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Investigating the properties of environmentally friendly green concrete (Geopolymer) under high temperature

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ABSTRACT

In recent decades, scientists have made extensive efforts to find an alternative material in concrete in order to stop the emission of gas CO_2 in the cement production process. Geopolymers are materials with aluminosilicate properties that play the role of cement in concrete in the presence of water. Past research has proven that geopolymer concretes (GPC) do not have CO_2 pollution due to the absence of cement in their mixing design, so they are environmentally and nature friendly. In this laboratory research, a mixed design of ordinary portland cement concrete (OPCC) containing Portland cement with a grade of 500 kg/m^3 and a mixed design of GPC based on granulated blast furnace slag (GBFS)was made. In order to check the mechanical properties and durability, tests of compressive strength and weight loss of concrete were carried out under the temperature of 21 and 600 °C at the age of 90 days. Applying high heat to concrete samples caused a decrease in the compressive strength test results in OPCC and GPC by 42.31 and 14.9 percent, respectively, and in the weight loss test by 0.0067, respectively. And 0.0064 percent weight loss was obtained in OPCC and GPC. In the compressive strength test under 21 and 600 °C, GPC showed 11.41 and 64.35% superiority over OPCC. The results obtained from the scanning electron microscope imaging analysis of concrete were in harmony and overlapping with the results of other tests in this research.

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1. Introduction

Cement production is always accompanied by high consumption of mineral resources, on the other hand, cement factories consume large amounts of fossil fuels, which results in the production of carbon dioxide gas in the atmosphere and environmental problems. (Mansourghanaei et al., 2022; Mansourghanaei et al., 2022; Mansourghanaei et al., 2024; Mansourghanaei et al., 2023; Mansourghanaei et al., 2023; Mansourghanaei et al., 2023; Mansourghanaei et al., 2023; Mansourghanaei et al., 2023). Past research has shown that cement factories are responsible for releasing about 5% of the total carbon CO_2 entering the Earth's atmosphere (Nosrati et al., 2018). Mechanical properties and low durability in OPCC are other disadvantages of this type of concrete, this issue led scientists to think of finding a material with high adhesion and filling properties as a substitute for cement in concrete. In this regard, the use of materials with alkaline properties such as GBFS as a substitute for cement was put on the agenda of researchers in the field of concrete production. Research by others has shown that the use of GBFS instead of cement can improve the strength of concrete and reduce the increasing demand for cement in concrete (Mansourghanaei et al., 2022; Siddique and Kaur, 2012; Yüksel et al., 2011).

Research has shown that GBFS composed of calcium silicate and aluminate meets the requirements for pozzolanic materials (Mansourghanaei et al., 2022; Mansourghanaei et al., 2022; Huseien et al., 2018). The activation of GBFS with activated alkali solution for the production of slag GPC has been studied a lot in the past few decades (Mansourghanaei et al., 2021; Mansourghanaei et al., 2022; Allahverdi et al., 2011). The use of fly ash, metakaolin, GBFS and other pozzolans as suitable substitutes for cement in concrete has also been reported in other researche (Nuaklong et al., 2016; Singh et al., 2015; Zhuang et al., 2016). Studies have shown that the products obtained from the geopolymerization process have special advantages such as excellent mechanical properties, good resistance to high temperature and chemical attacks, low shrinkage and others (Yunsheng et al., 2010). The structure of GPC was first proposed by a French researcher named Joseph Davidovits in 1972 (Davidovits, 2008). The amount of carbon dioxide produced in the production process of geopolymer materials is much less than in the production process of cement (Neupane et al., 2018). The production of GPC is carried out by conventional methods of concrete technology (Vora and Dave, 2013). Application of high heat in concrete brings destructive effects to the microstructure of concrete, evaporation of water under high heat, while delaying and weakening the process of hydration and geopolymerization in concrete, causes irreparable damage to the matrix part of the gels structure. It becomes hydrated. McNulty (2009) and some other researcher, by comparing concrete containing OPCC and GPC, have reported that alkaline materials perform better than OPCC due to their ceramic characteristics. when exposed to fire (Bakharev, 2006; Mane and Jadhav, 2012; Comrie and Kriven, 2004). When GPC is exposed to high temperatures, some changes occur in it, based on the temperature ranges of these changes (Bakhtiyari et al., 2001):

1) The release of evaporable water at a temperature of 100 °C.

