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RESEARCH ARTICLE

A study of the effect of industrial and natural wastes on cement mortar properties

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Abstract
Disposing of waste causes the majority of environmental and economic issues. Industrial and natural waste usage was necessary to balance construction requirements, environmental sustainability, and conservation of landfill space. The waste of red mud and pistachio shells caused environmental effects. The primary objective of this work is to provide a rough assessment of the effectiveness of using waste materials such as red mud and pistachio shells as partial replacements for cement and fine aggregate, respectively. In the mortar ratio, the proportions of cement to aggregate were 1:3, and the water-to-cement ratio (W/C) was 0.45. In this investigation, red mud was used to replace 10% of the cement, and waste pistachio shells were used to substitute fine aggregate from 5 to 30% of the mortar mix. Different mortar combinations were tested for density, water absorption, compressive strength, and thermal conductivity. The primary findings reveal that red mud and pistachio shells may partly replace the cement and sand in the mortar mixture while still increasing the mortar's characteristics. When red mud was added to 10% of the mortar at age 28 days, the compressive strength was 30 MPa. Also, when red mud and pistachio shell wastes were added to mortar, the maximum compressive strength at (CMRP2) was 54.8 Mpa. The mortar's density was reduced when the replacement of two additives increased. Also, adding red mud to the mortar decreased the water absorption after 28 days, while pistachio shells had the opposite effect. The thermal conductivity test results were positive, with a decrease in thermal conductivity with increased additive waste content.

Keywords Natural waste · Industrial waste · Red mud · Pistachio shells · Water absorption · Thermal insulation

1 Introduction

The high cost of building is a serious issue. For this reason, researchers focus on studying materials that are both abundant and cheap, like industrial and agricultural waste [1]. These waste products, however, might be harmful if not charged properly. Manufacturing of conventional masonry requires a significant amount of electrical and thermal power, which results in pollution of the air, water, and land [2]. Protecting natural resources, avoiding waste materials, and freeing up valuable ground are additional advantages of employing agricultural waste products in the building sector instead of natural materials. As the most noticeable waste of Bayer's aluminum and alumina production process, red mud is easily recognizable [3]. Because of its high pH, it is categorized as a strongly alkaline slurry. Red mud is categorized as a cementitious material because it contains the six essential oxides SiO_2, CaO, Al_2O_3, Fe_2O_3, Na_2O, and TiO_2, as well as trace quantities of several minor elements [4]. The use of affordable and easily accessible waste products as a substitute for conventional building materials is essential, and this requires prioritizing their identification. Cement demand is increasing and growing far beyond supply [5, 6]. Pistachios are the fully developed seed of the Pistacia vera L fruit. It may be found widely in Iran, Syria, and Iraq. Generally speaking, the ratio of shells to pistachios falls between 50 and 70%. After eating pistachio, a large quantity of shells is produced. Most shells are discarded in landfills or incinerated since there is no market for them [7]. Sethy et al. [8] examined the strength properties of concrete carrying up to 20% red mud in place of cement. They reported from the experiment work that till 10% has no noticeable effect on concrete properties after a 10% significant drop in compressive strength. Metilda et al. [9] determined the practicability

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of partially using red mud to substitute cement in concrete and investigated its compressing strength and splitting tensile strength. They discovered that red mud could effectively substitute 15% of cement. After 15%, both compressive strength and tensile strength start decreasing. An experiment was carried out in which red mud was used to partially substitute cement in concrete at various percentages (0%, 5%, 10%, 15%, 20%) along with 5% hydrated lime and examined for compressive strength, tensile strength, and workability. Sapna and Aravindhraj [10] reported a 17% improvement in strength by using red mud. Sawant et al. [11] assessed the effects of red mud on concrete. They reported from the experiment that there was a reduction in setting time of 5% and 10% in the replacement of cement with red mud. Strength was also reduced with an increase in the quantity of red mud in concrete.

