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ORIGINAL RESEARCH

Experimental Study of Modulus of Elasticity, Capillary absorption of water and UPV in Nature-Friendly Concrete Based on Geopolymer Materials

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Abstract

In the current study, granulated blast furnace slag (GBFS) based geopolymer concrete (GPC) was used with 0-2% polyolefin fibers (POFs) and 0-8% Nano silica (NS) to improve its structure. After curing the specimens under dry conditions at a temperature of 60 °C in an oven, they were subjected to Modulus of elasticity and Ultrasonic Pulse Velocity (UPV) tests to evaluate their mechanical properties, as well as Capillary absorption test to assess their durability. all tests were performed at 7 and 90 days of age at ambient temperature (20 ℃). The addition of NS enhanced the whole properties of the GBFS based GPC. Increasing the curing age improved the results of all tests. The results of all tests in GPC showed the superiority of the results over conventional concrete. At 28 days of curing age, the addition of up to 8% NS to the GPC composition improved the modulus of elasticity test results by 14.7%, UPV by 84.88% and capillary water uptake by 64.38%. Addition of up to 2% of POFs to the GPC composition improved the modulus of elasticity by up to 7.21%, capillary water uptake by up to 22.97% and decreased UPV by up to 8.77%. In the following, by conducting the SEM test, a microstructure investigation was carried out on the concrete samples. In addition to their overlapping with each other, the results indicate the GPC superiority over the regular concrete. Besides, it demonstrated the positive influence of NS addition on the concert microstructure.

Key words: Geopolymer Concrete (GPF), Polyolefin Fibers (POFs), Nano silica (NS), Granulated Blast Furnace Slag (GBFS), Scanning Electron Microscope (SEM). dynamic states had an average reduction of 55 and 60% when compared with the ordinary state.

Introduction

Production and utilization of cement severely affect the environment due to the emission of various gases, the application of GPC plays a vital role in reducing this flaw [1]. Research shows that cement plants are responsible for emitting about 5% of the total CO_2 into the Earth's atmosphere [2]. Research shows that GPCs have superior mechanical properties and durability compared to conventional concretes [3-5]. GPCs have lower CO_2 emissions than conventional concrete and Portland cement [6-9]. Geopolymers gained increasing attention because of their eco-friendly and superior mechanical characteristics and their ability to utilize numerous wastes as precursors [10]. Metakaolin, fly ash, and mostly GBFS are traditionally used in the production of geopolymer [7]. in GPC, GBFS were used as binder material, along with sodium hydroxide and sodium silicate solutions as activator solutions [9]. GBFS is among the environmental materials. Using this material instead of cement can improve concrete resistance and decrease the

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increasing demand for its usage in concrete [11-12].

In recent years, the use of nano-sized pozzolans such as NS due to the role of high adhesion and filling in combination with other concrete materials has found a wide perspective. The influence of the NS in improving the strength can be attributed to the following multi-stage mechanism that improves the concrete's microstructures and thus, increases the mechanical properties.

1. The rise in the pozzolanic reaction [13]. The presence of NS in the GPC accelerates the pozzolanic reaction.

2. The filling effect of NS particles [14-15]. First, the distribution of NS particles besides the other concrete particles results in a denser matrix. Second, the NSs reaction in the geopolymerization procedure produces a larger amount of aluminosilicate gel, along with the reaction products of the main materials. The reaction by-product is likely to deposit in the structure of the existing pores. The rise in SiO_2 increases the matrix density [16]. Therefore, the filling effect of NS is improved by the particle packing, and the by-product produces a denser matrix, reducing the porosity and increasing the strength.

3. It acts as a nucleus [17-18]. In the C-S-H gel structure, nanoparticles can act as a nucleus and form strong bonds with the C-S particles of the gel.

The impact of fiber on the long-term behavior of GPC have been highlighted [19]. Preventing the connection of pores and bonding the flow channels in the concrete, the POFs strengthen it and avoid its spalling [20]. In an investigation on the effect of POFs with different diameters and lengths in GPCs, it was revealed that the proper use of fibers increases the modulus of elasticity and reduces water absorption. Besides, adding fibers decreases the compressive strength [21]. The studies have indicated that adding POFs to the concrete beams significantly assists the resistance after being cracked due to increasing the modulus of elasticity [22]. Improved elastic modulus, and UPV have been reported with the use of NS in GPC [23]. Innovation in this laboratory research includes the following:

1- The production of nature-friendly concrete (GPC) due to the reduction of carbon dioxide gas production and GBFS consumption (as industrial waste).

