Strength and thermal conductivity of geopolymer pervious concrete made from artificial lightweight aggregate

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Abstract. In this paper, geopolymer lightweight aggregate pervious concrete (GPLWAPC) was studied. It utilized two ratios of blending, which are 1:4 and 1:5 (fly ash: local artificial coarse aggregate). The rough aggregates utilized were graded as well as made of single size. An optimal ratio of aggregates content was achieved via the technique of trial and error. The fly ash (FA) that was used was low calcium, while the alkali activating element represents sodium hydroxide (NaOH) along with sodium silicate (Na2SiO3) with proportion of 1:2.5. Mixture was made with alkaline liquid to fly ash 0.4 proportion, NaOH concentration of 16 molarity was used. The artificial graded coarse aggregate to fly ash proportion of 1:4 shows the highest compressive strength with 5.2 MPa at 7 days with density of 1340 kg/m3. Many experimental investigations on GPLWAPC were investigated; workability and the strengths of compressive and splitting tensile, at the age of 7, 28 and 56 day, were studied. Moreover, thermal conductivity and scanning electronic microscopy were examined at 28 day age for the same mixture.

Keywords
Geopolymer lightweight concrete, pervious concrete, artificial coarse aggregate.

1. Introduction
Geopolymer concrete have been studied by several innovators and were found to have a significant advantage in high early strength, high later age strength, and excellent resistance to acid attack. Geopolymer has attracted attention as a practical alternative to Portland cement. Many geopolymer concrete depend on marginally treated ordinary material or industrial waste material productions to offer the binding elements [1].

Pervious or no-fine concrete (PrC) represents exceptional sort of concrete with a high porosity contrasted with ordinary one. This is created by utilized cement binder to cover the coarse aggregates. PrC enables water to go through the solid components of concrete structure. Fundamentally, PrC comprises of, coarse aggregates covered by binder, water and admixture. At that point, the cover consistency covers any aggregate's particles and gives adequate workability execution. Cement paste as well as cementitious material, for example, geopolymer could be utilized as cover for pervious geopolymer [2].

Notwithstanding the need of huge space to get off of the fly ash, the utilization of ordinary Portland cement (OPC) as the essential binder in each building structure can be a notable ecological issue. With the development of construction industry, the utilization of binder material (cement) is fast expanding legitimately. Such situation would expand the produce of OPC all over the world. This growing interest gives generally 7% of the absolute ozone harming substance outflows to the air. By
implication, this circumstance causes a worldwide temperature alteration that contrarily influences the planet. Thus, choices must be set up to lessen OPC generation [3]. Readily accessible Cementitious materials, for example, slag and fly ash, have been embraced to fulfill these needs. By 2010, about 780 billion tons of fly ash had been obtained as by products [3].

Davidovits [4] recommended that geopolymer binder paste could be created by reacting aluminum and silicon with soluble fluid from a geographical resource or side-production material: rice husk and fly ash. Polymerization procedure represents the work in this research, and the term geopolymer can be utilized to portray the binder generation. The new concrete does not utilize OPC.

Geopolymer has appeared marvelous properties: great protection from corrosive and sulfate assaults, high early quality, and great execution in elevated temperature [5]. It was accounted that around nine billion tons of common aggregate every year were used in industry of construction [6].

River beds are considered to be one of the major natural source places for aggregates excavation, these activities have caused severe harm to the environment including pollution of soil, air and waters. So, reusing and reutilizing of wasting material has turned into an inexorably significant research zone lately. In this manner, minimizing the use of raw materials and utilizing recycled materials are fit for decreasing the quantity of energy that is consumed during the manufacturing procedures of materials [7].

Owing associated pores in size of about 2 to 8 mm, void contain in the range of 18% and 35%, in addition to compressive strengths of 2.8 to 28.0 MPa. PrC with these properties can be used in the construction of park areas, pedestrian walkways, tennis courts and make it possible for using it in many applications like thermal insulation, acoustic absorption, and that made pervious concrete environment friendly [8].

