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Effect of Ordinary Portland Cement on Some Properties of Pervious Geopolymer Concrete

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ABSTRACT

In this research, a study is made on the Pervious Geopolymer Concrete (PGC), which is based on local material (Metakaolin). The inclusion of Ordinary Portland Cement (OPC) as a partial substitute for Metakaolin (MK) for the production of (PGCs) has also been investigated. Pervious Geopolymer concrete was outputted from the local Metakaolin (MK), and ordinary Portland cement (OPC) as a partial substitute by weight of MK and silicate of sodium (Na2SiO3) and hydroxide of sodium (NaOH) solution. All PGC samples were cured after 24 hours from casting for five hours at a temperature degree of 50 ° C, then they tested after 28 days. The compressive-strength, total content of voids, the strength of bending, dry-density, and thermal-conductivity of pervious Geopolymer concrete were examined. The mechanical results of testing ranged from (11.03 and 2.25) to (14.3 and 2.75) MPa for compressive-strength and flexural strength respectively.

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1. INTRODUCTION

Producing geopolymer cementing requires alumina-silicate resources materials such as Metakaolin (MK) and Fly Ash (FA), a user- friendly alkaline agent (soluble of sodium or potassium silicate with a concentration of SiO_2 to M_2O equal or more than 1.65) and water. The temperature of room cause hardening is more-readily done with the addition of a source of calcium cation [1].

Geopolymer cement can be concocted to cure more-rapidly than ordinary Portland-based cement; some mixtures gain most of their ultimate strengths within 24 hrs. Also, they must set slowly sufficient that they can be mixed at a batch factory, either for delivery or precasting in a concrete mixer. The Geopolymer binding has the ability to produce a stronger chemical-bond with the high-silicate aggregates [2].

To get an alumina-silicate material Metakaolin (MK) with an amorphous shape, it should fire kaolin clay under the controlled condition that it becomes active in concrete. The Geopolymer concrete produced from this source material (MK) has a compressive strength greater than the concrete produced from the Portland cement. The binding material with its high compressive strength gave us the improvement of features [3].

Pervious concrete is one type of concrete that consists of cementing materials, coarse-aggregate, water and if needed some admixtures to be used. In this concrete, the aggregate particles were surrounded by the small layer of cement paste when mixed these components together. Therefore, the connecting voids between the aggregate particles will be formed that leads to enhanced permeability of pervious concrete [4]. Generally, in this concrete (pervious concrete) the ratio of water to cementing materials was ranged between (0.26 and 0.45) and fine-aggregate not greater than 10% [4]. Also, the size of connecting voids ranged from (2 to 8) mm and the total void ratio ranged from (15% to 35%) with a permeability of water between 2 and 12 mm/s [5]. The compressive strength of pervious concrete is low as compared with conventional concrete, it ranged between (3 and 28) MPa [6]. In this study, the dry-density, compressive, and flexural strengths, thermal conductivity, and voids content for pervious Geopolymer concrete that having OPC was determined.

2. MATERIALS

I. Metakaolin

In this study, the source material used was a local Metakaolin, which brought from the AL-Anbar governorate. In order to grind the kaolin, the air blast way was used. It burns at two hrs. at a degree of temperature of around 700 ^{o}C, and used a room temperature to cool it for 24 hrs., Metakaolin has 14300 cm^2/gm surface area, and also it has a 113% activity index with 2.54 as specific gravity. The test results of the MK were according to ASTM C 618[7].

II. Ordinary Portland Cement

Type (I) ordinary Portland cement was used as a partial replacement of Metakaolin in some of pervious geopolymer concrete mixtures throughout this work. The physical and chemical properties of the Portland cement used conform to the Iraqi Standard Specification IQ. No.5/1984 [8].

III. Coarse Aggregate

In this research, crushed natural aggregates that were brought from the Al-Naba'i area were used with a maximum aggregate size of 10 mm. This aggregate is graded separately in accordance with Iraqi Standard 45/1984. This aggregate was used in its saturated state and dry surface for all PGC mixtures.

IV. Alkali Liquid

To obtain the alkali solution for use as an activator in Geopolymer concrete, commercial sodium hydroxide was used with a purity of 98% and a concentration of 12 mol. Silicates and sodium hydroxide were mixed at a constant ratio of two to one for all mixtures.

V. Superplasticizer

To obtain good workability of PGC mixture, Conplast SP2000 superplasticizer (SP) additives produced from specific synthetic and organic polymers was used. This superplasticizer does not have any chlorides and conforming to the American standard ASTM C494 Type G. The function of this additive is to disperse and homogeneously disperse and distribute the binder particles and fine particles in the aqueous solution of fresh PGCs.