2- The superiority of the mechanical properties and durability of the produced concrete compared to (GPC) conventional concrete.

2. Experimental Program

2.1 Materials

In this experimental study, the Portland cement type II with a 2.35 g/cm^3 of specific weight according to standard En 197-1 and the GBFS was used in powder form with the density of 2.45 g/cm^3 according to ASTM C989/C989M standard. The chemical properties of these materials are indicated in Table 1. The NS particles made up of 99.5% SiO2 with an average diameter in the range of 15 to 25 nm were used. Crimped POFs according to ASTM D7508/D7508M standard, 30 mm in length, were also used, whose physical properties are shown in Fig. 1. The used fine aggregates were natural clean sand with a fineness modulus of 2.95 and a density of 2.75 g/cm^3, and the coarse aggregates were crushed gravel with a maximum size of 19 mm and a density of 2.65 g/cm^3 according to the requirements of the ASTM-C33. In this study, the GPC curing has been performed at 60 °C according to the GPC standards extracted from prestigious articles in this field.

Table1. Chemical Compositions of Materials

Component	GBFS (%)	OPC (%)
SiO_2 (%)	29.2	21.3
Al_2O_3 (%)	19.4	4.7
Fe_2O_3 (%)	5.8	4.3
CaO (%)	38.6	62.7
MgO (%)	2.8	2.1
SO_3 (%)	2.6	2
K_2O (%)	0.1	0.65
Na_2O (%)	0.2	0.18
TiO_2 (%)	0.6	-
Free Cao	-	1.12
Blaine (cm^2/g)	2200	3200
Loss on ignition (%)	0.3	1.84

Tensile Strength (N/mm^2)	>500	
Length (mm)	30	
Diameter (mm)	0.8	
Elasticity Modulus (GPa)	>11	
Bulk Density(g/cm^3)	2400	

Fig. 1. Physical Properties of the POFs

2.2 Mix Design

For accurate investigation, six mixture designs were considered, according to ACI 211.1-89 standard. The first sample included a regular concrete containing Portland cement where the water to cement ratio has considered to be constantly 0.45. Five other samples include GPC with different NS and POFs. The GPC samples are generally categorized into two groups: the first group lacks POFs with the NS amount of 0-8%. The second group contains 8% of NS, where the POFs are used in these designs in the form of 1 and 2 percent. In order to achieve the same performance in each mixture design and obtain a slump of about 20±100 mm, we have used normal polycarboxylate based superplasticizers. Besides, 202.5 kg/m^3 of the AAS used in this case. The used AAS is a combination of NaOH and Na_2SiO_3 with the weight ratio of 2.5, utilized with the mixture specific weight of 1483 kg/m^3 and the concentration of 12 M. The conducted studies indicate that due to the significant level of C-S-H formation when utilizing Na_2SiO_3, using a combination of NaOH and Na_2SiO_3 increases the compressive strength compared to single employment of CaOH [24]. The samples mixture design is indicated in Table 2.

Table 2. Details of the Mix Designs (Kg/m^3)

Mix ID	Cement	GBFS	Water	AAS	NS	Coarse Aggregates	Fine Aggregates	POFs	Super Plasticizer
OPCC	450	0	202.5	0	0	1000	761	0	9
GPCNS0POF0	0	450	0	202.5	0	1000	816	0	9
GPCNS4POF0	0	432	0	202.5	18	1000	767	0	10
GPCNS8POF0	0	414	0	202.5	36	1000	718	0	11
GPCNS8POF1	0	432	0	202.5	36	1000	672	24	11
GPCNS8POF2	0	432	0	202.5	36	1000	646	48	11

