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Thermal Properties of Light Weight Self - Compacting Concrete Incorporate Nano Silica

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ABSTRACT

In Iraq, certain rocks called porcelanite can be used to make lightweight concrete. The objective of this paper is to create lightweight self-compacting concrete (SCC) by utilizing 0.4 w/cm, coarse and fine porcelanite aggregate and adding nano silica to these mixtures. This study looks at a different way of doing things. Instead of using sand in concrete, they used varying amounts of fine porcelanite instead. We replaced 10%, 20%, 30%, 40%, and 50% of the sand with porcelanite to see how it would influence the concrete's thermal characteristics. Further examined the ratio of water to cement, using ratios of 0.4 and 0.5 by doing this, we wanted to see how both ratio of water to cement, and amount of porcelanite affected the thermal properties of the concrete. It was found that porcelanite makes self-compacting concrete harder to work with, and less able to conduct and spread heat. However, it does make the concrete hold more heat. When nano silica was used, it reduced workability of SCC. However, its effect on thermal properties was not of much significance.

1. INTRODUCTION

At the present time, people are really concerned about energy and the environment. In the past few years, there has been a large increase in the number of people and factories, which has resulted in more energy being needed. One of the main reasons for this is because buildings use up a lot of energy [1]. Concrete is a commonly employed substance in constructing structures such as buildings and roads due to its economy, versatility, and availability [2]. Samson et al. [3] state that concrete is very popular in construction because it is cheap and lots of people use it. Recent statistics indicate that the production of regular concrete surpasses 26.8 billion tons annually across the globe [4]. Investigators have been working on creating new strong materials that have the advantages of self-compacting concrete and lightweight concrete. Lightweight self-compacting concrete (LWSCC), a novel concrete with the characteristics of both LWC and SCC, has been created. By substituting light weight aggregate (LWA) for normal weight aggregate (NWA) in SCC, LWSCC is created. ACI 213 [5] says that structural lightweight concrete should have a density between 1120 kg/m^3 and 1920 kg/m^3. Aggregates make up most of the weight of concrete and typically make up about 60% of the volume in SCC [6]. Due to its small perforations, LWA has the ability to lighten concrete and enhance its heat insulation abilities. Using LWSCC has many advantages. It makes things lighter, which helps make the construction process faster and cheaper. It also gets rid of noise from vibrating machines and provides better insulation for heat and sound because of the empty spaces in the material [7-9].

When evaluating the quantity of heat carried, the ability of cement-based materials to transmit heat should be taken into account. Buildings require more energy when heat escapes through the walls and roof. Thermal conductivity can be measured primarily in two ways: transiently and steadily. The way concrete conducts heat depends on a number of factors, including temperature, moisture content, kind of aggregate, type of cement, and density [10].

In most countries, buildings are responsible for using one third of all the energy and producing 30% of the greenhouse gases [11, 12]. Because people spend most of their time inside buildings, discussions about saving energy and maintaining a comfortable temperature are often debated [13]. The amount of energy needed to cool or heat a building and make it comfortable depends on the properties of the materials used for construction [14]. Ventilation and when heat escapes through materials are two reasons why buildings lose heat. Ventilation heat loss means that heat is transferred through the air when it is replaced via systems for ventilation, heating, and air conditioning. That being said, there is a connection between the heat loss of the fabric and the heat loss through the floors, walls, roof, and windows of a space. Concrete is thought to handle heat differently depending on its thermal conductivity, specific heat, and thermal diffusivity. Thermal conductivity is how well heat moves through concrete. It's a really important property that affects how heat is transferred by conduction [15]. Concrete that is difficult for heat to travel through keeps buildings cooler and uses less energy. According to Real et al. [16], when compared to normal weight concrete (NWC), the usage of structural lightweight aggregate concrete in European structures can save up to 15% on heating energy. There are many different ways to measure how well materials conduct heat. Various ways of measuring thermal conductivity may lead to different values [17]. Choosing the right way to measure how well heat travels through concrete is crucial for getting accurate numbers on how much energy buildings use. Also, it is important to mention that there are many things that can change the k-value of concrete [10].