3. EXPERIMENTAL WORK

In this study, coarse aggregates were used in the saturated dry surface condition, with Metakaolin to coarse aggregate ratios (MK/CA) ratio 1/ 5 and 1/ 6. The alkali solution and the superplasticizer were also used at 0.6 and 2% by weight of Metakaolin, respectively; extra-water to improve the consistency was 10% of Metakaolin weight. Ordinary Portland cement (OPC) was added as a fractional replacement of 5, 10, and 15% by weight of Metakaolin. Table 1 illustrates all details of pervious geopolymer-concrete mix proportions. The local powder of Metakaolin (with and without OPC) was mixing with the coarse-aggregate in pan mixer with a capacity of ($0.1m^3$) in a few minutes. After that, the extra-water with alkali-solution (AL) and the SP dosage was added to these ingredients (mixture). All these materials mentioned in the above paragraphs were mixed well until a homogeneous concrete was obtained. After that, fresh concrete was inserted and placed inside metal molds with dimensions of (100 * 100 * 100) mm to check the compressive strength and thermal conductivity and (100* 100 *400) mm to test the bending strength and cylindrical molds with a diameter of 100 mm and 200 mm interactions to check the density and percentage of voids. Also, these molds were stacked directly after casting using the vibrating table mechanically. Then all the molds were covered with a plastic film to prevent the evaporation of water from the fresh pervious geopolymer concrete and leave it in the atmosphere of the room for 24 hours. After that, the molds were dismantled, the concrete models were taken out, and the concrete specimens were heat-treated in an electrical oven at a temperature of 50 ^oC for a period of 5 hours, and then transferred to be under direct sunlight until the time of the test after 28 days.

TABLE I: Elaborate of Experimental work

Mixtures	(MK:CA) ratio	(AL:MK) ratio	(OPC: MK) ratio (%)	Water by weight of Metakaolin ratio (%)	NaOH (Molarity)
M1	1:5	0.60	0	10%	12
M2	1:5	0.60	5	10%	12
M3	1:5	0.60	10	10%	12
M4	1:5	0.60	15	10%	12
M5	1:6	0.60	0	10%	12
M6	1:6	0.60	5	10%	12
M7	1:6	0.60	10	10%	12
M5	1:6	0.60	15	10%	12

4. TESTS DETAILS

I. Oven Dry-Density and Total Contents of Void

In this paper, the total void content and the dry density of pervious Geopolymer concrete were calculated using cylindrical samples with a diameter of 100 mm and a height of 200 mm according to the American standard ASTM C1754 / C1754M. Each result was calculated as average for three samples at the age of 28 days. Calculations were made according to the following equation:

$$\text{Density} = (K \times M)/(R^2 \times W) \quad (1)$$

where:
M = the mass of specimen in dry condition, gram.
R = the average specimen diameter, in mm.
W = the average specimen length, in mm.
K = 1 273 240 in SI units.

The total voids content of the pervious Geopolymer concrete specimen computed according to the bellow equation:

$$\text{Content of Voids} = [1-((K\times (M-B))/ (\rho w \times R^2 \times W))] \times 100 \quad (2)$$

where:
B = the weight of specimen underwater in grams.
ρw= the water bath density in kg/m^3.

II. Compressive-Strength Testing

In this work, the compressive strength of PGC mixtures was deliberated congruous to Standard of British, BS.1881 part 116:1983 [10]. The mechanical machine with a capacity equal to 2000 kN and cubic specimens with 100 mm dimensions were utilized. The average of three specimen's results with an age of 28 days was computed for all PGC mixtures

III. Flexural-Strength Testing

The test of the flexural strength for all PGC mixtures was accomplished according to ASTM C78 [11]. The average result of three prism specimens with dimensions of (100×100×400) mm was computed under the age of 28 days for all PGC mixtures.

IV. Thermal Conductivity

The Quick Thermal Conductivity Meter (QTM-500) [12] was used to conduct this test, which is illustrated in Figure (1). Cubic samples of 100 mm were used to conduct thermal conductivity test. Two samples at 28 days were prepared and dried for 24 hours in an oven of 110 ± 5 ° C. In accordance with ASTM 1113 [13] the test was performed three times for each sample and the mean value of each sample was calculated with a standard deviation of not more than 3%. The test was conducted at the National Center for Research and Research Laboratories.

Figure 1: Device of PGC thermal conductivity test

5. RESULTS AND DISCUSSION

All results of the experimental tests including, oven dry-density, content of voids, compressive strength, flexural strength, and thermal conductivity of pervious Geopolymer concrete with and without ordinary Portland cement were illustrated in Table (2) below.

