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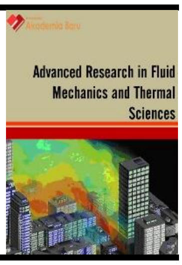

Thermal Properties of Concrete by Replacement Sand with Porcelain Waste

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ABSTRACT

Thermal mass gives significant benefits in building design, because property of a material enables it to absorb and store heat energy. The aim of this work is to determine the thermal properties of concrete by replacement of sand with porcelain waste. Sand is replaced with porcelain waste at different percentages of 10 %, 20 %, 30 %, 40 % and 50 %. The samples were prepared from cylinder concrete and cut it by the concrete cutter to produce the required specimens with a diameter of 4 cm and 0.5 cm thickness, hot plate method was basically employed throughout the experiment. Furthermore, the thermal conductivity, specific heat capacity and thermal diffusivity of the samples were measured. The addition of porcelain waste in the concrete were increased the thermal conductivity, specific heat capacity and thermal diffusivity and the results were obtained 2.31 (W/m.K), 974 J/kg·K and 0.9800 mm^2/s respectively at 50 % replacement and 60 days. The usage of porcelain waste in concrete has great potential in the construction industry in the future.

Keywords:
Concrete; sand; porcelain waste; thermal properties

1. Introduction

As the world population grows to unmatched levels, new challenges emerge. The world population will increase by 25 % by 2050, reaching an astonishing of 9.6 billion [1]. This overcrowding will put pressure on the Earth's natural resources in order to meet the demand for building materials while increasing the amount of waste generated to a critical level. Sustainable building is necessary to achieve the goals of the directive, so new materials must be explored and environmentally friendly products must be developed [2]. In addition to the obvious environmental advantages, the possibility of using ceramic waste materials as a partial replacement for concrete raw materials can be achieved by reducing the volume required for the raw materials. Previous investigations have been conducted

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to demonstrate the feasibility of recycling industrial waste in ceramic products, incorporating waste into ceramic tiles [3], concrete [4], ceramic tiles [5] and porcelain waste [6-8].

To assess the thermal properties of concrete, two phases model are mostly used. The procedure consists of dispersing a denser aggregate (microporous phase) in a more porous paste (macroporous phase). The type of aggregate, porosity and water content of the concrete are of great influence to the thermal conductivity of the paste, and the influence of cement hydrate is small [9]. The types of cementitious have a more pronounced effect on thermal conductivity in pastes, mortars and lightweight concrete. Due to the lower density and increased porosity of these materials, it has been shown that addition of fly ash and slag to concrete reduces the thermal conductivity of the paste and mortar [10- 12].

The quality of the paste and type of aggregate mainly affect the specific heat of concrete. Similarly, the paste density, porosity and moisture content have a significant impact on heat capacity and increase with increasing free water content of the concrete [13]. Due to the reduced density, the specific heat capacity of lightweight concrete is much lower than that of structural concrete, therefore it reduces the thermal quality of the material. It was found out that, concrete made of fly ash has specific heat slightly lower than that of similar Portland cement concrete due to lower free water content as a result of pozzolanic reaction and lower density [14,15].

The ability of a material to exchange heat at its surface as the temperature of the surface changes is known as thermal diffusivity. To have the effectiveness of the wall, the thermal mass and thermal diffusivity, are related to the square root of the product of density, specific heat and thermal conductivity [16]. It appears that the concrete's thermal diffusivity containing slag or fly ash has not been announced, but it is expected that, the thermal diffusivity is lower than that of concrete with Portland cement as a result of their specific heat capacity and thermal conductivity after drying [17,18]. The objective of this research is to determine the thermal properties of concrete by replacement of sand with porcelain waste.

2. Materials and Methodology

Crusher machine was used to crush porcelain waste as presented in Figure 1 and Figure 2 shows the porcelain waste before and after grinding. Porcelain waste used in this study was collected from landfill in Baghdad. The Iraqi ordinary cement produce by the (ALjasar) cement factory was used. Natural gravel of mix size 12.5 mm as coarse aggregate, natural sand brought from AL-Ekadir zone and tap water was used. The chemical and physical properties of Portland cement compound from Central Organization for Standardization and Quality Control (COSQC) are shown in Table 1 and Table 2.