In order to use "thermostone" as aggregate after crushing, Ibrahim et al. [18] measured the thermal characteristics (thermal diffusivity, specific heat & thermal conductivity) of concrete made by reusing the waste of clay brick. To accomplish this, they created three distinct blends. One of them used crushed clay brick instead of normal aggregate, and the other two used crushed thermostone in different amounts. Then compared these three mixes with a usual concrete mixture. Using a method called semi-adiabatic calorimeter, the specific heat was measured. Using the semi-adiabatic calorimeter method in the work, the specific heat was measured. While using the heating - cooling system method, thermal diffusion and specific heat were measured. To find thermal conductivity, they multiplied the thermal diffusivity, specific heat, and density. The researchers found in their experiments that as the concrete density increases, the ability of heat to spread out quickly also increases. However, the amount of heat that the concrete can hold decreases as its density increases. Thermal conductivity and thermal diffusivity are closely related. The amount of each ingredient in concrete affected how it handled heat.

Three different kinds of equipment were invented and built by Ahmed [19] to measure the thermal diffusivity, thermal conductivity and specific heat of concrete. These apparatuses are used to measure different properties of concrete. One tool measures how well concrete holds heat, another measures how heat moves through concrete, and a third measures how well concrete conducts heat. It was found that the lee disc method is a reliable way to measure how well heat moves through concrete. It is easy and convenient to use on a website to solve the problem of not having enough devices to measure thermal conductivity in building materials. In addition, they found that they could use a semi-diabatic calorimater method to detect the specific heat of any kind of concrete. A device that heats and cools the concrete can also be used to measure its thermal advantage, as long as the concrete density is within the range of 900-2400 kg/m^3.

The goal of this work is to investigate how the characteristics of both fresh and hardened concrete are affected when LWA and nano Silica are added to an SCC mixture. This covers the heat-transfer and heat-holding capacities of the concrete. additionally examined the water-to-cement ratio, doing so with ratios of 0.4 and 0.5.

2. EXPERIMENTAL PROGRAMS

The experimental setup involved the casting of 120 (100*200 mm) cylinders for the assessment of specific heat and thermal diffusivity, 120 (280*280*40 mm) square plates for the measurement of thermal conductivity, and 120 (100*25 mm) discs for the measurement of thermal conductivity for various concrete mixes.

2.1 Material

Portland cement (Type I) was used in this work. The cement chemical and physical characteristics demonstrate that it satisfies the criteria of Iraq standard No. (5)-1984. The crushed gravel supply from Al-Soddor region was used. It was known as porcelainnite and had a maximum size of 12.5 mm. The test results for the physical properties and chemical compositions of the coarse porcelanite aggregate are shown in Tables 1 and 2, respectively. Al-Ukhaider, a natural sand, was sieved using a 4.75 mm sieve size before being utilized as a fine aggregate. Grading of fine porcelanite and its properties are shown in Tables 3 and 4. In our study, we employed a high range water-reducing admixture called glenium 51. The supplier of silica fume (SF) was SIKA Company. Table 5 lists the features of the used SF. AEROSIL ® Company powdered silica nanoparticles, imported from North America, were employed in this experiment. The physical and chemical characteristics are displayed in Tables 6 and 7.

Table 1. Physical properties of course porcelanite aggregate

Physical Properties	Results
Absorption %	32
Saturation percentage	3.6
Bulk density Kg/m^3	891

Table 2. Chemical analysis of porcelanite stone aggregate

Analysis of Porcelanite Stone Chemically Aggregate	Percentage
Silicon dioxide	62.2%
Calcium oxide	11.5%
Magnesium oxide	7.2%
Aluminium oxide	2.7%
Iron (III) oxide	0.8%
Titanium dioxide	0.2%
Sulfur trioxide	0.3%
Letter of intent	13.8%

Table 3. Grading of fine porcelanite

Sieve Size (mm)	%Passing
9.5	100
4.75	99
1.18	53
0.3	23
0.15	15

Table 4. Physical properties of fine porcelanite

Physical Properties	Test Result
Absorption%	32
Specific gravity	1.38
Loose bulk density (SSD) Kg/m^3	977

Table 5. The properties of silica fume

Type	Densified Silica Fume	ASTM C1240-05
Form	Powder	-
Color	Gray	-
Surface area	2400-2800 m^2/kg	≥15000 m^2/kg
SiO_2	≥90%	≥85%
SO_3	≤0.29%	-
CaO	≤0.8%	-
Cr	≤0.035%	-
Strength activity index	106%	≥105%