2.3 Test Methods

After fabricating the samples, for better curing and increasing the resistance properties, the samples were placed in an oven at 80 °C with a thermal rate of 4.4 °C/min for 48 h. Modulus of elasticity test according to ASTM C469 standard was performed on cylindrical specimens (15 cm in diameter and 30 cm in length). The UPV tests were conducted according to ASTM C597 using a non-destructive ultrasonic electronic apparatus, PUNDIT MODEL PC1012, with an accuracy of ±0.1 μs for a transformator with a vibrational frequency of 55 kHz and a movement time accuracy of ±2% for the distance. According to ASTM C1585-04, for the water absorption tests, cylindrical specimens, 100 mm in diameter and 50 mm in height, were kept at a temperature of 50±5°C in an oven for three days. Then, they were kept at the ambient temperature for 24 hours, put into a polyethylene container, and again kept at the ambient temperature for 15 days. In order to prevent water evaporation and water flow in different directions during the test, the lateral sides of the concrete specimens were sealed. One side of the specimens was placed in water, and a plastic wrap was put on the opposite side [24-25]. The amount of water absorbed by the specimens was measured after eight days. The absorption coefficient is expressed as follows [26]:

$$S = \frac{(Q / A)}{\sqrt{t}} \qquad \text{Eq. 1}$$

In the equation above, Q is the volume of the absorbed water, A is the area of the concrete in contact with water, and t is time.

3. Results and Discussion

3.1 Results of the Modulus of Elasticity Test

The results of the concrete modulus of elasticity test are shown in Figure 2. Figure 3 shows a concrete sample undergoing a modulus of elasticity test. Increasing the curing age has improved 21.63% modulus of elasticity in ordinary concrete and improved the modulus of elasticity up to 31.58% in GPC. This issue is mostly due to the progress of the geopolymerization process and the increase in the production volume of hydrated gels in concrete, which has led to the improvement of strength in hardened concrete.

At the 90-day curing age (as the best performance), the addition of 8% NS and 2% POFs to the GPC composition improved the modulus of elasticity in the concrete by 13.42% and 7.05%, respectively. This issue is mostly due to the effect of silica nanoparticles in accelerating the geopolymerization process. At the same age, the lowest (32.44 GPa) and highest (42.51 GPa) values of the modulus of elasticity obtained belong to the OPCC and GPCNS8POF2 designs, respectively. Addition of NS particles to the composition of GPC while accelerating the geopolymerization process has resulted in the production of large volumes of hydrated gels. These gels fill cavities and pores well, resulting in better adhesion to ITZ areas, thereby improving strength in concrete. Research has shown that NS particles First, the nanoparticles fill the pores of the matrices, which reduces the porosity of the geopolymer nanocomposites, resulting in uniformity, less pores, and a more compact geopolymer matrix [26]. The presence of fibers in the composition of GPC by bridging between the cracked plates delays the expansion of cracks against the forces. On the other hand Preventing the connection of pores and bonding the flow channels in the concrete, the POFs strengthen it and avoid its spalling [38].