2) Hydration of calcium-silicate hydrates starts at 180 °C and with increasing temperature up to 200 °C, the vapor pressure in the geopolymeric structure is continuously increasing.

3) Hydroxyl groups (OH^-) evaporate at 500 °C, the Dihydroxylation process changes the structure of aluminosilicate and reduces the resistance.

4) At a temperature of 800 °C, a highly porous ceramic structure is formed.

The goals and innovation in this laboratory research through the production of GPC can be to improve the mechanical and microstructural properties of GPC compared to OPCC, help to reduce the amount of carbon dioxide gas emissions compared to OPCC production, help to maintain the health of the environment by consuming GBFS accumulated in iron smelting plants, which are known as substances harmful to the environment, preserving and reducing the consumption of mineral resources that are used as main materials in the process of making conventional cement, preserving and reducing the consumption of fossil fuels, which are used as Fuel is used in normal cement factories, mentioned.

2. Material and Methods

In this laboratory study, type 2 Portland cement produced by Gilan Sabz Cement Industries (Dilman) with a specific weight of 3250 kg/m^3 and a specific surface of 3000-3200 cm^2/g produced under the ISIRI 389 standard was used. GBFS, a product of Isfahan iron smelting plant with a specific weight of 2750 kg/m^3, a specific surface area of 2200 cm^2/g and an apparent density of 960 kg/m^3 was used according to the ASTM C989/C989M standard, the chemical characteristics of this product It is shown in Table 1. The water used for the preparation of lime water and the construction of the mixed design in the upcoming research is from the drinking water of Lahijan city, this type of water has a pH in the range of 5.6 to 7.5 and a specific weight of 1000 kg/m^3 is a cube according to clauses 9-10-4-2 and 9-10-4-3 of the fourth edition of Iran's National Building Regulations, drinkable water does not have a specific taste and smell, and is clean and smooth can be used without testing. concrete is used, unless previous records indicate that this type of water is unsuitable for concrete. The aggregates used in the preparation of the concrete mix design in this laboratory research are synthetic and based on the requirements of the ASTM C33 standard, prepared from the sand factories of Lahijan city. Some characteristics of the aggregate used in this research are shown in Table 2. Research has shown that fresh GPC has a poorer performance due to the high viscosity in active alkali solution compared to concrete containing fresh normal Portland cement. To solve this problem, a polycarboxylate-based superplasticizer is often used. The reason for strong bonds between positively charged calcium and negatively charged polycarboxylate is the best option (Pilehvar et al., 2018). In this regard, the 4th generation superplasticizer based on normal polycarboxylate, a product of Durocham Middle East company, was used based on the characteristics of Table 3. The activated alkali solution used in this research is a combination of sodium silicate and sodium hydroxide solution with a weight ratio of 2.5, which was used with a combined specific gravity of 1483 kg/m^3. Some of the characteristics of the activated alkali solution used in this research are in the Table 4 is shown. There is no separate standard for the GPC mix design, so according to some laboratory research (Deb et al., 2015), the GPC mix design is in accordance with the standard of preparation of OPCC under the recommendation of the ACI 211.1-89 committee based on Table 5 was prepared and adjusted. At first, based on Table 5 containing the concrete mix design, the raw materials were weighed and then the dry materials including cement (or GBFS) and aggregate were poured into the circulating electric mixer and the process of mixing the materials for 5 lasted 1 minute. Next, wetter materials including water (or active alkali solution) were added to the mixture and the combination of materials continued for another 2.5 minutes. Then, the fresh concrete mixture was poured into pre-oiled and foiled metal molds in three stages, in this direction, in order to apply compression and remove excess air in the concrete sample, in each stage, 25 blows by A special rod was added to