Table 6. Physical properties of SiO_2 nano particles

Form	Powder
Color	White
Specific surface area	200 m^2/k
Diameter size	4 nm

Table 7. SiO_2 nano particles chemical analysis

SiO_2 Content Based on Ignited Material	99.8%
PH	3.7-4.5
L.O. I	≤1%

Table 8. The details of the mixes

Group	Mixture Name	Cement (Kg/m^3)	Silica Fume (Kg/m^3)	Nano Silica Replacement (%) by Weight of Cement	Fine Aggregate: Sand (Kg/m^3)	Fine Aggregate: Fine Porcelinite (%) Replacement by Volume of Sand	Coarse Aggregate: Gravel (kg/m^3)	Coarse Aggregate: Coarse Porcelinite Replacement (%) by Volume of Gravel	W/P	Water (kg/m^3)	HRWRA (L/m^3)
1	0.5C	510	90	0	785	0	890	0	0.5	300	5
	M1	510	90	0	706.5	10	890	0	0.5	300	5
	M2	510	90	0	628	20	890	0	0.5	300	5
	M3	510	90	0	549.5	30	890	0	0.5	300	5
	M4	510	90	0	471	40	890	0	0.5	300	6
	M5	510	90	0	392.5	50	890	0	0.5	300	6
2	0.4C	510	90	0	785	0	890	0	0.4	240	9
	M6	510	90	0	706.5	10	890	0	0.4	240	9
	M7	510	90	0	628	20	890	0	0.4	240	9
	M8	510	90	0	549.5	30	890	0	0.4	240	10
	M9	510	90	0	471	40	890	0	0.4	240	10
	M10	510	90	0	392.5	50	890	0	0.4	240	10
3	M11	494.7	90	3	785	0	890	0	0.4	240	13
	M12	484.5	90	5	785	0	890	0	0.4	240	16
4	M13	517.6	90	0	0	100	890	0	0.4	240	12
	M14	494.7	90	3	0	100	890	0	0.4	240	17
	M15	484.5	90	5	0	100	890	0	0.4	240	22
5	M16	517.6	90	0	785	0	0	100	0.4	240	10
	M17	494.7	90	3	785	0	0	100	0.4	240	14
	M18	484.5	90	5	785	0	0	100	0.4	240	18

2.2 Concrete mixture amount

2.2.1 Mix details

In this search, we made and tried out twenty different mixtures. We divided them into five groups to test them. ACI 237R-07 [20] was used to design a self-compacting concrete mixture for reference. To make LWSSC, they used coarse porcelanite aggregate instead of gravel and fine porcelanite aggregate instead of sand. Table 8 shous the information about the combinations.

2.2.2. Mixing procedure

Before mixing, make sure the inside surface of mixer is dry and too clean. Initially, aggregate (Coarse and fine) is mixed for one minute. Then, the cement and binder materials (silica fume, and nano silica) are blended with the aggregate for one minute. Next step, two-thirds of the water is mixing with mixture and we continue mixing it for two minutes. Then, glenium 51 is blended with one-third of water and added to mixture. At last, the mixing continues for an additional 2 minutes.

2.2.3 Casting and curing of test specimens

To keep the concrete from adhering to the mold once it hardens, it's crucial to clean it well and oil it before pouring the concrete into its. After the molds are filled, a trowel is used to make the top surface even and smooth. Before removing the specimens, they are covered in nylon sheets for 24 hours. This reduces the probability of the drying and prevents cracking. The samples were removed from the molds and submerged in tap water until the testing phase.

2.2.4 Test method

As for the evaluation of fluidity of SCC, Slump flow and T50 test, J-ring test L-Box test [21] were used in laboratory. The test for heated guarded plates is the accepted gold standard for figuring out the flat slab's homogenous insulating material's heat transmission properties. The steady state test protocol has been standardized by ASTM C 177 [22]. The capacity of a material to transfer heat is indicated by its thermal conductivity, often represented by the symbol (k). These properties are measured using the Ahmed technique [19]. Concrete thermal diffusivity was measured using a heating-cooling apparatus [19]. Concrete's specific heat can be determined using a variety of techniques, including electrical and calorimetric approaches. This study makes use of a calorimeter. Concrete using the semi-adiabatic calorimeter approach [19].

3. RESULTS

3.1 Workability

The workability test result for SCC mixtures is presented in Figures 1, 2, 3 and 4. All of the test results are within specified limits of [21]. It can be inferred from these figures that the utilization of additional fine porcelanite results in a decrease in the workability of SCC mixtures. Two factors are thought to be responsible for this effect: first, the high absorption of porcelanite reduces the amount of water needed to mix the material in order to achieve the necessary workability; second, the laminar form of the fine porcelanite may provide additional challenges for workability. By using HRWRA, the impact of these elements was reduced.