Nikbin et al. [12, 13] reported that red mud could be utilized till 25% replacement of cement. They test for modulus of elasticity (MOE), flexural strength, compressive strength, and splitting tensile strength. They discovered that the MOE, splitting tensile strength, compressive strength, and flexural strength of concrete all decrease when additional red mud is added. Cement mortar containing pistachio shell waste utilized as a partial substitute for fine aggregate was evaluated for absorption, density, and compressive strength [14]. In the case of shells, she said that density might be decreased to meet the ASTM criteria, and compressive strength is reduced as a natural result of a lower density product. Modani and Vyawahare's [15] study found that using ash from sugarcane bagasse as a substitute for sand in concrete (ASB) enhanced compressive strength by 10% and 20%, respectively, with no negative impact on concrete strength or workability. In place of gravel, Hilal et al. [16] used walnut shells (WS) to make their SCC. Their research showed that SCC's mechanical characteristics were reduced when WS was used. As suggested, lightweight SCC may be made using between 35% and 50% WS. According to research by Sada et al. [17], using groundnut as a fine aggregate substitute decreases the concrete's density, compressive strength, and workability because of the groundnut shell's high water absorption. In an experiment, Obilade observed that the density of concrete made using rice husk as fine aggregates decreased as the amount of husk rice increased. He also came to the conclusion that rice husk has excellent promise as a fine aggregate for making lightweight reinforced concrete [18]. .

The novelty of this research lies in the fact that it investigates the two different kinds of waste—industrial and natural—that are put into cement mortar. It also investigated how adding red mud and pistachio shells affected the mortars'.

Table 1 Red mud and cement chemical composition

Chemical composition	Percentage by weight Cement	Percentage by weight-red mud	Limits of IQS 5:1984
CaO	60.76	3.40	
SiO_2	19.33	11.4	
Fe_2O_3	3.7	38.3	
Al_2O_3	5.4	21.6	
MgO	2.95	-	< 5
SO_3	2.5	-	< 2.8
LOI	1.15	25.30	< 4
IR	0.2	-	< 1.5

Table 2 Physical characteristics of pistachio shells, fine aggregate, and red mud

Physical properties	Test results			
	Cement	Fine aggregate	Pistachio shell	Red mud
Fine modulus	225	2.96	2.582	4.10
Specific gravity	3.15	2.58	0.12	2.90

2 Materials and methods

2.1 Materials

2.1.1 Cement

Ordinary Portland Cement (OPC), manufactured according to ASTMC150 Type 1 [19], is available at cement factories. According to the findings of the tests, the embracing cement complies with the Iraqi criteria outlined in IQS No5(1984) [20]. The OPC's physical characteristics and chemical makeup are detailed in Tables 1 and 2.

2.1.2 Fine aggregate

All of the fine aggregate used in this project originated in the Al-Ekhadir area. Fineness modulus, specific gravity, and gradation have all been determined by testing, as seen in Tables 2 and 3. The tests on the fine aggregate showed that it met all of the specifications in IQS No. 45/1984 [21].

2.1.3 Pistachio shells

The pistachio shells were obtained from Hila City and gathered as discarded material from pistachio vendors. The shells were cleaned and dried in the sun for two days to remove dirt from the peel. After that, an electric power grinder machine was used to reduce the Pistachio shells to sizes consistent with fine aggregate, as specified by IQS No. 45/1984 [21]. Pistachio shell samples' physical characteristics and classifications are shown in Tables 2 and 3.

2.1.4 Red mud (RM)

Markets in Iraq provided the red mud utilized in this investigation. It is a byproduct of the Bayer method for making alumina from bauxite, and it consists of solid waste. Tables 2 and 3 display the chemical and physical characteristics of red mud, respectively.

2.1.5 Water

All mixing and curing processes were carried out using potable water.