the concrete mix. In the end, the molds containing concrete samples were kept in a dry environment under a temperature of 21 °C for 24 hours. After this time passed, the samples were molded and the normal concrete samples were stored and processed in water-lime at a temperature of 21 °C until the age of the test. After molding, GPC samples were subjected to heat treatment in the oven at 60 °C for 48 hours in order to improve the strength of this type of concrete. After this time, the samples of the concrete blocks were removed from the furnace and stored and processed in a dry environment under a temperature of 21 °C until the time of testing. In line with heat treatment in GPC, research has shown that GPC samples subjected to heat treatment in the temperature range of 50 to 70 °C have more strength than samples processed under 20 °C. (Mehta and Monteiro, 2017). The compressive strength test of concrete at the age of 7, 28 and 90 days was performed according to BS 12390-3 standard on cube samples with dimensions of 10×10×10 cm. In this regard, the samples were placed in the concrete-breaking jack machine in such a way that the two opposite surfaces that were adjacent to the mold during concreting are in contact with the upper and lower stirrups of the machine and after the sample is solidified, the force loading was carried out in the standard range at a speed of 0.9 MPa/s (54 MPa/min) in a constant, uniform manner, without sudden changes and perpendicular to the direction of concreting until the moment of failure of the concrete sample, the maximum load The input determines the resistance value of the concrete sample against the applied pressure. The weight loss test of concrete samples at the age of 90 days was performed at room temperature and under high heat (600 °C), in accordance with the ISO834 standard, on cubic samples with dimensions of 10×10×10. In this standard, the temperature applied to concrete samples is recommended up to 1000 °C and the duration of heat application is one hour. In this regard, the samples were first weighed at room temperature, then the samples were exposed to a temperature of 600 °C in the oven for 1 hour, this action caused water to evaporate from the capillary spaces and possible holes in the concrete. At the end of the heating time and after the temperature of the samples reached room temperature, the samples were weighed again and the average weight loss of the samples was entered as the final result. SEM analysis and analysis were done at the processing age of 90 days at room temperature and under high heat (600 °C) by scanning electron microscope with FEI Quanta 200 model. The images were recorded with the desired magnification and were then analyzed for microstructure. Before performing high temperature tests, which were performed at the age of 90 days, according to the ISO834 standard, the concrete samples were placed in the oven at 600 °C for 1 hour, then the samples were heated for 1 hour. They remained in the furnace off for another hour so as not to be affected by temperature shock. After the samples were taken out of the furnace, the samples were kept at room temperature for 24 hours to reach temperature equilibrium. The use of this standard has been reported in other researche about tests under high temperatures in concrete (Kong and Sanjayan, 2010).

Table 1. Chemical Characteristics of GBFS (%)

CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	TiO_2	Na_2O	K_2O	MnO	SO_3	L.O.I
36.72	35.5	9.17	4.45	6.24	2.49	1.21	0.92	0.18	0.12	0.02

Table 2. Characteristics of Aggregates

Materials	Minimum Diameter	Maximum Diameter (mm)	Modulus of Softness (mm)	Special Weight (kg/m^3)	Water Absorption %
CA[1]	4.75 (mm)	19	5.7	2750	2.2
FA[2]	75 (µm)	4.75	2.85	2650	2.9

Table 3. Characteristics of Normal Polycarboxylate Superplasticizer

Chemical Formula	Physical State	Color	Special Weight (kg/m^3)	Standard	pH	Chlorine Ion Content	Ignition Point
PCNS[3]	Liquid	Brown	1100	ASTM C494	About 7	Does Not Have	Does Not Have

Table 4. Characteristics of Active Alkali Solution

Type of Solution	Color	Molarity (mol/m^3)	Special Weight (kg/m^3)	Modulus of Elasticity (p)	Ignition Point (°C)	Molar Mass (g/mol)	Weight Ratio (molar) Silicate to Sodium	The Weight (molar) Ratio of Silicate to Water
NaOH	White	12	2130	3.3	318	39.99	-	-
Na_2SiO_3	White	12	2400	-	1088	122.06	2.4	47