Fig. 1. Crusher machine

(a) (b)

Fig. 2. (a) before grinding, (b) after grinding

Table 1
Chemical properties of cement

Abbreviation of Oxide	% by weight	Limits of Iraqi Specification
SiO_2	19.90	-
CaO	60.80	-
MgO	1.50	≤5.0
Fe_2O_3	3.00	-
Al_2O_3	5.69	-
SO_3	2.30	≤ 2.8
Loss on Ignition	1.50	≤ 4.0
Insoluble residue	1.10	≤1.5
Lime saturation factor	0.85	0.66-1.02

Table 2
Physical properties of cement

No.	Property	OPC
1	Specific Surface area (Blaine Method) m^2/kg	290
2	Setting time (Vicat Apparatus) Initial setting, hr: min Final setting, hr: min	1:48 4:47
3	Compressive strength, MPa 3 days 7 days	25.6 31.8
4	Soundness (Autoclave Method), %	0.05

Tables 3 and 4 show the chemical and physical properties of natural sand and physical properties of coarse aggregate and Table 5 shows the chemical properties of porcelain waste.

Table 3
Chemical and physical properties of natural sand

Property	Specification	Result	Iraqi Specification No.45/2002
Specific gravity	ASTM C128-88	2.63	-
Absorption, %	ASTM C128-88	0.75	-
Dry loose- unit weight, kg/m^3	ASTM C29-89	1592	-
Sulphate content as SO_3, %	I.O.S No.45/1984	0.08	≤ 0.5
Material finer than 75µm sieve, %	I.O.S No.45/1984	3.8	≤ 5

Table 4
Physical properties for coarse aggregate

Physical properties	Test result	Limits of Iraqi specification
Specific gravity	2.630	-
Sulfate content	0.06%	≤ 0.1%
Absorption	0.63%	-

Table 5
Chemical properties of porcelain waste

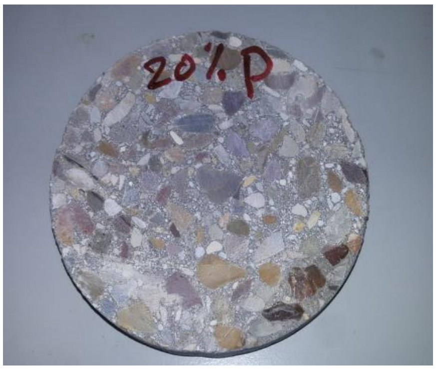
Abbreviation of Oxide	% by weight
MgO	0.0255
Al_2O_3	18.74
SiO_2	59.76
P_2O_5	0.6293
SO_3	0.1325
Cl	0.3018
K_2O	1.895

Table 6 shows the sieving process for the porcelain waste, crushed porcelain waste and sand passed through sieve size of 4.75 mm to 0.15 mm.

Table 6
Sieving process for porcelain waste

Sieve size (mm)	% passing	Remain (%)
4.75	100%	0
2.36	59.8%	40.2
1.18	32.8%	27
0.6	18.4%	14.4
0.3	10%	8.4
0.15	5.6%	4.4
0	0	5.6

The thermal test was conducted to determine the thermal properties of the concrete samples which include the thermal conductivity, specific heat capacity and thermal diffusivity. The thermal conductivity, specific heat and thermal diffusivity tests were carried out on dried samples for 60 days according to EN 12667. Hot plate method was used for determining the thermal conductivity (K). The samples were prepared from cylinder concrete and cut by concrete cutter to produce the required specimens with diameter of 4 cm and 0.5 cm thickness. Three specimens were used for each mix and tested. Figure 3 shows the specimen and concrete cutter that was used in this research.



(a)

(b)

Fig. 3. (a) specimen, (b) concrete cutter

3. Results and Discussion

3.1 Thermal Conductivity

The thermal conductivity measurements are carried out by using hot plate method. The result of the thermal conductivity of the concrete was measured at curing age of 60 days and presented in Table 7 and Figure 4.