2.2 Mixture proportioning

The specimens were prepared using Portland cement and fine aggregate. They were mixed in the proportion of 1:3, and the water/cement (w/c) proportion was 0.45, as shown in Table 4. The specimens were partially processed by substituting the fine aggregates with pistachio shell waste, using percentages of 5–20% of the weight of the sand. The specimens were processed by substituting the cement with red mud, using 5–20% of the cement's weight. The mortar specimens were prepared using pistachio waste to replace fine aggregate at a ratio of 5–30%. At the same time, red mud waste was replaced with cement at a rate of 10% by weight. It was poured into the mold and allowed to sit for a day. After that, it cured compressive strength specimens in 7 and 28 days when pistachio shells and red mud mixed with mortar were added, curing for 28 days for all testing mixes.

Table 3 Fine aggregate pistachio shells grading

Sieve size mm	Cumulative passing%		Iraqi standards No45-1984 limits
	Pistachio shells	Sand	
4.75	91	97	90–100
2.36	90	78	75–100
1.18	81	56	55–90
0.06	40	34	35–59
0.30	20	10	8–30
0.15	4	1	0–10

2.3 Testing

2.3.1 Compressive strength test

The compressive strength is measured using a 50 mm x 50 mm x 50 mm specimen as specified in ASTM C150-04a [22]. The cubes' compressive strength was evaluated using a digital 200kN ELE-Auto test compressive machine. The testing was carried out at 28 days, and the average of three readings was adopted. The mechanical characteristics of the cement mortar are revealed by this test (strength and durability).

2.3.2 Density test

The density test is determined according to ASTMC188-17 [23]. That cement mortar cube density was calculated by dividing weight in grams by cube volume (50 mm in all dimensions).

Table 4 Mixture proportions of waste-mortar mixes

Proportion mix % R%+P%		Cement g/m^3	Sand g/m^3	Waste materials (g/m^3)		W/C
				Red mud by weight of cement	pistachio by weight of sand	
CM0	0%	250	750	0	0	0.45
CMR5	5%	237.5	750	12.5	0	0.45
CMR10	10%	225	750	25	0	0.45
CMR15	15%	213	750	37	0	0.45
CMR20	20%	200	750	50	0	0.45
CMP5	5%	250	712.5	0	37.5	0.45
CMP10	10%	250	675	0	75	0.45
CMP15	15%	250	637.5	0	112.5	0.45
CMP20	20%	250	600	0	150	0.45
CMRP1	10%+5%	225	712.5	25	37.5	0.45
CMRP2	10%+10%	225	675	25	75	0.45
CMRP3	10%+15%	225	637.5	25	112.5	0.45
CMRP4	10%+20%	225	600	25	150	0.45
CMRP5	10%+25%	225	562.5	25	187.5	0.45
CMRP6	10%+30%	225	525	25	225	0.45

2.3.3 Absorption test

The specimens are weighed after demolding and then submerged in water for a short period before being removed and dried with a towel to ensure maximum surface water extraction. Applying Eq. 1 yields the absorbed water absorption.

$$\% Water\ absorption = \frac{Ws - Wd}{Wd}(100) \quad (1)$$

Where;
Ws: Soaked pieces weight (gm).
Wd: Dry pieces weight (gm).

2.3.4 Thermal conductivity test

The ASTM C1058-03 and C177-10 [24] are utilized in this research. It is a fundamental objective and an essential requirement of the testing. The material's capacity to transmit heat is indicated by its thermal conductivity. This is the quantity of thermal units that flow through a unit area of material with a thickness of one unit and in a unit of time when the body's two sides have different temperatures by one degree. The unit utilized by the metric system is W/m.k. For dried models, ACI provided the following equation, which connects the dry density to the thermal conductivity coefficient.

$$K = 0.027 * e^{0.00125\rho} \quad (2)$$

Where:
ρ = density of dry sample.
K = thermal conductivity coefficient.