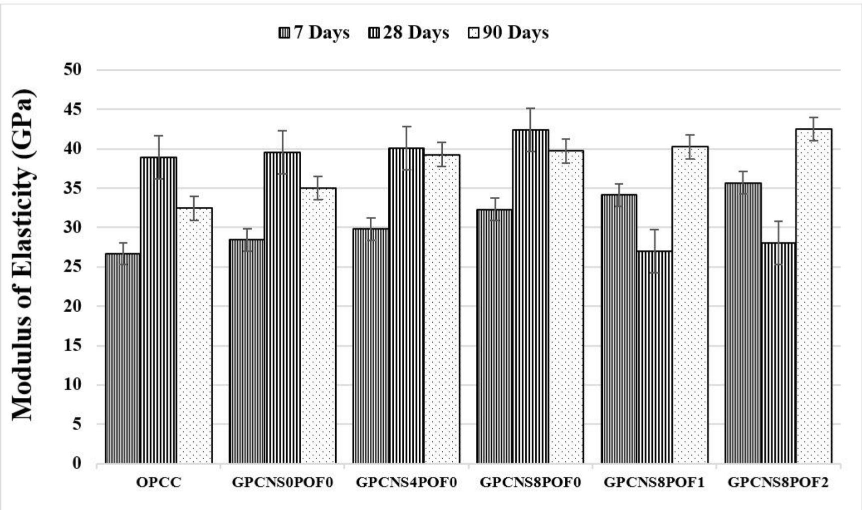

Fig. 2. The Modulus of Elasticity of the Specimens

Fig. 3. Concrete Specimen Undergoing Modulus of Elasticity Test

3.2 Results of the Ultrasonic Pulse Velocity (UPV) Test

Figure 4 shows the results of the UPV test. The results show that the addition of POFs reduces the speed of ultrasonic waves. The amount of this reduction is not large and is in the range of less than 12.5%. This reduction can be due to the type of fibers used and the way it is connected in the interfacial transition areas between the fibers and the geopolymer mortar.

Based on concrete quality classification in UPV test [27]. At the processing age of 28 and 90 days, all designs are in the Excellent range. As long as the UPV values are classified as "excellent", the concrete has no large cracks or pores that can affect the integrity of the specimen structure [28]. With the increase of curing age in concrete, the chemical process known as hydration in concrete increases and this leads to the production of a larger volume of hydrated gels such as C-S-H, hydrated gels are also the main factor in creating strength in concrete. They are concrete.

The decrease in UPV in GPC samples compared to conventional concrete samples can be due to microcracks created in the heat treatment process (60 °C). Nevertheless, these cracks had very fine dimensions and could only influence the UPV having no remarkable effect on the compressive strength of the specimens [29]. The addition of NS to the GPC composition improved the UPV results. Improved UPV have been reported with the use of NS in GPC [23]. Fine NS particles penetrate well into inter-layer and inter-surface capillary pores and thereby guarantee the improvement of mechanical properties in hardened concrete.

Addition of POFs to the composition of GPC has reduced the UPV results. This can be due to the movement and dispersion of the POFs in the concrete composition. Of course The small effect of POFs on the pulse velocity was also reported by Sahmaran et al. They attributed the negligible changes in the pulse velocity to the uniformity of the concrete matrix in all mixtures [30].

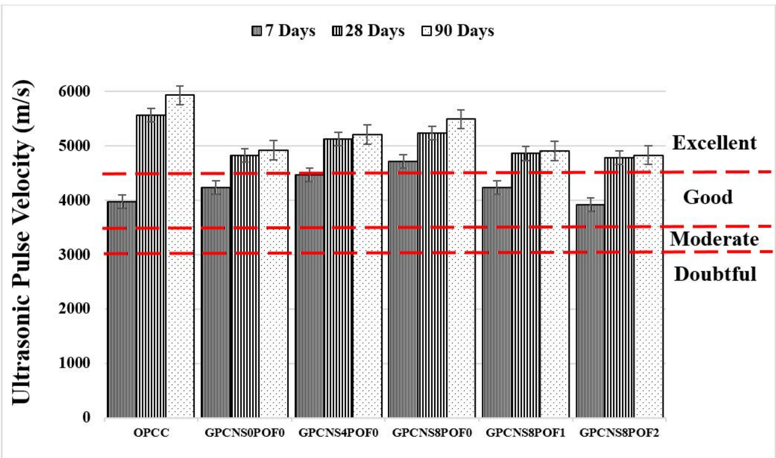

Fig. 4. The UPV of the Specimen

3.3 Results of the Water Absorption Test

The results of capillary water uptake test at 7, 28 and 90 days of processing age are shown in Figure 5. Increasing the curing age improves 26.31% in the capillary water adsorption results in ordinary concrete and up to 33.74% in the 90-day curing age (as the best performance), which adds 8% NS and 2% POFs to the concrete composition. Geopolymer has improved 23.8% and 23.43% capillary water absorption in concrete, respectively. For OPCC design concrete, the minimum water capillary adsorption rate belongs to the 90-day age with a velocity of 0.14 $Cm/S^{1/2}$. For NS-free and non-fibrous GBFS geopolymer concrete, the lowest capillary water adsorption rate in concrete belongs to the 90-day sample of GPCNS8POF0 design with a rate of 0.064 $Cm/S^{1/2}$. For GBFS geopolymer concrete containing NS and POFs, the best case belongs to Scheme 6 containing 92% GBFS, 8% NS and 2% POFs with a velocity of 0.049 $Cm/S^{1/2}$. The water absorption of 28-day-old samples is much lower than that of 7-day samples (between 11 and 32%), and from 28 days to 90 days the absorption rate decreases slightly (2 to 18%).