Table 5. Specifications of Concrete Mix Design

Type of Concrete	Parameter	Cement	GBFS	Water	CA	FA	PCNS	Curing	SG[4] (kg/m^3)	W/C
OPCC	kg/m^3	500	0	225	1000	765	7	in the water	2497	45 %
	%	20.02	0	9.01	10.04	30.63	0.0028			
GPC	kg/m^3	0	500	225	1000	762.63	7	Heat + Dry Environment	2494	45 %
	%	0	20.04	9.19	40.08	30.57	0.0028			

- In GPC, W/C ratio means the ratio of active alkali solution to the used GBFS.

3. Results and discussion

3.1. Interpretation and Results of Compressive Strength Test

The results of destructive and mechanical compressive strength tests on normal concrete and GPC samples under 21 and 600 °C are shown in the graph of Fig. 1. At the temperature of 21 and 600 °C, 11.41 and 64.35 percent superiority of compressive strength was obtained in GPC compared to normal concrete, respectively. This superiority in GPC under the heat of 600 °C is more than the temperature of 21 °C. This is due to the production of a large volume of hydrated gels in the structure of GPC paste due to the presence of abundant aluminosilicate materials in the composition of GBFS in the mixture of this type of concrete. Hydrated gels such as hydrated calcium silicate (C-S-H), hydrated calcium-aluminum silicate (C-A-S-H) and hydrated sodium-aluminum silicate (N-A-S-H) are the main factors in creating compaction and strength in hardened concrete. These gels guarantee density and strength in hardened concrete by filling pores, holes, cracks and creating adhesion in transition areas. In this regard, research has shown that in the geopolymerization reaction, based on the mechanism of geopolymerization, by converting CH into a hydrated gel such as C-S-H, the microstructures in the concrete are condensed and cause the homogeneity of the concrete (Hongjian et al., 2014). Based on the compressive strength diagram in this section, high temperature has caused the results to drop. In this regard, in normal concrete and GPC, we see a drop of 42.31 and 14.9 percent of compressive strength in concrete under 600 °C

[1] Cross Aggregate
[2] Fine Aggregate
[3] Polycarboxylate Normal Superplasticizer
[4] Special Gravity

compared to 21 °C. By removing Portland cement and using GBFS in concrete, while reducing air pollution due to the reduction of CO_2 gas emissions in concrete, natural and mineral resources are preserved (Mansourghanaei et al., 2024; Mansourghanaei et al., 2023; Mansourghanaei et al., 2023).