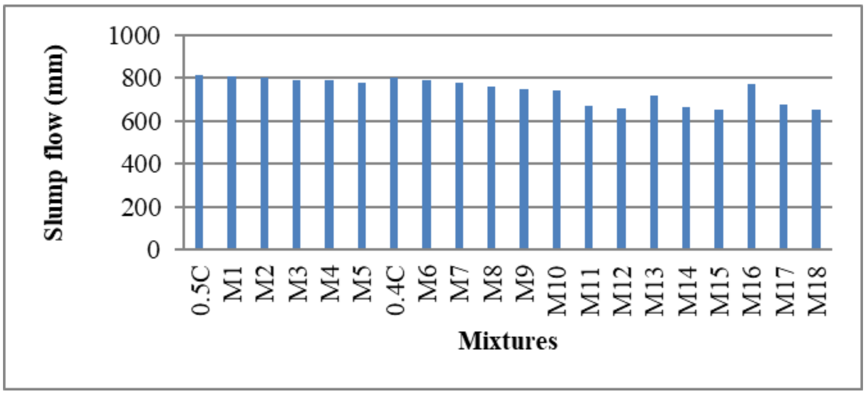

Figure 1. Slump flow test results

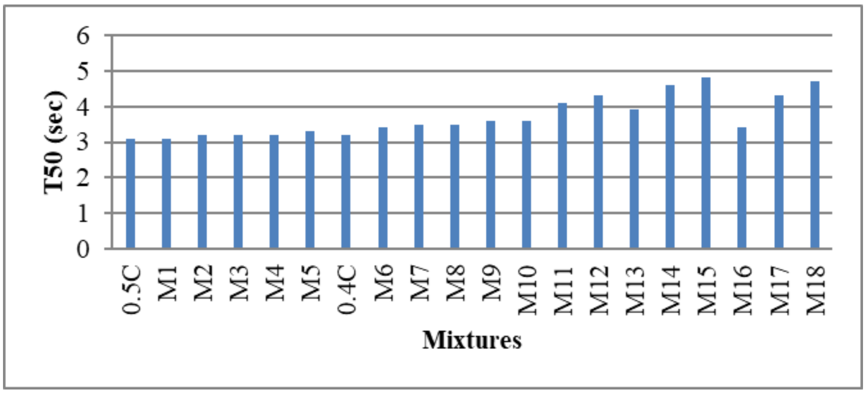

Figure 2. T50 test results

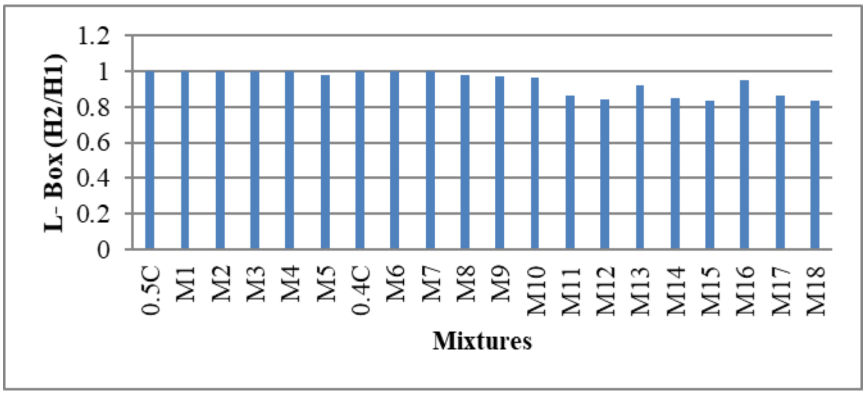

Figure 3. L-Box test results

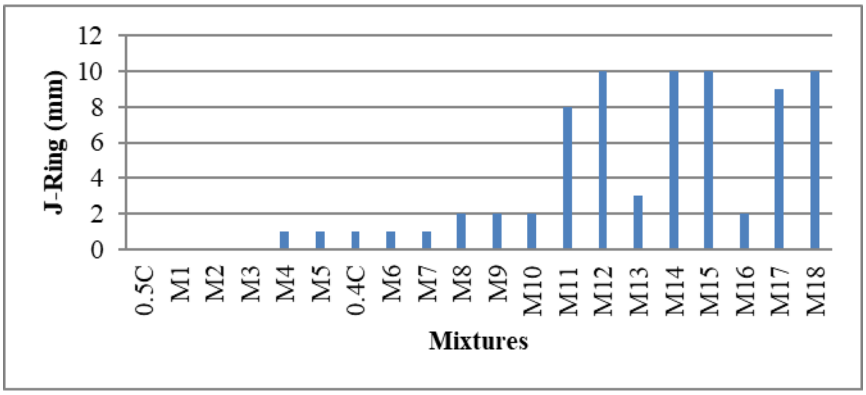

Figure 4. J-Ring test results

3.2 Using hot guarded plate method (HGP) & Lee's disc method to measure thermal conductivity (k) plate

Figure 5 displays the results of thermal conductivity for saturated surface dry case (SSD) and oven dry case at ages 7 and 28 days using the "HGP" technique. As well as the results of thermal conductivity in oven dry case at ages 28 days using Lee's disc method for all SCC mixes. It is evident that for all SCC mixes (SSD case and oven dry case) at 28 days the results of thermal conductivity are greater than thermal conductivity for mixtures at 7 days. This happens because hydration products are constantly formed, which makes the concrete matrix denser and increases its ability to conduct heat. The thermal conductivity of concrete is higher when it is in a saturated surface dry (SSD) state compared to when it is completely dry. Water contained within the pores of the micro - structure of concrete causes the increase in thermal conductivity. This is true for both 7 and 28 days (see Figure 6). Additionally, using the HGP approach, it displays the proportionate growth in SSD thermal conductivity and oven dry thermal conductivity between the ages of 7 and 28 days. Figures 7 and 8 show that when the replacement % of fine porcelanite aggregate increases, the thermal conductivity for both SSD and oven dry decrease at 7 and 28 days. This behavior happens