table 4 Grading of fine aggregate, pumice & olive stones

Sieve size(mm)	Cumulative passing%			Limit of Iraqi specification No.45/1984
	Sand	Pumice stone	Olive stone	
4.75	97	91	93	90-100
2.36	78	90	87	75-100
1.18	56	81	77	55-90
0.06	34	40	64	35-59
0.30	10	20	20	8-30
0.15	1	4	7	0-10

Table 5 Mix proportions

Mix type	(Pumice & olive) stone % from sand	Cement (gm)	Sand(gm)	w/c	Pumice stone(gm)	Olive stone(gm)
M	0%	250	750	0.5	-	-
MT1	5%+5%	250	675	0.5	37.5	37.5
MT2	10%+10%	250	600	0.5	75	75
MT3	15%+15%	250	525	0.5	112.5	112.5

2.2 Tests Methods

2.2.1 Compressive Strength

The test was conducted in accordance with ASTM:C109M-07e1 [13] using 50×50×50 mm testing cubes. The testing cubes were examined using a compressive digital machine (ELE-Auto test) with a capacity of 200 KN. The test was conducted after ageing for 28 days.

2.2.2 Water Absorption Test

The primary aim of the test is to demonstrate the pores in the composite material. Specimens were weighed after the extraction from a template and immersed in water for 28 days. The model was weighed after removal from water and dried using a cloth.

2.2.3 Density Test

The density (g/cm3) of the cement mortar cubes was determined by weighing the cubes and dividing the values (mass in grams) by volume (50×50×50 mm).

2.2.4 Thermal Conductivity Test

An important aspect of this research is the calculation of the thermal conductivity coefficient of the cement mortar cubes based on US standards (ASTM C1058-03 and C177-10) [14]. Thermal conductivity was measured using a simple device that was manufactured locally. The hot wire method, which calculates thermal conductivity by measuring the increase in temperature of the metal wire before reaching thermal balance, was used in the test. Two scales for each wire were used between the models, which were exposed to the temperature generated by the passage of electric current. The device used in the inspection comprised two external cylinders with diameters of 35 and 30 cm and internal cylinders with diameters of 30 and 25 cm. The cylinders were separated by layers of glass wool with a thickness of 5 cm as thermal insulation for all sides. A heater was connected to the electric current, and the masonry cubes were installed on top of the cylinder. The edges of the cube were painted with thermal silicon to prevent heat leaks. A high-resolution multimeter (M890G) was used to measure the temperature and differences in current and voltage. Samples were placed on the designated place (i.e., top of the device). Afterwards, the input capacity of the heater was set by controlling the voltage exerted on the heater to generate the required amount of heat to enter the sample. The examination process lasted for 8 hours until stability. The following readings were then recorded:

i. Voltage and current entering the heater.
ii. Temperatures at the top and bottom of the model.

The thermal conductivity factor (K) was calculated using Fourier's Law. The temperature was gradually increased up to 50°C (the highest temperature that can reach concrete during summer), as specified in the manufacturer instruction. Voltages were gradually increased up to 3 V, and the current was increased up to approximately 0.6 A.

3. RESULTS AND DISCUSSION

3.1. Compressive Strength

Figure 1 depicts the compressive strength of the mortar cubes with two additives (pumice and olive stones). The figure shows the effect of pumice and olive stones that were untreated and treated with the superplasticizer on the compressive strength of cement at 28 days. The compressive strength of cement decreased with the increase in the proportions of additives. The reduction in strength is mainly dependent on the bonding between cement and aggregates and the size and hardness of aggregates [15]. When the two additives were treated with superplasticizer, an increase in compressive strength was observed with the increase in the ratio of the additives (olive and pumice stones). The rate ranged from 7% to 28%, which is approximately the standard ratio of additives (i.e., 10% to 30%) treated with the superplasticizer.

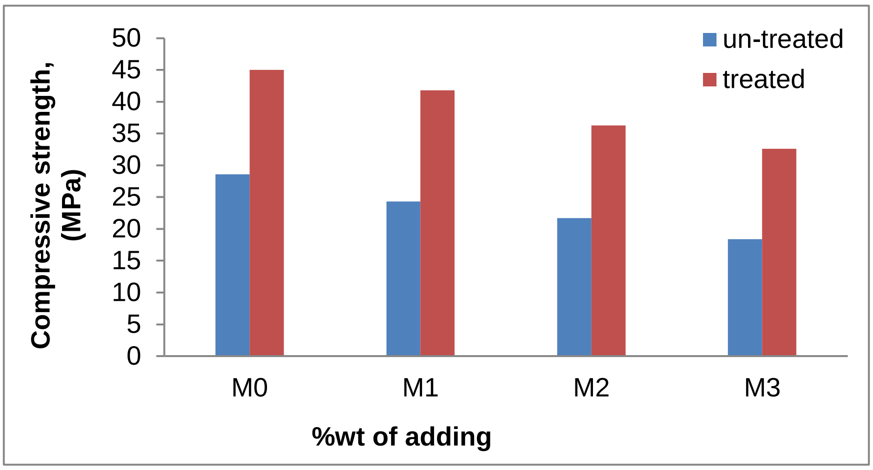

Figure 1. Effect of (pumice & olive stones) on the compressive strength.

3.2 Water Absorption

Figure 2 indicates that the water absorption increased after ageing for 28 days when additives were added to the cement mortar. Water absorption increased because the mixture enabled water to penetrate the interface voids between the cement mortar and additives. In addition, the weakness of bonding between particles increased absorption. The composite water absorption test is an important factor for determining composite durability. In general, superior protection of reinforcement additives within composite materials is achieved when water absorption is minimal.