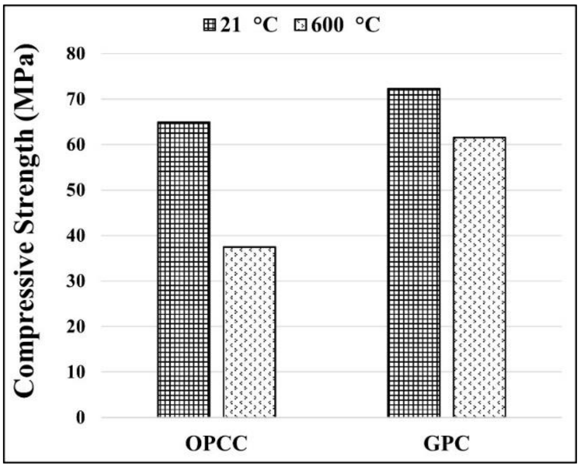

Fig. 1. Compressive Strength Test Results

3.2. Interpretation and Results of Weight Loss Test

The results of the durability test of the weight loss type on the samples of normal concrete and GPC in this research, under a temperature of 21 and a temperature of 600 °C, are shown in the graph of Fig. 2. According to these results, it can be seen that the normal concrete and GPC samples at 21 °C lsius have a higher weight than after applying high heat (600 °C) in concrete samples. This issue is due to the presence of water in the cavities, interlayer and intersurface capillary pores in the microstructure of hydrated concrete gels, but by applying high heat to the concrete samples and leaving the water in the concrete microstructure as a result Evaporation, the weight of concrete samples has decreased. On the other hand, due to higher density and less pores and holes in the microstructure of GPC, this type of concrete has experienced less weight loss than normal concrete. In this regard, they obtained 0.0067 and 0.0064 percent weight loss in normal concrete and GPC, respectively. Researches have shown that due to the high inter-pore pressure, water exit from the chemical bond space in hydrated calcium silicate (C-S-H) leads to concrete failure at a temperature of more than 450 °C (Pilehvar et al., 2018). The lower weight loss of GPC samples compared to normal concrete indicates superior durability characteristics in this type of concrete compared to normal concrete. Microstructural images of the combination of normal concrete and GPC in this research show signs of higher density and less volume of holes and pores in GPC, and this issue overlaps with the results of the weight loss test in this section.

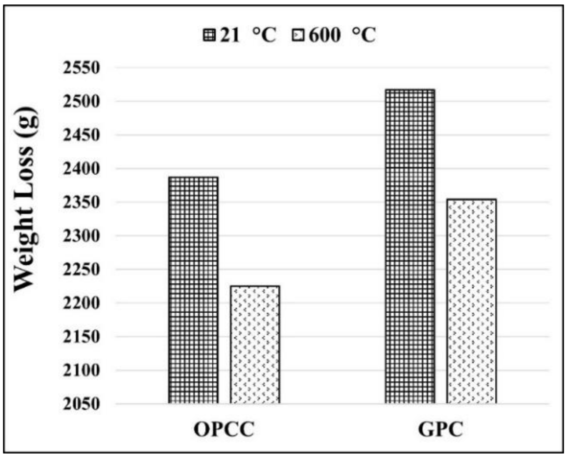

Fig. 2. Results of the Weight Loss Test

3.3. Interpretation of SEM Results

The images obtained from SEM at a scale of 1 micrometer on the samples of normal concrete and GPC at the temperature of 21 and 600 °C from this laboratory research are shown in Fig. 3. In general, the images obtained from the microstructure of OPCC and GPC can be divided into several parts as described below.

a) It includes hydrated gels resulting from the process of sorption and geo-sorption, which are mainly seen as dark colored areas in the Figs.

2) Unhydrated clinker grains and particles due to the presence of impurities in raw materials, which are mainly seen as white areas in the Figs.

3) Cracks and micro-cracks in the mixture, due to thermal contraction caused by heat treatment and heat of hydration and geopolymerization due to the high quality of Portland cement and GBFS in the concrete composition.

4) interlayer capillary holes and pores in the structure of hydrated gels and interlayer capillary holes and pores in the transition regions.

5) Other particles not participate in the chemical process.

According to the pictures, it is evident that the volume of hydrated gels in the composition of GPC is more than that of OPCC, this is due to the high pozzolanic activity of GBFS in the process of chemical combination with an active alkali solution. Abundant aluminosilicate particles in the GBFS composition produce dense gels with high adhesion and filling power, such as hydrated calcium silicate gel (C-S-H) in the process of chemical reaction with active alkali solution. These gels are the main factor in creating density and strength in hardened concrete. The size and volume of holes and pores in OPCC is more than that of activated alkali concrete, but the microcracks in activated alkali concrete, which are caused by the heat treatment of this type of concrete at a temperature of 60 °C, are more visible in the microstructure of GPC than in OPCC. It is visible. Applying high heat (600 °C) to concrete samples has caused a decrease in density in the microstructure of OPCC and GPC, so that with the exit of heated water from the concrete samples, the volume and size of existing pores and holes in the mixture, it is more exposed to the temperature of 21 °C than in the sample, and with the destruction of the structure of the hydrated gels due to the application of high heat, their volume in the composition has been reduced. In this regard, the presence of porous and tree-shaped structures in the mixture of OPCC and GPC is one of the effects of high temperature in concrete samples. Research by others shows that heat between 500 and 900 °C can cause crystal changes, destruction of the microstructure of hydrated gels and the formation of carbonate minerals in the concrete matrix (Amiri and Aryanpoor, 2019; Provis and Van Deventer, 2009; Brindley, 1975).