TABLE II: Tests results of dry-density, the permeability of water, the content of voids, and mechanical strengths for PGCs.

Mixtures	Density (kg/m^3)	Void-Content (%)	Compressive-Strength (MPa)	Flexural-Strength (MPa)	Thermal Conductivity-[W/ (m.K)]
M1	1921	24	12.23	2.5	0.6434
M2	1927	24	13.06	2.55	0.649
M3	1953	24.2	13.90	2.67	0.6705
M4	1979	24	14.30	2.75	0.6913
M5	1846	26.1	11.03	2.25	0.536
M6	1851	26	12.10	2.35	0.5401
M7	1873	26.3	12.96	2.5	0.5470
M8	1892	26	13.33	2.55	0.5803

I. Oven Dry-Density and Total Content of Voids

The dry-densities of all pervious geopolymer concrete mixes with and without OPC were ranged from 1846 kg/m^3 to 1979 kg/m^3 as shown in Table (2) and Figure (2). The dry density of all PGC mixes that contain ordinary Portland cement as an incomplete substitution via the weight of Metakaolin was observed in Table (2) and Figure (2). The results indicated that the inclusion of OPC in Metakaolin-based PGC leads to a slight increase in the oven-dry density. This increment increased by increasing the replacement level. For instance, the oven-dry density increased by 0.3, 1.6 and 3% and 0.3, 1.4, and 2.4% when OPC replacement level was 5%, 10% and 15% by weight of Metakaolin with 1/5 and 1/6 (MK/CA) ratio, respectively at age of 28 days. This was imputed to the low specific gravity of Metakaolin (2.02) relative to the specific gravity of Portland cement (3.15)

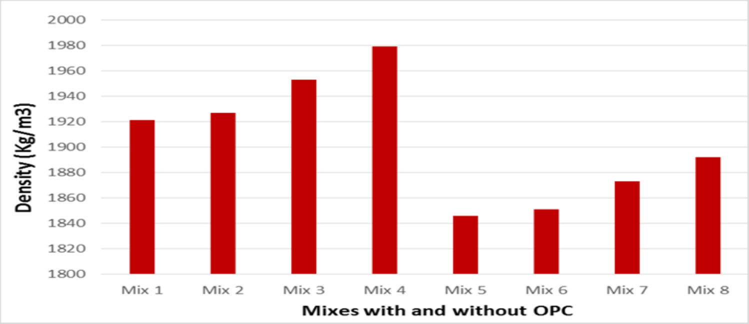

Figure 2: Oven dry density of all PGC mixes with and without ordinary Portland cement at age of 28 days

Table 2 and Figure (3), observed the effects of ordinary Portland cement on the total content of voids for PGCs. The results show that the use of OPC has a slight effect on this property. The void content of mixes with the replacement of Metakaolin by 0, 5, 10 and 15% Portland cement were 24, 24, 24.2, and 24% and 26.1, 26, 26.3, and 26% for 1/5 and 1/6 (MK/CA) ratios.

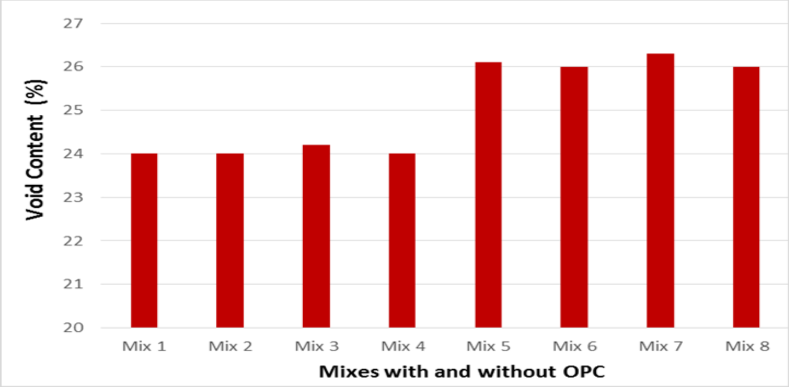

Figure 3: Effects of ordinary Portland cement on void content of PGC

II. Compressive Strength

The results observed that the compressive strength of PGC increased by the inclusion of Portland cement for all the mixes and this augmentation depends upon the degree of replacement level, as observed in Table (2). The replacement of Metakaolin by 5%, 10%, and 15 % of Portland cement leads to an increase in compressive strength by 6.8%, 13.6% and 17 % and 10%, 17.5% and 21% for mixture with 1/5 and 1/6 (MK/CA), relative to reference mixes (with-out OPC). This augmentation in compressive strength may have resulted from an adjustment that accrues to the chemical compound of Metakaolin that causes by a chemical compound of Portland cement such as SiO_2/AL2O_3 content and others.