because the porcelanite aggregate has lots of tiny holes. When the fine and coarse porcelanite aggregate is fully replaced with a water to cement ratio of 0.4, the thermal conductivity of self-consolidating concrete (SCC) decreases because of the pores present in the porcelanite aggregate. Because fine porcelanite aggregate contains fewer interior holes filled with air, which reduce thermal conductivity, the thermal conductivity is higher in the case of fine porcelanite than in the case of coarse porcelanite. Figures 8, 9, and 10 show when the proportion of nano silicarises, thermal conductivity also rises for SCC mixes (SSD and oven dry) at 7 and 28 days. The decrease in accessible pores brought on by a rise in nano silica concentration is the reason for this behavior. It was hardly a noteworthy rise, though.

3.3 Thermal diffusivity and specific heat

The material thermal diffusivity determines the rate at which temperature changes may occur inside a unit mass [23]. The thermal diffusivity for each SCC combination at age 28 days is displayed in Table 9 and Figure 11. It is evident that when concrete's density drops, so does its thermal diffusivity. Thermal diffusivity in the SCC mixture is not greatly increased by adding nano silica. The term "specific heat" refers to the amount of heat required to change the temperature of a given quantity of material by a specific degree [23]. The specific heat for each SCC combination at age 28 days is displayed in Table 9 and Figure 12. It is evident that when concrete's density drops, the specific heat rises. The specific heat of the SCC mixture is unaffected by the addition of nano silica.