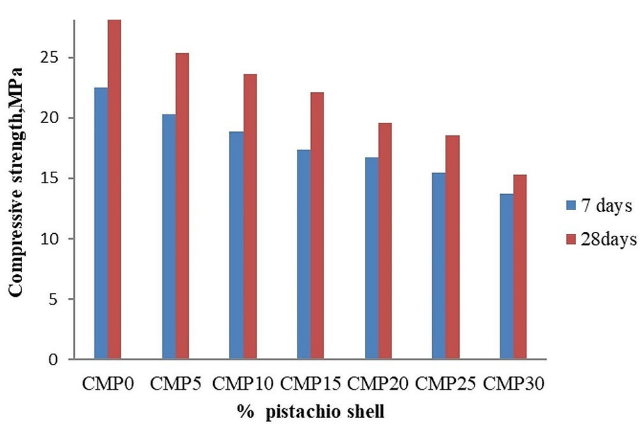

Fig. 1 Effect of pistachio on mortar's compressive strength at 7,28 days

3 Test results and discussion

3.1 Compressive strength

Compressive strength varies with the replacement ratios shown in Fig. 1. Age was found to increase compressive strength, while an increase in replacement ratio decreased it. Consistent with the findings of the study by Sada et al. [17] that looked into the feasibility of using ground nut as an alternative to fine aggregate, Neville added that the anhydrate cement continues to hydrate, leading to a new output of hydration within the mortar over time, which increases the mortar's compressive strength [25]. Compressive strength drops off at higher pistachio shell replacement levels, possibly due to the shell's water absorption during mixing, reducing the mixture's workability. At 28 days, the maximum loss ratio in compressive strength was 34% for the CMP25 mix and 46% for the CMP30 mix. Meanwhile, the CMP25 and CMP30 mixtures, respectively, showed 31% and 39% in 7 days. The results are presented in Fig. 1.

The compressive strength of mortar at 7 days and 28 days is shown side by side in Fig. 2. Compressive strength rises smoothly together with increasing red mud content, as seen in the figure. At that 10% mark, it was at full strength. Red mud was used in place of cement. And then, it went worse from there, with the lowest strength achieved when 30% of the cement was substituted with red mud. Red mud has not been shown to conduct pozzolanic reactions [26, 27]. Hence previous research has shown that its usage in the building sector must be restricted to 10% or less. In addition, red mud with a high age of fineness provides initial strength in concrete right from the start [28, 29].

Figure 3 illustrates how applying red mud causes a progressive increase in compressive strength. At CMRP2, the highest compressive strength was 54.8 MPa. The compressive strength then decreased when the amount of additives in the mortar was increased.

3.2 Density

Figure 4 shows that the density decreased by increased replacement ratio of (red mud and pistachio shell) wastes for all mortar mix. In fact, the pistachio shells and red mud have a lower density than utilized natural sand. This is consistent with Obilade's study [18], which examined the effects on concrete properties of substituting husk rice for fine aggregate. After 28 days, the red mud in the mortar has helped lower the density because its finer particles promote more compactness in the mortar (density). However, packing issues may emerge at a particular addition level as paste workability decreases, and density may drop (porosity augment) [30].

