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Effect of Superplasticizer on Thermal Properties of Concrete Containing Porcelain Waste as Sand Replacement

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Mohammed Jamal Jasim[1], Mohamad Zaky Noh[1,*], Shihab Ahmed Zaidan[2], Mohd Haziman Wan Ibrahim[3], Zakiyyu Ibrahim Takai[1]

1 Materials Physics Laboratory, Faculty of Applied Science and Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Educational Hub, 84600 Pagoh, Johor, Malaysia
2 Applied sciences Department, University of Technology, Baghdad, Iraq
3 Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia

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ABSTRACT

Building material demand is putting enormous consumption on the Earth's natural resources**,** as many raw materials have reached critical and painful levels. Therefore, new materials that can replace traditional raw materials in whole or in part attracted the attention of researchers and thus became a hot topic for research. Due to huge production, waste is an ideal candidate for partial replacement of ceramic raw materials. Although porcelain wastes are produced at an annual rate, it is rarely used in construction materials, so their value in the construction sector will be very advantageous from an environmental and economic point of view. In the current research, the samples were prepared from cylinder concrete and cutting it using concrete cutter to produce the required specimens with diameter of 4 cm and 0.5 cm thickness according to the method used (hot plate method). Superplasticizer and water were homogeneously mixed for 2 minutes and added to the composition of concrete for casting process. Subsequently, the thermal conductivity, specific heat capacity and thermal diffusivity were studied. The investigation revealed that the addition of porcelain waste increased the thermal conductivity, specific heat capacity, and thermal diffusivity which was found to be 2.41 K(w/m.k), 979 J/kg.k and 1.06 mm^2/s respectively at 50 % replacement for 60 days. The results show improved thermal properties with an added superplasticizer.

Keywords:
Concrete; Sand; Porcelain waste; Thermal properties; Superplasticizer

1. Introduction

The increasing world population is increasing the amount and type of waste generated by human activities. Many wastes produced today will remain in the environment for hundreds and perhaps thousands of years. One solution to this crisis lies in recycling wastes and treat them suitable chemical admixture so as to make useful products [1-2]. The study of thermal properties of the concrete is the ongoing research since most people spend around 90% of their lives indoors [2], energy conservation

[*] *Corresponding author.*
E-mail address: zaky@uthm.edu.my (Mohamad Zaky Noh)

and thermal comfort in buildings are controversial topics. The energy required for building cooling and heating and thermal comfort depends greatly on the thermophysical properties of the construction materials [3].

Heat transfer is a vector quantity and occurs through conduction, convection, and radiation [4]. Conductive heat transfer in solids is a mixture of molecular vibrations and energy transport by free electrons [5]. Thermal conductivity (k-value) is a material's property that demonstrates its heat conduction capability [5].

Specific performance plays a vital role in the development of infrastructure including commercial, industrial, residential, and military structures. Recently, the widespread use for reinforcement in the concrete is not only suitable for medium structures, but also for large-span heavy-duty architectures, in order to obtain high strength concrete with homogenous structure, the minerals, and chemical admixtures are added to the fresh mixture of ordinary concrete. Heating and cooling systems consume a large amount of total energy consumption in the world energy production center [6]. The energy consumption must be minimized through economic and environmental values. The construction industries are considered to be one of the fastest-growing industries and play an important role in global energy consumption [7]. In order to designed and reduce heat loss to achieve energy efficiency. As well as minimize energy consumption in buildings by improving the thermal insulation properties in the concrete associated with the use of these materials [8]. Furthermore, thermal properties are an important property of construction and design; therefore, these structures also need to have suitable mechanical and thermal properties [9].

The rate at which concrete materials are responded to heat is considered as the thermal properties of those materials, once the temperature increases subsequently the size and shape of that materials increase as well as the energy absorption of that materials can also increase inform of heat [10]. Normally, the summer and winter have different energies require for building materials, which usually depend on the physical structure of that material, the most useful thermal properties of building materials include thermal diffusivity, thermal conductivity, specific heat and density [11]. In general, the value of specific heat of building materials is expected to be high, in order to conserve the surrounding heat energy, while lower thermal conductive values in the concrete materials usually provide good insulating behavior of the structure [12]. However, the thermal behavior of the concrete materials varies with proportion, types of the aggregate, cement quality and water content [13]. Furthermore, aggregate material generally accounts for 70-80 % of the volume of Portland cement concrete. It is expected that the influence of aggregate on concrete is also more important than other parameters [14].