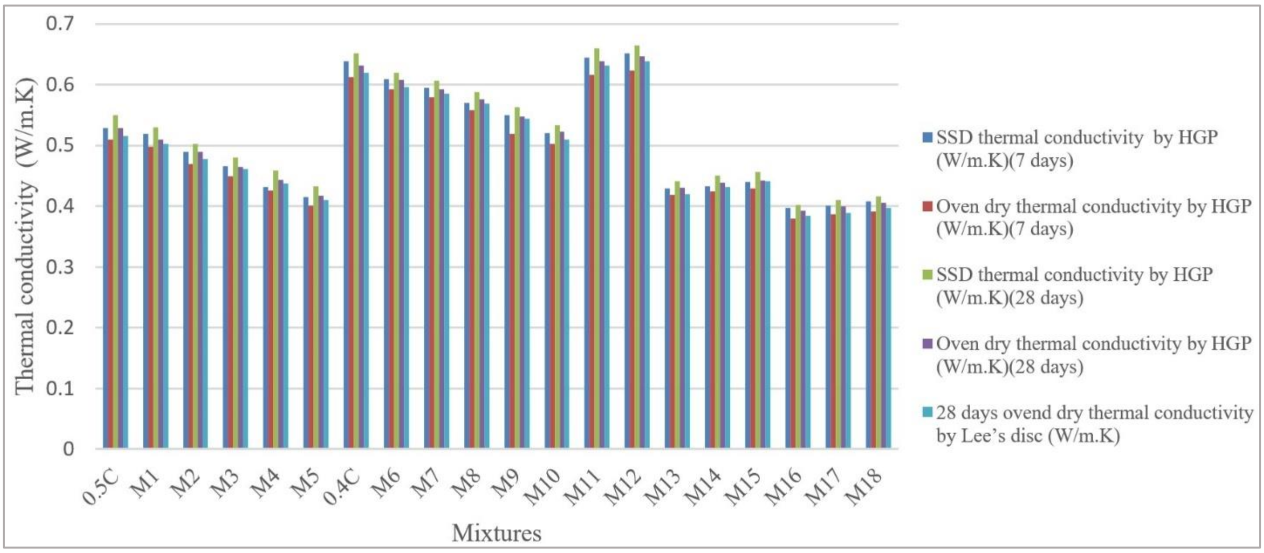

Figure 5. Test results for thermal conductivity (k) for every mixture

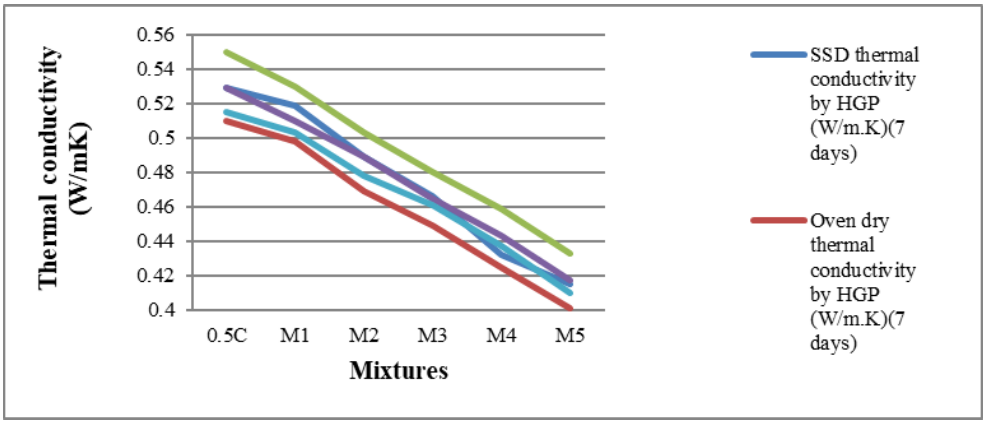

Figure 6. Results of the thermal conductivity (k) test for each mixture in G1

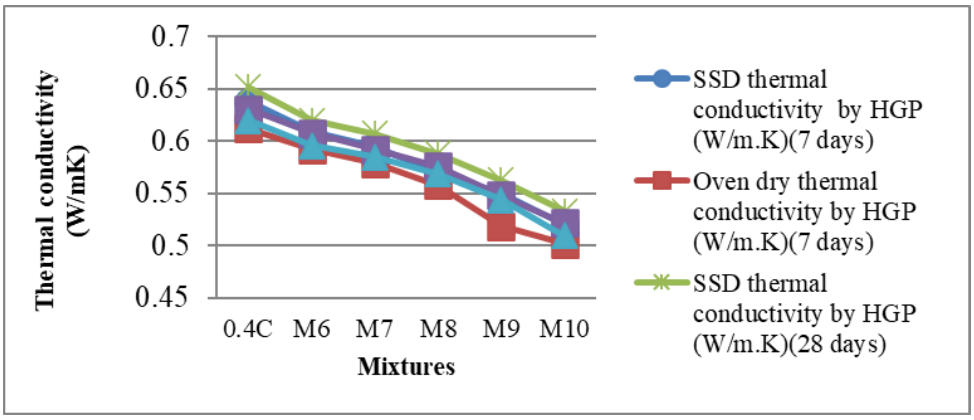

Figure 7. Test results for thermal conductivity (k) for every mixture in G2

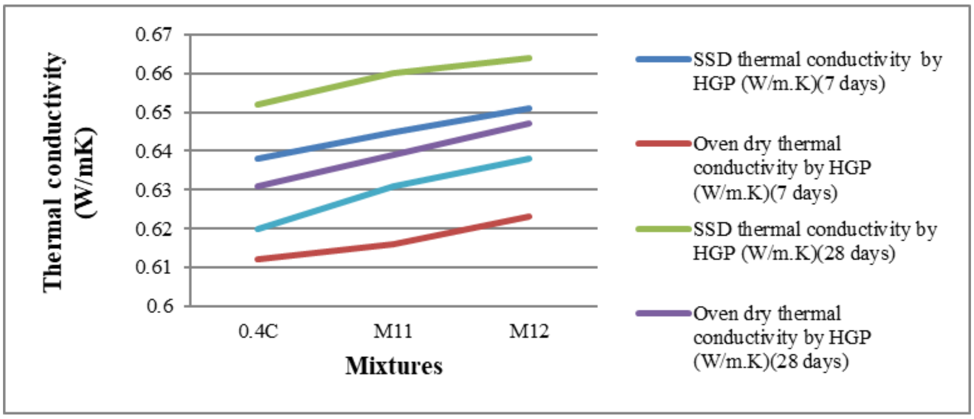