The current work focuses upon the usage of a geopolymer concrete to produce pervious concrete that contains fly ash, Na₂SiO₃ plus NaOH solution, with artificial local coarse aggregates. Physical and mechanical features of the GPLWAPC were tested. Thus the main goal for the current work is to make more maintainable pervious concrete which used artificial local aggregates as a total alternative for natural coarse aggregates. Moreover, this paper will calculate the density for pervious concrete samples, voids’ contents and both compressing as well as tensile strength.

2. Experimental work
The aim of this study was to investigate the strength and thermal conductivity of GPLWAPC, as these properties havent been taken much in consideration in researches dealing with geopolymer lightweight aggregate concrete.

2.1 Materials
The material utilized to make GPLWAPC are: fly ash type F (low-calcium), artificial local coarse lightweight aggregate, alkaline solution, as well as water. The Fly ash that was utilized was imported from Turkey as a by product of coal combustion from ISKENment-Turkey power station during production of electricity. The tests show that the fly ash meets the specification of ASTM C 618 [9].
Table 1. Properties of artificial lightweight coarse aggregate

| Properties                                      | Results for local product coarse aggregate |
|------------------------------------------------|---------------------------------------------|
| Absorption, (%), [10]                          | 11.5                                        |
| Specific gravity, [10]                          | 1.63                                        |
| Dry rodded unit weight, (kg/m3), [11]           | 773.31                                      |
| Dry loose unit weight, (kg/m3), [11]            | 768.52                                      |
| Aggregate crushing value, (%), [12]             | 51.6                                        |
| Sulfate content (as SO₃), (%), [13]             | 0.97                                        |

Na₂SiO₃ sol plus NaOH sol was used for making the alkali-activated solution. Sodium silicate solution’s chemical composition and properties were: specific gravity of 1.534 and viscosity of 600. Sodium hydroxide takes the flakes’ shape (NaOH pure by 98 %), it was manufactured in Iraq. The solution had been made on previous day so as to cool it, after that it has been blended with Na₂SiO₃ by a weight ratio of 1: 2.5 before the start of mixing the GPLWAPC, after that the mixture was added to the fly ash. Artificial lightweight aggregates produced from bentonite clayey as well as water glass Na₂SiO₃ [14, 15], were utilized with maximum size of 19 mm as coarse aggregate complete substitution in samples was done in this research, as shown in figure 1. The properties of artificial lightweight coarse aggregate (ALWCA) that was used in this investigation were prepared based on the requirements of ASTM C330-03 [16] are shown in table 1.

2.2 Production of GPLWAPC

In order to produce GPLWAPC, ratio of alkali sol, molarity, superplastizaier ratio, fly ash contents had been utilized as shown in Table 2. Two mixes ratios, which are 1:4 and 1:5 (fly ash: ALWCA), had been utilized. The ALWCA utilized was graded plus made single size according to the Limit of Iraqi Specifications.[17]

The experimental work started with finding the ideal extent of ALWCA proportion acquired by trialing. Along these lines, the impacts of different parameters had been investigated by planning PGP1, PGP 2, PGP 3 and PGP 4 groups as their details can be seen in Table 2. ALWCA was dampened for one day, after that, it was dried for other 24 hours to simulate dried-state. Fly ash was added to the ALWCA inside the rotating drum and mixed for three minutes, approximately. Sodium silicate and sodium hydroxide solutions were mixed before minimum twenty four hours to prepare it to be mixed for two minutes with the mixture. The superplasticizer with the final quantity of the water had been at last blended within two minutes and included to the mixture.

The GPLWAPC was cast in the molds (Figure 2) and had been left in surrounding circumstance for twenty four hours, after that, they were demolded and restored in a furnace during forty eight hours at 90°C [18, 19] as shown in Figure 3. All the specimens were kept at surrounding circumstance with a normal temperature of 28°C up to the testing’s age. Pervious concrete ought to be examined with a specific measure of voids to improve the seepage of water, the most positive feature, and in order to produce a light structure, it ought to have a density below 2000 kg/m3 and a compressive strength more than 15 MPa [20].
Table 2. The mixtures’ details for GPLWAPC

| Mixing Designating | FA / ALWCA | FA (kg/m³) | Contents of activated sol (kg/m³) |
|--------------------|------------|-----------|----------------------------------|
| PGP₁               | 1:4        | 250       | 100                              |
| PGP₂               | 1:5        | 200       | 80                               |
| PGP₃               | 1:4        | 250       | 100                              |
| PGP₄               | 1:5        | 200       | 80                               |

NaOH molarity= 16, A/FA = 0.4, W/FA=0.5,  Na₂SiO₃ plus NaOH sol = 3.5, for PGP₁ and PGP₂ mixes, ALWCA graded was used, and for PGP₃ and PGP₄ mixes; ALWCA single was used.