Table 7
Thermal conductivity results for concrete specimens made with different percentage of porcelain waste at 60 days

Sample	Thermal conductivity at 60 days K (w/m. K)
R	1.43
M 10	1.49
M 20	1.57
M 30	1.77
M 40	1.94
M 50	2.31

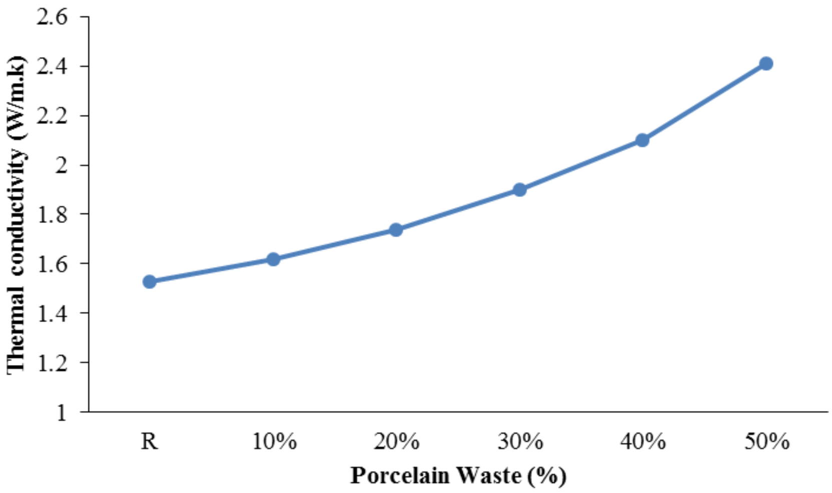


Fig. 4. Thermal conductivity with different percentage for porcelain waste

Table 7 illustrates the result of the thermal conductivity of a concrete that has been cured for 60 days. From Figure 4, the thermal conductivity of the control sample was obtained 1.43 (W/m. K). Therefore, it is very important to note that, by adding porcelain waste at 10 % replacement of sand, the thermal conductivity increases to 4.2 %. The maximum thermal conductivity was achieved at 50 % replacement of sand as 2.31 K (W/m. K). The increase in thermal conductivity is attributed to several factors such as the shape and size of porcelain waste, type of aggregate, porosity and quality of cement used.

3.2 Specific Heat Capacity

The specific heat capacity of materials was measured in accordance with standard test method (ASTM C351 and E1269) by using "Calorimeter". The following equation was used for mean specific heat capacity calculation as shown below.

$$m_s . cp_s \ (T_S - T_2) = m_w . cp_w \ (T_2 - T_1) + m_c . cp_c \ (T_2 - T_1) \quad (1)$$

where m_s is the mass of specimen, cp_s mean specific heat capacity for specimen, T_s temperature of heated specimen (100 °C) before putting inside the calorimeter, T_2 final temperature after putting the heated specimen inside calorimeter, T_1 initial temperature of water (0 °C), m_w is the mass of water, cp_w is specific heat capacity of water (4200 J. $kg^{-1}.K^{-1}$), mc is the mass of calorimeter and cp_c specific heat capacity of calorimeter. The specific heat capacity of the concrete was determined at curing age of 60 days and presented in Table 8 and Figure 5.

Table 8
Specific heat capacity results for concrete specimens made with different percentage of porcelain waste at 60 days

Sample	Specific heat capacity at 60 days (J/kg. K)
R	753
M 10	768
M 20	791
M 30	841
M 40	902
M 50	974