Figure 8. Results of the thermal conductivity (k) test for each mixture in G3

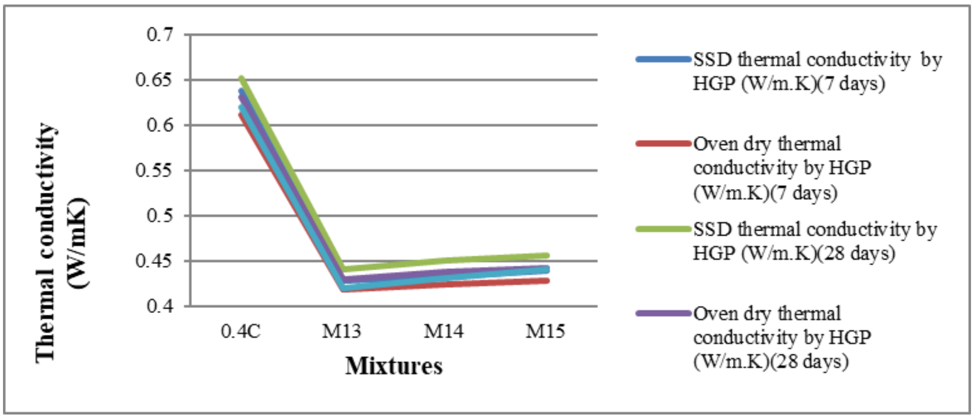

Figure 9. Results of the thermal conductivity (k) test for each mixture in the G4 and 0.4C mixes

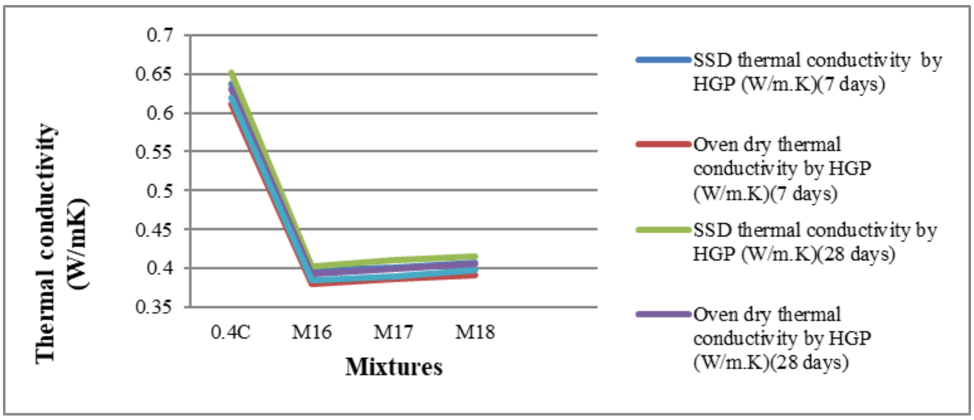

Figure 10. Results of the thermal conductivity (k) test for the 0.4C mixture and all mixtures in G5