However, the superplasticizers are used in almost 70% of the world's cast-in-place concrete is produced from the ready-made concrete industry. Ready-made concrete producers usually use super plasticizer (SP) admixture which is easily available from various manufacturers. Therefore, super plasticizer (SP) can be used to improve the workability of the concrete materials, without changing the water/cement ratio. It can also be used to increase the high strength of concrete by reducing water content while maintaining adequate workability of the structure [15].

The research described in this paper is a continuation of the author's own studies presented in [4]. The results indicate that addition the of super plasticizer (SP) admixture in the concrete material varies thermal stability of that concrete due the facts that these materials may have the ability to accumulate heat energy thermal energy storage—TES, which is associated with new methods of its potential use, for this study focus on the investigation of thermal properties of the concrete such as thermal diffusivity, thermal conductivity, specific heat, and density.

2. Materials and Methodology

Porcelain waste crushed by crusher machine as presented in Figure 1 and Figure 2(a) and (b) which show the porcelain waste before and after grinding. Porcelain waste used in this study is brought 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 were 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.

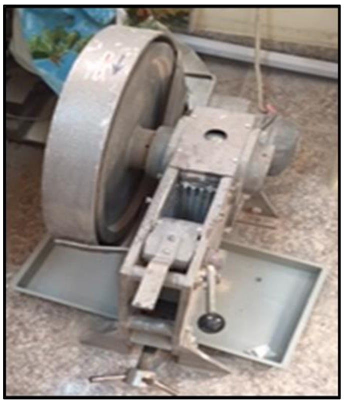

Fig. 1. Crusher machine [4]

(a)

(b)

Fig. 2. (a) before grinding, (b) after grinding [4]

Table 1
Chemical properties of cement [4]

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 [4]

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

Table 3 and Table 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 [4]

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 [4]

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 [4].

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 for the porcelain waste, crushed porcelain waste and sand passed through sieve size of 4.75 mm to 0.15 mm.

For the methodology part to determine the properties of the fresh and hardened concrete samples, the thermal test was carried out. These include thermal conductivity, thermal diffusivity, and specific heat capacity. The tests were conducted on air-dried samples at the age of 60 days according to EN 12667. The hot disk method was used to determine the thermal properties of the concrete. Super plasticizer and water were homogeneously mixed for 2 minutes and added to the composition of concrete. The samples were prepared from cylinder concrete by cutting it by using 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 at 60 days. Thermal properties test such as thermal conductivity; specific heat capacity and thermal diffusivity were conducted to determine the effect of replacement and addition of super plasticizer to the mixture. The mixture of the concrete was done according to IS 10262:2009, IS 456:2000 and IS 383:1997. Water-cement w/c ratio is 0.37. Table 7 and Table 8 show the quantities of mix for one cubic meter of concrete and replacement percentage from porcelain waste and super plasticizer added at 0.75 wt. % of cement.

Table 6
Sieving process for porcelain waste [4]

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

Table 7
The quantities of mixture for concrete

Materials	Quantity
Cement	180 kg
Sand	270 kg
Coarse aggregate	540 kg
Water	67.5 lit
Waste porcelain	67.5 kg
Superplasticizer	1.35 lit

Table 8
The different percentage for porcelain waste and super plasticizer (0.75%) from cement weight

Porcelain waste (%)	Cement (kg /m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	SP (lit)	Water (lit)
0	30	45	90	0.225	11.25
10%	30	40.5	90	0.225	11.25
20%	30	36	90	0.225	11.25
30%	30	31.5	90	0.225	11.25
40%	30	27	90	0.225	11.25
50%	30	22.5	90	0.225	11.25

3. Results and Discussion
3.1 Thermal Conductivity

The thermal conductivity of concrete is one of the key parameters needed to predict temperature variation during hydration. This measures the ability of the material to conduct heat and is defined as the ratio of the flux of heat to temperature gradient. It is measured in joules per second per square meter of area of body when the temperature difference is 1°C per meter of the thickness of the body [16]. The conductivity of concrete is determined by the conductivities of its constituents. The major factors influencing the conductivity are the moisture content of concrete, the type of aggregate, the mix proportions [16], the type of cement and the temperature of the concrete. The conductivity of concrete is highly affected by its moisture content, as water has a higher conductivity than air. Though the effects a variation in the moisture content are not as large as those caused by the aggregate type for normal weight concrete [17].