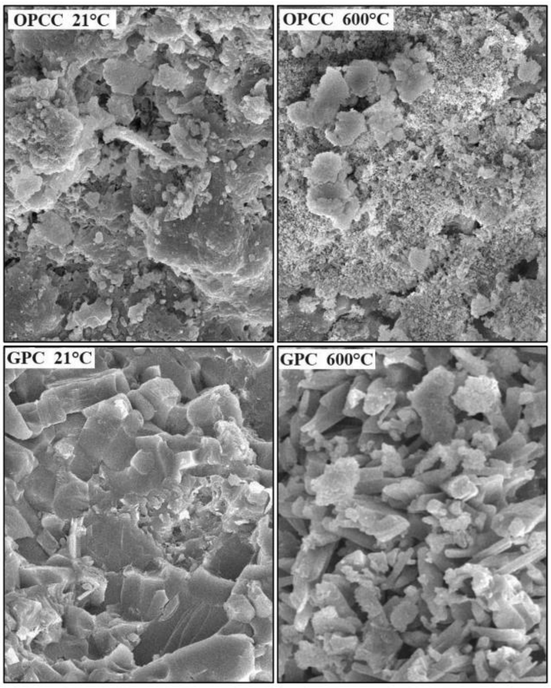

Fig. 3. SEM Images

4. Conclusion

In this laboratory study, a mixed design of OPCC and a mixed design of GPC concrete were made in order to evaluate the mechanical properties and durability of concrete at a working age of 90 days and a temperature of 21 and 600 °C. In this regard, the compressive strength and weight loss tests of concrete samples were performed, and in the following, the microstructure was analyzed by scanning electron microscope (SEM) images. The results of this laboratory research are presented as follows.

1) Applying high heat to concrete samples caused a decrease in the compressive strength test results in normal concrete and GPC by 42.31 and 14.9 percent, respectively.

2) In the weight loss test, 0.0067 and 0.0064 percent weight loss was obtained in normal concrete and GPC, respectively.

3) In the compressive strength test under 21 and 600 °C, GPC showed 11.41 and 64.35 percent superior strength compared to normal concrete, respectively.

4) The results obtained from the analysis of scanning electron microscope images were in harmony and overlapping with the results of other tests in this research. In this regard, in heated concrete samples compared to non-heated concrete samples, due to the evaporation of water and the breaking of the bond between the components of the concrete, the results of the compressive strength test and the weight loss test show a significant drop. earned

5) The use of GBFS in concrete leads to the preservation of natural resources due to the non-use of mineral and underground resources.

6) By reducing the consumption of cement in concrete, environmental pollution is reduced due to the reduction in the production and emission of CO_2 gas in the air.

7) In similar researches, the improvement of mechanical properties (based on compressive strength and weight loss tests) and microstructural properties (based on SEM analysis) of GPC containing GBFS compared to OPCC has been reported (Mansourghanaei et al., 2022; Mansourghanaei et al., 2024; Mansourghanaei et al., 2023).

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References

Allahverdi, A.L.I., Kani, E.N. & Yazdanipour, M., 2011. Effects of blast-furnace slag on natural pozzolan-based geopolymer cement. *Ceramics-Silikáty*: 55(1), 68-78.

Amiri, M. & Aryanpoor, M., 2019. The Effects of High Temperatures on Concrete Performance based on Nanostructural Changes in Calcium Silicate Hydrate (CSH). *Concrete Research*: 12(4), 69-80.

Brindley, G.W., 1975. Thermal transformations of clays and layer silicates. In *Proceedings of the international clay conference*: 119-129, Applied Publishers Wilmette, IL.