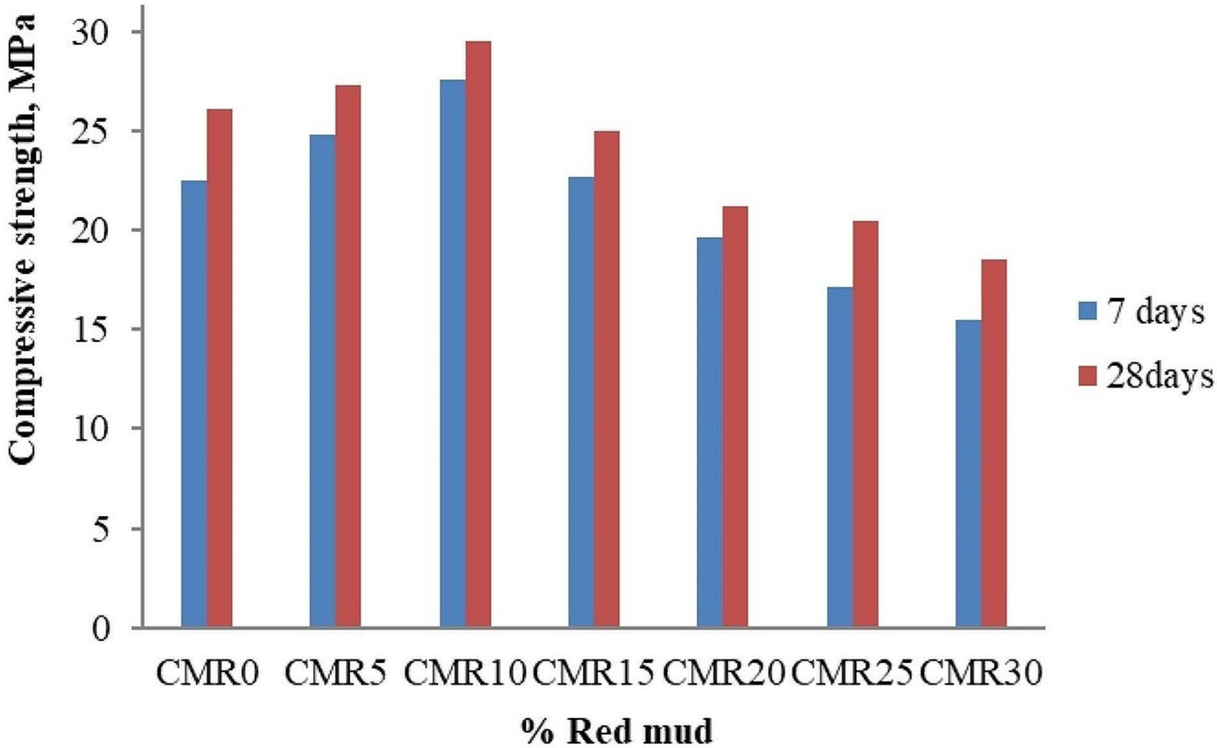

Fig. 2 Influence of Red mud on mortar's compressive strength at 7,28 days

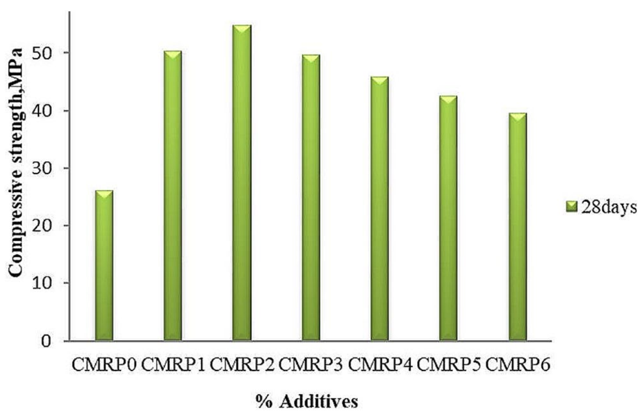

Fig. 3 The additives (red mud and pistachio shells) affect the mortar's compressive strength at 28 days