Furthermore, the thermal conductivity measurement (K in W/m.K) was performed by using a hot plate method. However, the thermal conductivity of concrete was determined at 60 days of curing age and the result is recorded in Table 9 and plotted in Figure 3.

Table 9 shows the results of the thermal conductivity of concrete cured within 60 days. A control sample was obtained from Figure 3, and thermal conductivity of 1.53 K (W/m·K) was obtained. Then it is very important to note that by adding 10% sand to replace the porcelain waste with super plasticizer, the thermal conductivity increases to 5.8 %. The maximum thermal conductivity is 2.41 K (W/m·K) at 50% replacement of sand with super plasticizer. It was observed in the sample preparation that when a super plasticizer was added to the mixture, the mixture became very hot due to the chemical reaction between the super plasticizer and the mixture. The thermal conductivity varies with the different contents of porcelain waste in the concrete, with heavier aggregates resulting in higher thermal conductivity [17]. The conductivity of concrete is known generally to decrease with increased temperature, through the loss of pore water and the dehydration of cement paste, hence addition of super plasticizer in the sample reduces the water content in the concrete thereby reducing the pore size and increase the workability of the sample [16-17]. However, once the concrete surface exposed to sufficiently high temperature will undergo these changes and effectively produce an insulating layer of lower thermal conductivity, which acts as a refractory material and reduces the ingress of heat, the mineralogical character of the aggregate greatly affects the conductivity of concrete [18].

Table 9
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	1.53
M 10	1.62
M 20	1.74
M 30	1.9
M 40	2.1
M 50	2.41

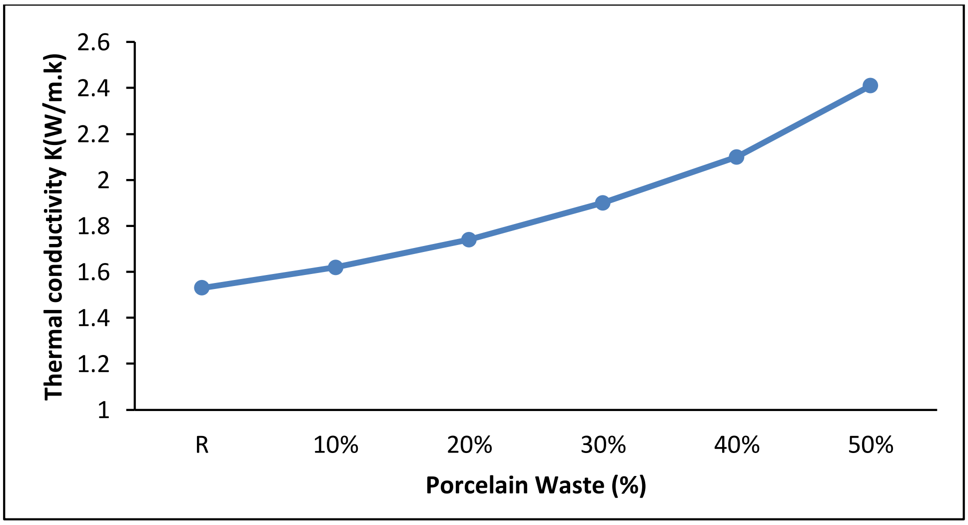

Fig. 3. Thermal conductivity with different percentages for porcelain waste with super plasticizer

3.2 Specific Heat Capacity

The test specimens of cylindrical shapes were prepared and cured according to ASTM standard for 60 days. The specific heat capacity of concrete contains porcelain waste replacement was presented in Table 10. From these results can be clearly observed that the specific heat of concrete using the 50 % replacement of porcelain waste shows is greater than the pure concrete without porcelain waste. The highest value of specific heat of the concrete containing 50 % was found to be 979 J/kg-K and the lowest value at 10 % is 761 J/kg-K, due to variation of porcelain waste content in the concrete materials. The graph values are characterized with respect to coarse aggregate types and mixing ratio. It is observed that this concrete which has lower density show greater specific heat and the higher density concrete has lower specific heat. From Figure 4 it can be concluded that the specific heat is directly proportional to the porcelain waste content in the concrete material.