Bakharev, T., 2006. Thermal behaviour of geopolymers prepared using class F fly ash and elevated temperature curing. *Cement and concrete Research*: 36(6), 1134-1147.

Bakhtiyari, S., Allahverdi, A., Rais-Ghasemi, M., Zarrabi, B.A. & Parhizkar, T., 2011. Self-compacting concrete containing different powders at elevated temperatures–Mechanical properties and changes in the phase composition of the paste. *Thermochimica acta*: 514(1-2), 74-81.

Comrie, D.C. & Kriven, W.M., 2004. Composite cold ceramic geopolymer in a refractory application. In *Advances in Ceramic Matrix Composites IX, Proceedings*: 211-225.

Davidovits, J., 2008. *Geopolymer chemistry and applications*. Geopolymer Institute.

Deb, P., Nath, P. & Sarker, P., 2015. Drying shrinkage of slag blended fly ash geopolymer concrete cured at room temperature. *Procedia Engineering*: 125, 594-600.

Nosrati, A., Zandi, Y., Shariati, M., Khademi, K., Aliabad, M., Marto, A. & Khorami, M., 2018. Portland cement structure and its major oxides and fineness. *Smart structures and systems*: 22(2), 425-432.

Huseien, G.F., Mirza, J., Ismail, M., Ghoshal, S.K. & Ariffin, M.A.M., 2018. Effect of metakaolin replaced granulated blast furnace slag on fresh and early strength properties of geopolymer mortar. *Ain Shams Engineering Journal*: 9(4), 1557-1566.

Hongjian, D., Suhuan , D. & Liu, X., 2014. Durability performances of concrete with nano-silica. *Construction and building materials*: 73, 705-712.

Kong, D.L. & Sanjayan, J.G., 2010. Effect of elevated temperatures on geopolymer paste, mortar and concrete. *Cement and concrete research*: 40(2), 334-339.

Mansourghanaei, M., Biklaryan, M. & Mardookhpour, A., 2022. Experimental study of the effects of adding silica nanoparticles on the durability of geopolymer concrete. *Australian Journal of Civil Engineering*: 1-13.

Mansourghanaei, M., Biklaryan, M. & Mardookhpour, A., 2022. Experimental study of properties of green concrete based on geopolymer materials under high temperature. *Civil Engineering Infrastructures Journal*. (doi: 10.22059/ceij.2022.345402.1856

Mansourghanaei, M., Biklaryan, M. & Mardookhpour, A., 2024. Durability and Mechanical Properties of Granulated Blast Furnace Slag Based Geopolymer Concrete Containing Polyolefin Fibers and Nano Silica. KSCE *Journal of Civil Engineering*: 28(1), 209-219.

Mansourghanaei, M., Biklaryan, M. & Mardookhpour, A., 2023. Experimental study of properties of green concrete based on geopolymer materials under high temperature. *Civil Engineering Infrastructures Journal*: 56(2), 365-379.

Mansourghanaei, M., 2023. Investigating the Mechanical and Durability Properties of Geopolymer Concrete Based on Granulated Blast Furnace Slag as Green Concrete. *Journal of Civil Engineering Researchers*: 5(3), 24-34.

Mansourghanaei, M., 2023. Evaluation of Mechanical Properties and Microstructure of Pozzolanic Geopolymer Concrete Reinforced with Polymer Fiber. *Journal of Civil Engineering Researchers*: 5(2), 1-13.

Mansourghanaei, M. & Mardookhpour, A., 2023. Numerical Investigation of the Effect of Concrete Injection on the Concrete Joints of the Arched Dam, Under the Applied Stresses. *International Journal of Advanced Structural Engineering*: 13(1). Doi: 10.30495/ijase.2023.705234

Mansourghanaei, M., Biklaryan, M. & Mardookhpour, A., 2023. Experimental Study of Mechanical Properties of Slag Geopolymer Concrete under High Temperature, Used in Road Pavement. *International Journal of Transportation Engineering*: 11(1), 1371-1385.