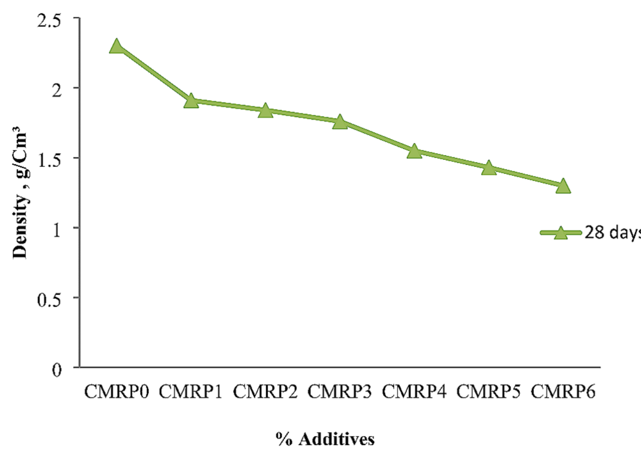

Fig. 4 Impact of the additives on the cement mortars' density

3.3 Water absorption

According to the study by Viyasun et al. [31], which looked at the effects of red mud on concrete, the water absorption of cement mortar decreased after 28 days owing to the impact of mortar with the addition of red mud (see Fig. 5). They observed that increasing the quantity of red mud in the concrete lowered water absorption. It was found that the tiny particles of red mud filled every crack and pore in the concrete, reducing water absorption. The hydration mechanism of cement made from red mud was similarly explained by Manfroi et al. [32]. The larger $Ca(OH)_2$ crystals were broken down into smaller, less-oriented crystals to reduce pore connections and water absorption. The findings then corroborated those of Boukhelkhal et al. [33] and Barreca et al. [34]. They discovered that concrete prepared with a high ratio of natural wastes absorbs more water than concrete prepared with natural aggregate.

3.4 Thermal conductivity

Figure 6 compiles the thermal conductivity results as a function of (pistachio shell and red mud) waste content for the different combination specimens after 28 days of curing.

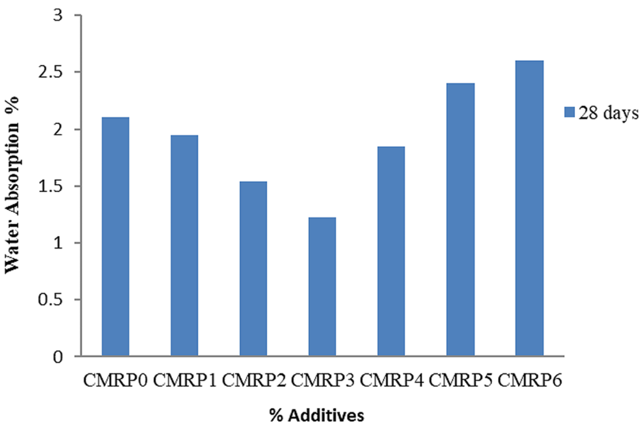

Fig. 5 Effect of additives on cement mortars' water absorption at 28 days

The findings demonstrate that the thermal conductivity of the waste mixes is lower than that of the mortar before waste was added. The decrease rates were as follows: 19% for the control mortar, 29% for the first four mixes, 37% for the third set, 62% for the fifth set, and 72% for the sixth set of mixtures. Pistachio shells improve porosity in the bond zone between cement paste and sand grains, which likely explains the lower thermal conductivity. According to Korjenic et al. [35], changing the microstructure of the cement by adding organic waste increases the mix's thermal conductivity. Due to its poor thermal conductivity, red mud can disperse heat more efficiently, as shown by research by Das et al. [36].

4 Conclusions

Pistachio shells and red mud both pollute the waste and should be avoided. This study's main goal is to estimate the efficiency of employing waste materials like red mud and pistachio shells as partial replacements for cement and fine aggregate, respectively. Many conclusions could be drawn from the research finding. The greatest compression strength may be achieved by substituting 10% cement with red mud. A mortar containing red mud and pistachio shells has a maximum compression strength of 54.8 MPa at CMRP2. The cement mortar's density was lowered by the mix of pistachio shell and red mud, which also reduced deadweight. After 28 days, cement mortar with red mud reduced water absorption, but mortar with pistachio shells enhanced water absorption. As the proportion of pistachio shells to red mud in mortar rises, the thermal conductivity of the mortar decreases.