The increase in curing age in concrete follows the completion of the chemical process in concrete, and with the increase in density in concrete, the volume of capillary pores in concrete decreases, this leads to a decrease in water penetration in the capillary pores of concrete.

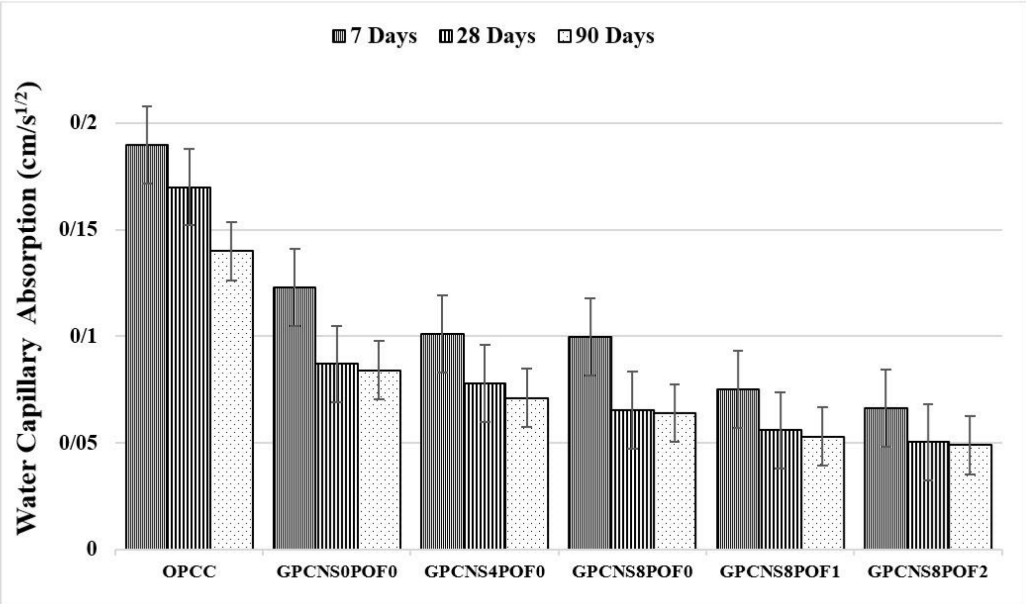

Fig. 5. The Water Capillary Absorption of the Specimens

3.4 Results of the SEM Analysis

In this study, 1 µm scale SEM analysis were taken on concrete samples at a 90-day processing age, as shown in Figure 6. It can be seen in the pictures that ordinary concrete has a weaker microstructure than GPC. In Portland cement, C-S-H gel consists of silicone and geopolymer groups of materials with high polymerization and Aluminosilicate structure [31]. Less cavities and more hydrated gels are more common in GPC samples. The presence of NS particles has improved the microstructure of GPC. NS is amorphous and the increase in amorphous material in nanocomposite samples is usually attributed to the additional NS loaded in the pastes at the nan fill capacity [32-33]. The NS addition to the GPC increases the geopolymerization reaction. In this case, more amorphous geopolymer gel is created in the matrices. This issue, in turn, indicates that the NS particles prevent the resistance decline of GPC [13]. In fact, the pozzolanic reaction condenses and homogenizes the microstructures by converting C-H to C-S-H [34], thus creating more geopolymer gel and a denser matrix [32] However, further increase in NS content causes insufficient dispersion and accumulation of NS particles, which slightly reduces matrix density [31]. In the sample containing NS, very few fine cracks are observed, in which NS acts as a filler to fill the spaces inside the hardened microstructure skeleton of the geopolymer paste and increase its compaction [35-36]. While accelerating the geopolymerization process, NS particles have the nature of adhesion and filling in the composition of GPC, and by improving the density of concrete, they provide the strength of hardened GPC.