Notice 1: Mixing ratio by weight, FA= fly ash, A=activator, W= water,
Notice 2: DRAMCEM 19 superplasticizer amount =1.9% by weight of fly ash.

Table 3. Density and compressing strength of GPLWAPC

| Mixes  | Slump (mm) | Dry Density (kg/m³) | Compressive strength within 7 days (MPa) |
|--------|------------|---------------------|----------------------------------------|
| PGP₁   | 120        | 1340                | 5.2                                    |
| PGP₂   | 122        | 1300                | 4.3                                    |
| PGP₃   | 125        | 1070                | 3.2                                    |
| PGP₄   | 127        | 950                 | 2.3                                    |

Figure 1. Lightweight aggregate

Figure 2. Casting of GPLWAPC
Figure 3. Curing of GPLWAPC

Table 3 exhibits PGP₁ having the higher compressing strength during 7 days of about 5.2 MPa with density of 1340 kg/m³. Thus, GPLWAPC mixes of PGP₁ was chosen to be considered in the current examinations.

2.3 Experimental tests

Table 4 shows the experimental tests, and their Standard Specifications, Specimens’ dimension and their ages that have been carried out in this research on the GPLWAPC.

Table 4. The mixtures’ tests of GPLWAPC

| Tests                      | Slump test          | Fresh density | Dry density   | Compressive strength |
|----------------------------|---------------------|---------------|---------------|----------------------|
| Standard specifications    | ASTM C143[21]       | ASTM C138 [22]| ASTM C642[23]| BS. 1881: Part 116[24] |
| Specimens dimension        | -                   | Cube specimens of 100 mm | 100×200 mm cylindrical | Cube of 100 mm |
| Age of tests (days)        | After the mixing    | 28            | 28            | 7,28,56              |

3. Results and discussion

3.1 Properties of fresh and hardend GPLWAPC

Pervious geopolymer concrete mixes show a workability value of 120 mm, though an increment within W/FA: to 0.5 had been utilized. It has fresh density and dry density of 1440 kg/m³, 1340 kg/m³ respectively. Geopolymer concrete as OPC concrete increase in compressive strength with time, although GPLWAPC had the low compressive strength, because fine aggregates were not present, as they would occupy the hollow spaces within the concrete structure with geopolymer paste, causing extra strength. The same results were obtained in split tensile strength.
The shapes of various GPLWAPC broken samples can be seen in figure 6. The GPLWAPC specimens represent a brittle failure with rapid breaking companion with loud voice.

Due to the presence of many voids, absorption test cannot be well controlled. Figure 7 demonstrates the enormous open pores. In view of this, a total void testing had been performed according to the ASTM C 1688-08 [25], the outcome is 29%.

The thermal conductive ability testing had been taken out using Quick Thermal conductive ability Measure (QTM-500) [26], the value was very low (0.281 W/m. K).
The microstructure of GPLWAPC matrix is by all accounts heterogenous with large numbers of hydrated fly ash particles, as shown in figures 8 and 9, large numbers of enormous pores are exhibited within microstructure of GPLWAPC matrix because of the absence of lower sized aggregate, similarly microcracks show up obviously in the GPLWAPC microstructure.

4. Conclusions

1- In this research GPLWAPC had been produced, utilizing fly ash activated by alkali activating solution.
2- Using locally artificial lightweight aggregate leading to the production of sustainable concrete.
3- Low strength result for GPLWAPC of 5.3 MPa for compressive strength and 0.9 MPa for split tensile strength at 28 days, can be attribute to the big pores of this concrete.
4- GPLWAPC had very low thermal conductivity of 0.281W/ (m. K), that made possible for it to be used in thermally insulating, acoustic absorption.
5- The microstructure of GPLWAPC shows high number of big pores which made it suitable for construction of park areas, pedestrian walkways.

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