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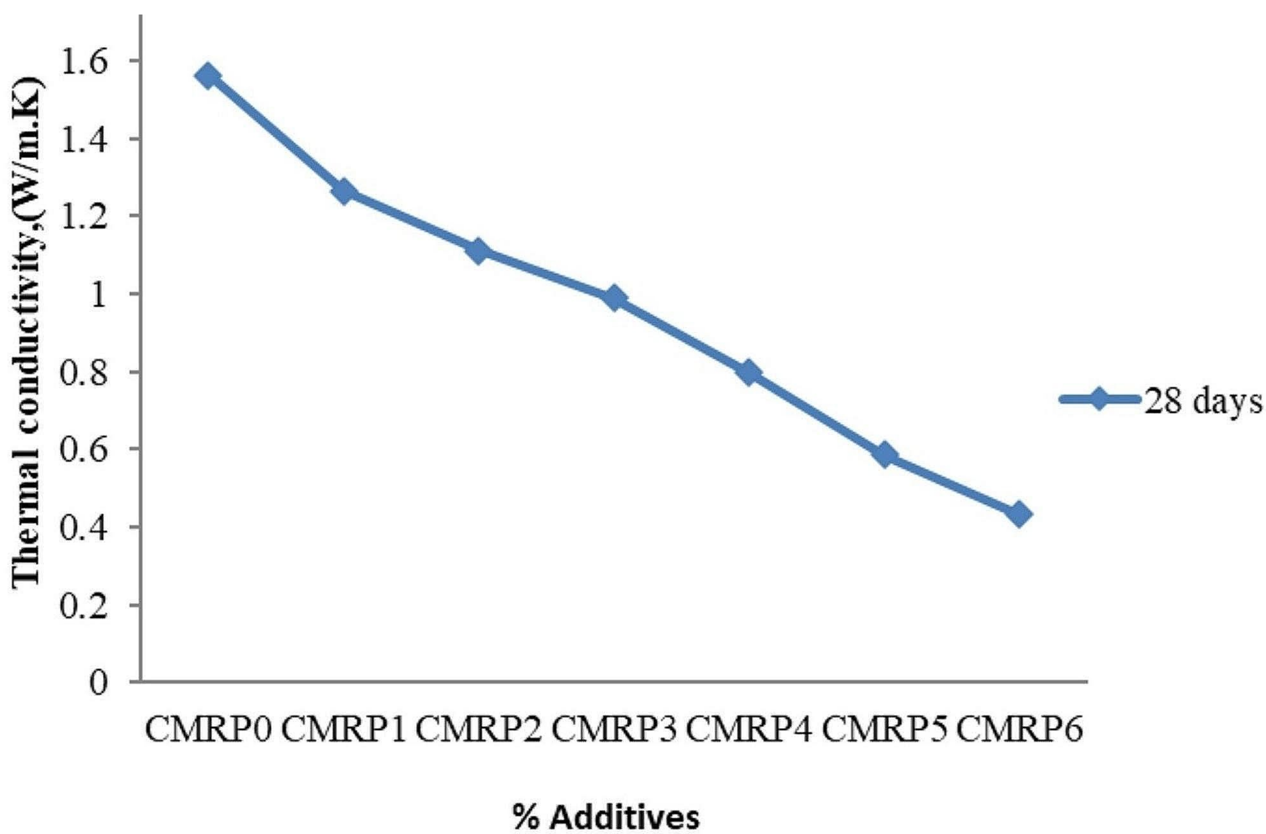

Fig. 6 Impact of additives on mortars' thermal conductivity at 28 days

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Author contributions All authors contributed to the study conception and design. Material preparation, data col-lection and analysis were performed by [Mais A. Abdulkarem 1, Dalia Adil Rasool2, and Baydaa jabber Nabhan3]. The first draft of the manuscript was written by [Mais A. Abdul-karem] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Informed consent Authors consent to the ethics.

Conflict of interest The authors declare that they have no competing interests.

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