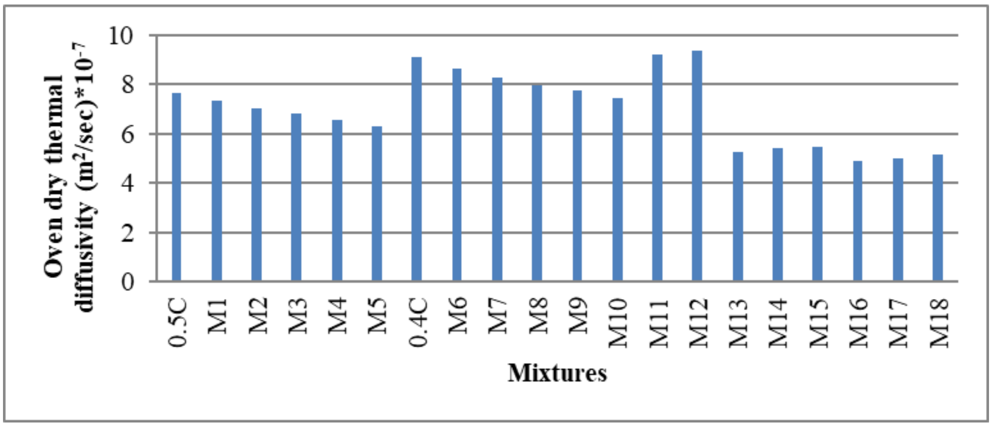

Figure 11. Oven dry thermal diffusivity at 28 days for all SCC mixtures

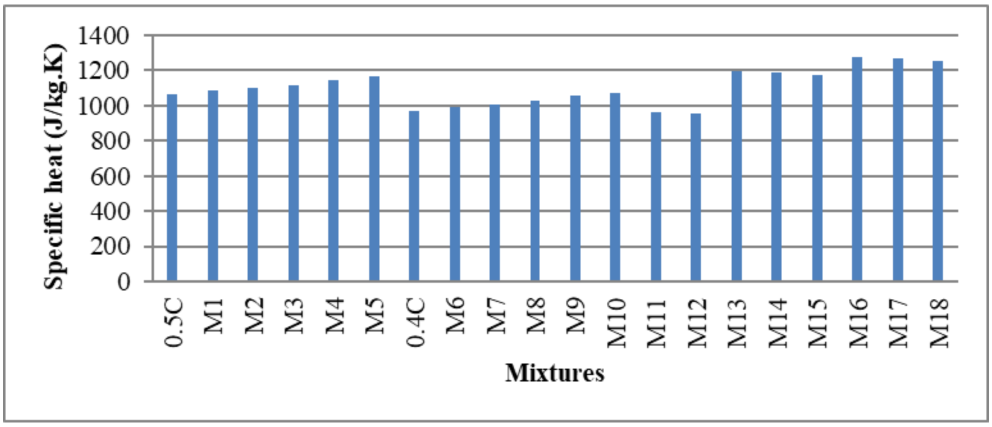

Figure 12. Oven dry specific heat at 28 days for all SCC mixtures

Table 9. Specific heat and oven-dry thermal diffusivity for all SCC mixes at 28 days

Groups	Designation of Mixtures	Density of Oven Dry at 28 Days (kg/m^3)	Thermal Diffusivity of Oven Dry (m^2/sec) *10^{-7} at 28 Days	Specific Heat of Oven Dry (J/kg.) at 28 Days
1	0.5C	2177.4	7.66	1066
	M1	2145.1	7.35	1086
	M2	2115.9	7.01	1101
	M3	2085.5	6.83	1118
	M4	2059.3	6.55	1141
	M5	2028.1	6.31	1167
2	0.4C	2317	9.13	971
	M6	2287.1	8.64	992
	M7	2255.3	8.28	1008
	M8	2227.8	7.95	1030
	M9	2194.3	7.76	1059
	M10	2166.2	7.47	1074
3	M11	2323.1	9.24	962
	M12	2327.9	9.37	955
4	M13	1985.1	5.27	1193
	M14	1990.7	5.39	1185
	M15	1996.2	5.46	1173
5	M16	1864.4	4.9	1274
	M17	1869.6	5.01	1266
	M18	1872.8	5.13	1252

4. CONCLUSION

In this paper, we studied the nano materials and the applications of lightweight aggregates in self-compacting concretes. So, we discuss thermal properties SCC and the fresh properties, based on that, it is concluded that:

1. We can make a special kind of concrete called structural lightweight self-compacting concrete.
2. Using porcelanite as a material in self-compacting concrete makes it harder to work with, especially when

using fine porcelanite compared to coarse porcelanite.

3. Using fine and coarse porcelanite aggregate instead of sand and gravel reduces how easily heat can move through and how quickly heat can spread in SCC. However, it also increases the ability of SCC to store heat.
4. Nano silica makes self-compacting concrete (SCC) better at conducting heat and spreading heat quickly. However, it makes SCC less effective at storing heat. However, this impact is not very important or noticeable.
5. Lee's disc method showed high reliability in measuring thermal conductivity of the produced samples when compared with hot guarded plate method.
6. It was discovered that how much fine porcelanite aggregate is replaced impacts thermal conductivity, thermal diffusivity, and specific heat more than the water-to-cement ratio.
7. The future proposal is to study other types of lightweight aggregates and other nanomaterials and their effect on the thermal insulation of concrete.

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