The presence of some microcracks in the samples of Yenashi GPC is due to the heat treatment of this concrete at a temperature of 60 ℃. The results of SEM analysis covered the findings of other tests in this study.

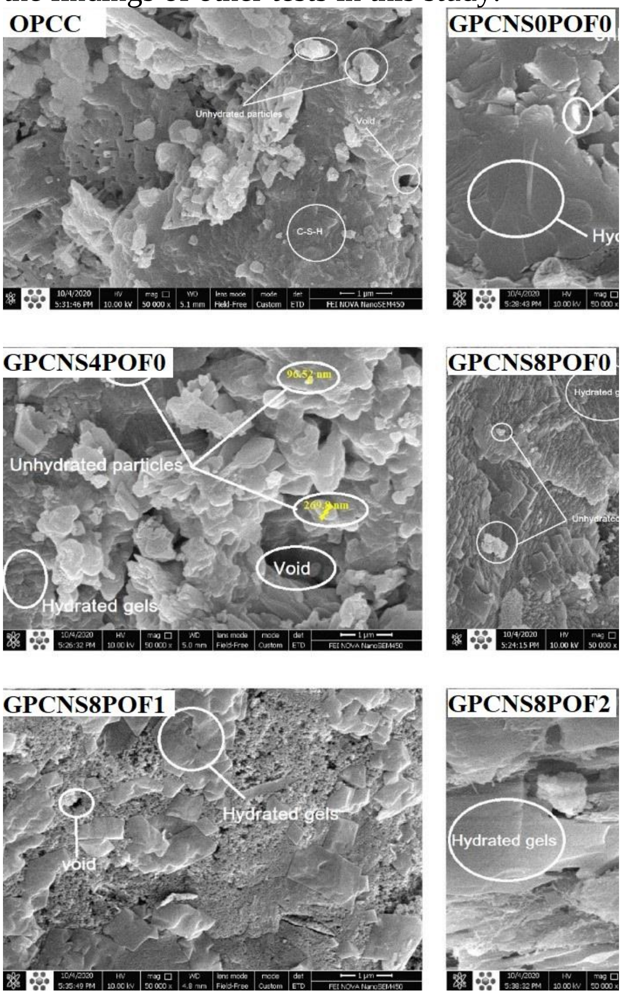

Fig. 6. SEM Image Under Room Temperature

4. Conclusions

In this experimental study, the modulus of elasticity, UPV and water Capillary absorption of GBFS geopolymer concrete at 7 and 28 days of treatment were investigated. SEM test was performed on concrete samples at 90 days of processing age. The results of this research are as follows:

1. Increasing the curing age improved the results. In this regard, at the 28-day processing age, the lowest (30.4 G. P) and highest (42.37) modulus of elasticity belonged to design 1 (ordinary concrete) and design 6 (GPC containing 8% NS and 2% POFs). In UPV, the lowest (4780 m/s) and maximum (5570 m/s) velocities belonged to Scheme 6 (GPC containing 8% NS and 2% POFs) and Scheme 1. In the capillary water absorption test, the best (0.0503 $cm/s^{1/2}$) and the weakest (0.17 $cm/s^{1/2}$) performance belonged to Scheme 6 and Scheme 1.
2. At 28 days of processing age, adding up to 8% NS to the GPC composition improved the modulus of elasticity test results by 13.04%, water capillary absorption by 1.6 times and UPV by up to 8.48%.
3. Addition of up to 2% of POFs in the composition of GPC at the age of 28 days of curing, improved 7.21% modulus of elasticity, 22.79% water capillary absorption and 8.77% decrease in ultrasonic pulse rate.
4. The results of all tests showed the superiority of mechanical properties and durability in GPC compared to ordinary concrete.
5. SEM analysis, due to the microstructural superiority of GPC over control concrete, covered the results of other tests in this study.

Abbreviations

OPC: Ordinary Portland Cement
OPCC: Ordinary Portland Cement Concrete
GPC: Geopolymer Concrete
GBFS: Granulated Blast Furnace Slag
POFs: Polyolefin Fibers
NS: Nano Silica
UPV: Ultrasonic Pulse Velocity
SEM: Scanning Electron Microscope
AAS: Active Alkali Solution

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