Furthermore, the specific heat capacity can also be express as the heat capacity of the material measured by "calorimeter" according to standard test methods (ASTM C351 and E1269). The following equation can also be used to calculate the specific heat capacity of the concrete materials.

$$m_S . cp_s \, (T_S - T_2) = m_w \, . cp_w \, (T_2 - T_1) + m_c . cp_c \, (T_2 - T_1) \tag{1}$$

where m_s is the mass of specimen, c_{ps} 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, C_{pw} is specific heat capacity of water (4200 J/kg.K), m_c is the mass of calorimeter and C_{pc} specific heat capacity of calorimeter. The specific heat capacity of the concrete was determined at curing age 60 days and is present in Table 10 as well as plotted in Figure 4.

Table 10
Specific heat capacity results for concrete specimens made with different percentages of porcelain waste with superplasticizer at 60 days

Sample	Specific heat capacity at 60 days J/kg. K
R	761
M 10	783
M 20	796
M 30	851
M 40	911
M 50	979

It can be seen from Figure 4 that the specific heat capacity of the control sample shows the minimum value for the curing age as 761 J/kg.K for 60 days, with addition of porcelain waste in the concrete materials make the specific heat capacity increase due to increase of more contents of porcelain waste (10 %, 20 %, 30 %, 40 % and 50 %) present of super plasticizer in the concrete make the sample less porous thereby reducing the water content in the concrete which leads to decrease of specific heat capacity [17-18]. The maximum value of specific heat capacity was found to be 979 J/kg.K with the addition of 50 % porcelain waste. The increase in specific heat capacity can be attributed increased in the temperature of mixture, thus, the high temperature of the mixture is caused by super plasticizer in the concrete sample, and furthermore, increase in temperature leads to increase in the specific heat capacity as shown in the Figure 4, similar findings were reported by [19].

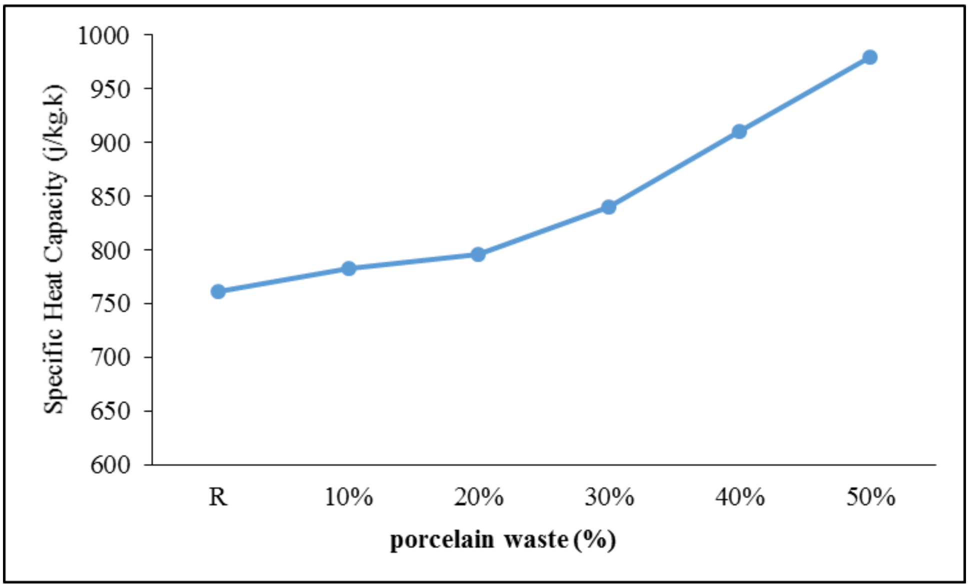

Fig. 4. Specific heat capacity with different percentages of porcelain waste with superplasticizer

3.3 Thermal Diffusivity

Thermal diffusivity is a measure of the rate at which temperature changes within the mass of the materials. The larger the value of thermal diffusivity of a mass the faster the changes will occur. The value of thermal diffusivity is dependent on the aggregate type, moisture content, degree of hydration of the cement paste, and exposure to drying [18-19].