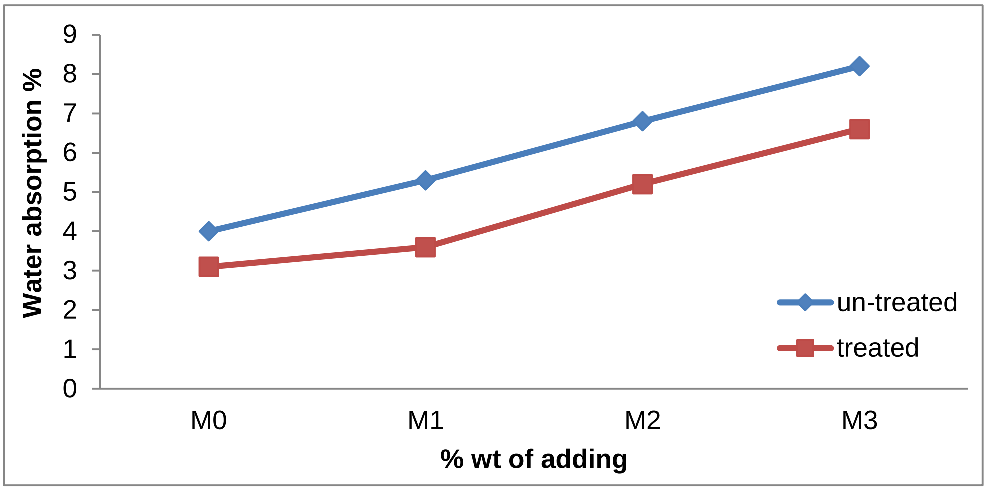

Figure 2. Effect of (pumice & olive stones) on the water absorption.

3.3 Density

Figure 3 shows the results of density, which decreased with the increase in the proportion of additives. Typically, density is inversely proportional to replacement. In other words, density decreases with the increase in the proportion of replaced cement because olive and pumice stones have less specific gravity compared to sand.

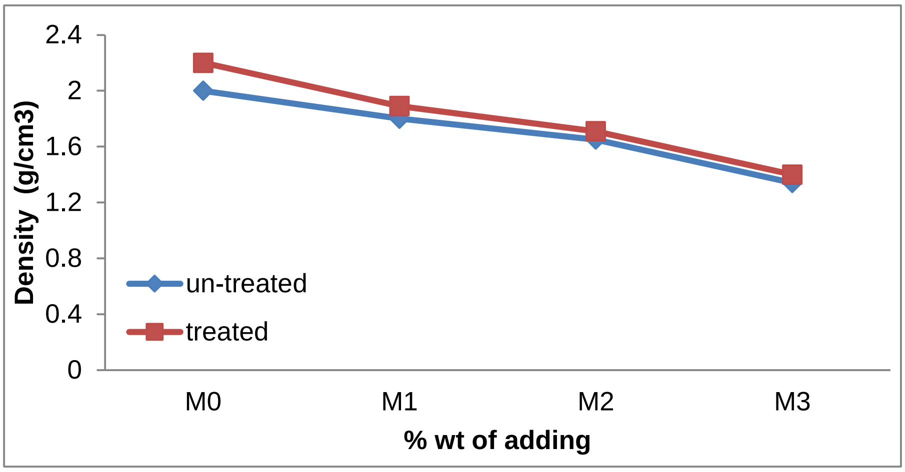

Figure 3. Effect of (pumice & olive stones) on the density.

3.4 Thermal Conductivity

Figure 4 depicts the thermal conductivity of mortar with the two additives (olive and pumice stone) when untreated and treated with the superplasticizer. A reduction in thermal conductivity was observed, where the rate ranged from 22% to 54% and from 10% to 30% for the untreated and treated additives, respectively. This finding indicates the positive performance of the additives as thermal insulators. In addition, the figure shows that the additives treated with the superplasticizer lead to a slight increase in thermal conductivity and represent little improvement in compression resistance.

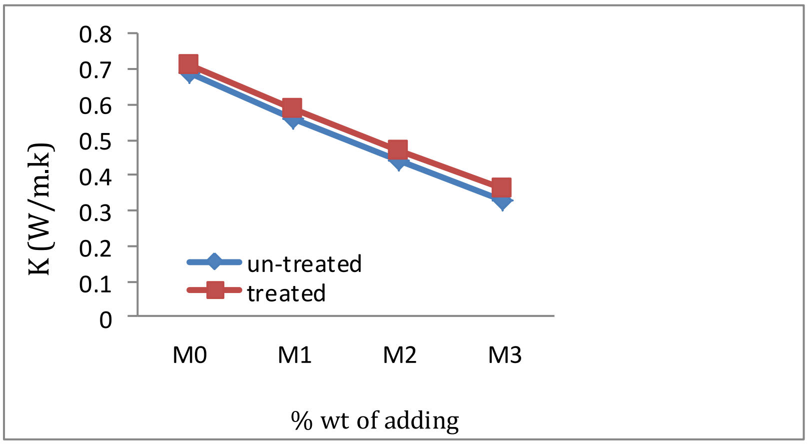

Figure 4. Effect of (pumice & olive stones) on the thermal conductivity.

4. CONCLUSION

This study was conducted to assess the properties of cement mortar produced using different proportion of the superplasticizer, and olive and pumice stones as partial replacements for sand at 10%, 20%, and 30%. The present study draws the following conclusions:

i. Using olive and pumice stones treated with the superplasticizer increased the compressive of mortar cement by 7% to 28%, which is close to standard values.
ii. Using olive and pumice stones treated with superplasticizer slightly decreased the water absorption of mortar cement.
iii. Using olive and pumice stones remarkably decreased the density.
iv. When untreated, using olive and pumice stones decreased the thermal conductivity from 22% to 54% at ratios of 10% and 30%, respectively.

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