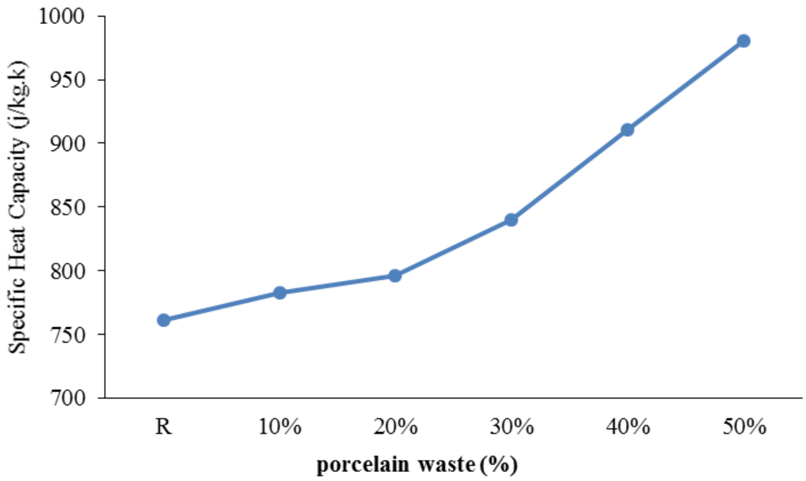


Fig. 5. Specific heat capacity with different percentage of porcelain waste

Figure 5 shows that the minimum value of specific heat capacity was achieved for the control sample as 753 J/kg·K for the curing age of 60 days. As the addition of porcelain waste was introduced to the sample the specific heat capacity increased for 10 %, 20 %, 30 %, 40 % and 50 %. The maximum value was attained at 50 % addition as 974 J/kg·K. The increase in specific heat capacity might be attributed to the shape, type of porcelain waste and the density of concrete. Others suggest factors such as quality of cement, porosity, and type of aggregate.

3.3 Thermal Diffusivity

The thermal diffusivity is described as the ratio of thermal conductivity to the specific heat and density and has units of m^2/s or mm^2/s. It is a physical property of a material which define the rate at which temperature changes within a mass. The thermal diffusivity of the concrete was determined at curing age of 60 days and presented in Table 9 and Figure 6. The thermal diffusivity in this study was calculated from the equation below.

$$D = \frac{K}{Sd} \quad (2)$$

where D = Thermal diffusivity (mm^2/s), K = Thermal conductivity (J/s m K), S = Specific heat (J/kg K) and d = Density of concrete (kg/m^3).

Table 9
Thermal diffusivity results for concrete specimens made with different percentage of porcelain waste at 60 days

Sample	Thermal diffusivity at 60 days (mm^2/s)
R	0.8221
M 10	0.8255
M 20	0.8374
M 30	0.8806
M 40	0.8924
M 50	0.9800

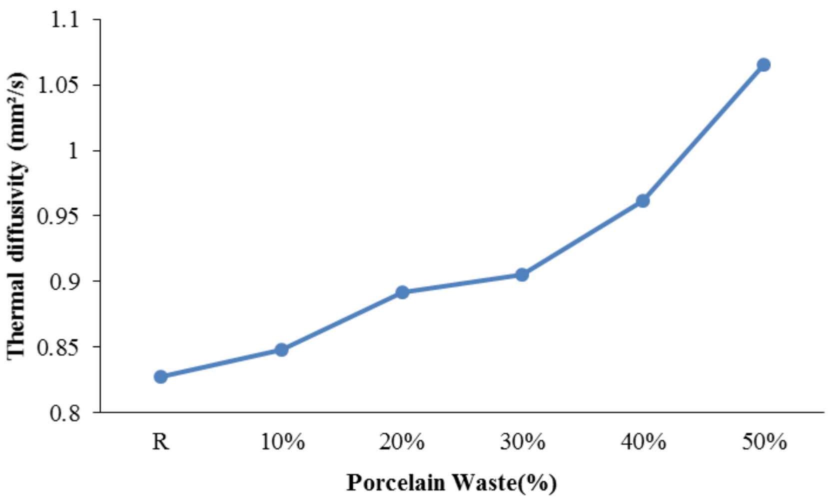


Fig. 6. Thermal diffusivity for concrete with different percentage for porcelain waste

Figure 6 shows that, thermal diffusivity of concrete with substitution of porcelain waste with sand and can be denoted that the control sample has the lowest thermal diffusivity compare to the other samples. It is also important to note that the addition of porcelain waste has significant impact on the thermal diffusivity as the values keep increasing for 10 %, 20 %, 30 %, 40 % and 50 %. The maximum thermal diffusivity reported was obtained at 50 % as 0.9800 mm^2/s for 60 days. The increase in thermal diffusivity can be attributed to several factors such as size of porcelain waste, type of aggregate, porosity, and quality of cement used.

4. Conclusions

Based on the findings of the research, it is clearly seen that, porcelain waste is a good alternative to be used as sand in concrete production. From the results above, it was observed that the increase in the thermal properties; thermal conductivity, specific heat capacity and thermal diffusivity of the produced samples at 60 days are 61.5 %, 29.4 % and 19.3 % respectively. This increase in the thermal properties of concrete could be attributed to the effect of porcelain waste which lead to filling all the voids. Similarly, the finding of this study shows that, the thermal properties of concrete depend on not only density but also bond between and the type of aggregate and porcelain waste with cement matrix.

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