The thermal diffusivity of the concrete was determined at curing age 60 days and is present in Table 11 and subsequently plotted in Figure 5. This section discusses the results obtained from the surface pressure measurement study. The effects of angle of attack, Reynolds number and leading-edge bluntness are discussed accordingly.

$$D = \frac{K}{Sd} \tag{2}$$

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 11
Thermal diffusivity results for concrete specimens made with different percentage of porcelain waste with superplasticizer at 60 days

Sample	Thermal diffusivity at 60 days (mm^2/s)
R	0.827371
M 10	0.847937
M 20	0.892216
M 30	0.905007
M 40	0.961617
M 50	1.065226

Figure 5 shows the thermal diffusivity of concrete with replacement of porcelain waste as sand with super plasticizer, it was revealed that the control sample has the lower thermal diffusivity compared to the other samples. It is also important to note that the addition of porcelain waste with super plasticizer 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 at 50 % as 1.065226 mm^2/s for 60 days. It is shown that the thermal diffusivity of concrete specimens containing porcelain waste and super plasticizer to the concrete show greater value of thermal diffusivity than the concrete without super plasticizer which was further reported in [19-20]. This is probably due to the variation of the waste materials as well as chemical admixture (super plasticizer) in the concrete materials [20]. Again, in case of coarse aggregate types, the diffusivity of concrete is less when brick chips were used as coarse aggregate and the stone chips [21].

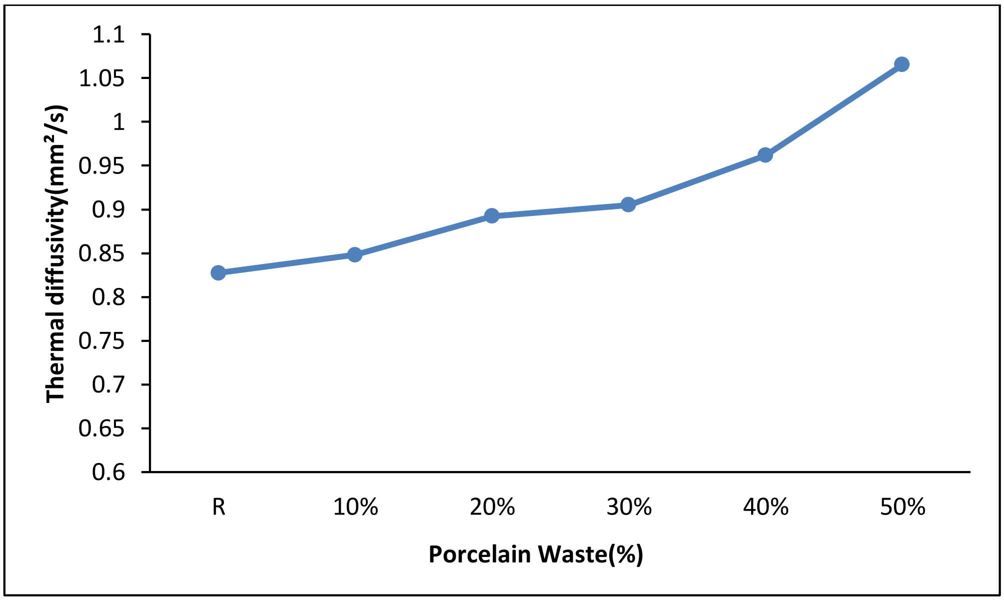

Fig. 5. Thermal diffusivity for concrete with different percentages for porcelain waste with super plasticizer

4. Conclusions

In summary, the addition of super plasticizer 0.75 % to the concrete mixture contains porcelain waste replacement as sand possesses excellent conductive properties of the concrete materials. Conclusively, the concrete mixtures contain porcelain waste and super plasticizer shows greater thermal properties than the reference concrete. Similarly, the result further revealed that at 60 days there is increase in thermal conductivity, specific heat capacity, and thermal diffusivity 57.5 %, 28.6 %, and 27.8 % respectively. This increase in the thermal properties can be attributed to the chemical reaction of super plasticizer with the mixture which leads to the formation of continuous three-dimensional network of super plasticizer molecules throughout concrete thereby increasing the binder system due to good bond characteristics of the super plasticizer.

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