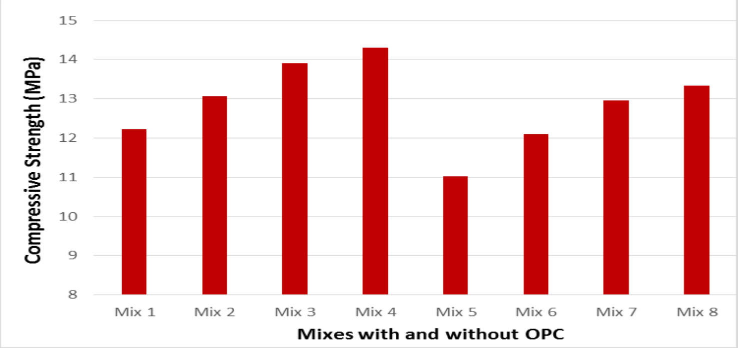

Figure 4: Effects of ordinary Portland cement on compressive strength of PGC at 28 days

III. Flexural Strength

Flexural strengths of PGC after or before using Portland cement as a partial replacement of Metakaolin by weight are given in Table (2) and Figure (5). The experimental results of this part of the work illustrate that the flexural strength increases accordingly with increasing Portland cement replacement content up to 15%. Whereby, these augmentations were 2%, 6.8%, and 10%, and 4%, 11% and 13% with Portland cement replacement level 5%, 10% and 15% for mixes with 1/5 and 1/6 (MK/CA) ratio respectively compared with those without OPC.

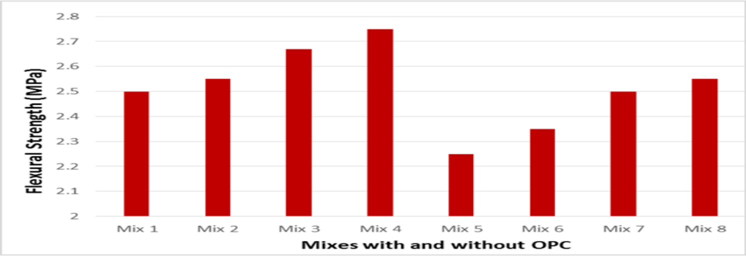

Figure 5: Flexural strength for PGC mixes with and without Portland cement

IV. Thermal Conductivity

The effect of ordinary Portland cement on thermal conductivity of pervious Geopolymer concrete is illustrated in Table 2 and Figure (6). The results show that the inclusion of Portland cement up to 15% as a replacing by the Metakaolin weight increases the value of thermal conductivity from (0.6434 to 0.6913) W/[m.K] and from (0.536 to 0.5803) W/[m.K] for mixes with 1/5 and 1/6 (MK/CA) ratio. This is imputed to the high oven-dry density for PGC containing OPC as shown in Table (2).

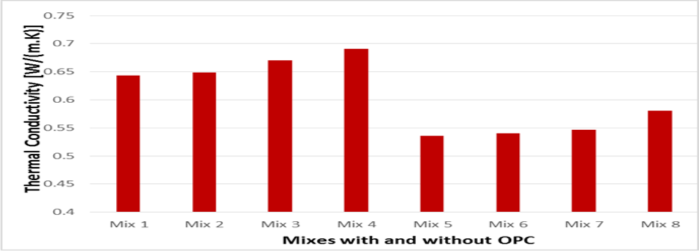

Figure 6: Thermal conductivity of all PGC mixes with ordinary Portland cement at age of 28 days

6. CONCLUSIONS

There are many conclusions that can be noted from the research results:

1) The oven-dry density increased by 0.3, 1.6, and 3% and 0.3, 1.4, and 2.4% when OPC replacement level was 5%, 10%, and 15% by weight of metakaolin for 1/5 and 1/6 (MK/CA) ratio at age of 28 days respectively.
2) The value of thermal conductivity increases accordingly with the increase of the replacement level of OPC.
3) The replacement of Metakaolin by 5%, 10% and 15 % of Portland cement leads to an increase in compressive strength by (6.8%, 13.6%, and 17 %) and (10%, 17.5%, and 21%) for mixture with 1/5 and 1/6 (MK/CA) ratios respectively.
4) The augmentations in flexural strength were (2%, 6.8%, and 10%) and (4%,11%, and 13%) with Portland cement replacement level 5%, 10%, and 15% for mixes with 1/5 and 1/6 (MK/CA) ratio relative to mixtures with-out OPC respectively.

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