Mansourghanaei, M. & Biklaryan, M., 2022. Experimental evaluation of compressive, tensile strength and impact test in blast furnace slag based geopolymer concrete, under high temperature. *Journal of Civil Engineering Researchers*: 4(2), 12-21.

Mansourghanaei, M. & Biklaryan, M., 2022. Experimental study of compressive strength, permeability and impact testing in geopolymer concrete based on Blast furnace slag. *Journal of Civil Engineering Researchers*: 4(3), 31-39.

Mansourghanaei, M., Biklaryan, M. & Mardookhpour, A., 2022. Experimental Study of Mechanical Properties of Geopolymer Concrete as Green Concrete with a Sustainable Development Approach in the Construction Industry, Under High Temperature. *Journal of Civil Engineering Researchers*: 4(4), 1-11.

Mansourghanaei, M., biklaryan, M. & Mardookhpour, A., 2021. Evaluate Effect of Temperature On mechanical properties of Geopolymer Concretes blast furnace slag by using nanosilica and polyolefin fiber. *Journal of Structural and Construction Engineering*: 8(10), 334-352. doi: 10.22065/jsce.2021.277150.2382

Mansourghanaei, M., Biklaryan, M. & Mardookhpour, A., 2022. Experimental Investigation of the Effect of Nanosilica on the Mechanical Properties and Durability of Slag Geopolymer Concrete. *Journal of Concrete Structures and Materials*: 7(1), 76-89. doi: 10.30478/jcsm.2022.333669.1260

Mane, S. & Jadhav, H.S., 2012. Investigation of geopolymer mortar and concrete under high temperature. *Magnesium*: 1(5).

McNulty, E., 2009. Geopolymers: an environmental alternative to carbon dioxide producing ordinary Portland cement. *Department of Chemistry, The Catholic University of America*.

Mehta, P. K. & Monteiro, P.J., 2014. *Concrete: microstructure, properties, and materials*. McGraw-Hill Education.

Nuaklong, P., Sata, V. & Chindaprasirt, P., 2016. Influence of recycled aggregate on fly ash geopolymer concrete properties. *Journal of Cleaner Production*: 112, 2300-2307.

Neupane, K., Chalmers, D. & Kidd, P., 2018. High-strength geopolymer concrete—properties, advantages and challenges. *Advances in Materials*: 7(2), 15-25.

Pilehvar, S., DuyCao, V., M.Szczotok, A., Carmona, M., Valentini, L., Lanzón, M. & LenaKjøniksen, A., 2018. Physical and mechanical properties of fly ash and slag geopolymer concrete containing different types of micro-encapsulated phase change materials. *Construction and Building Materials*: 173, 28-39.

Provis, J.L. & Van Deventer, J.S., 2009. Introduction to geopolymers. In *Geopolymers*: 1-11. Woodhead Publishing.

Siddique, R. & Kaur, D., 2012. Properties of concrete containing ground granulated blast furnace slag (GGBFS) at elevated temperatures. *Journal of Advanced Research*: 3(1), 45-51.

Singh, B., Ishwarya, G., Gupta, M. & Bhattacharyya, S.K., 2015. Geopolymer concrete: A review of some recent developments. *Construction and building materials*: 85, 78-90.

Vora, P.R. & Dave, U.V., 2013. Parametric studies on compressive strength of geopolymer concrete. *Procedia Engineering*: 51, 210-219.

Yüksel, İ., Siddique, R. & Özkan, Ö., 2011. Influence of high temperature on the properties of concretes made with industrial by-products as fine aggregate replacement. *Construction and building materials*: 25(2), 967-972.

Yunsheng, Z., Wei, S. & Zongjin, L., 2010. Composition design and microstructural characterization of calcined kaolin-based geopolymer cement. *Applied Clay Science*: 47(3-4), 271-275.

Zhuang, X.Y., Chen, L., Komarneni, S., Zhou, C.H., Tong, D.S., Yang, H.M. & Wang, H., 2016. Fly ash-based geopolymer: clean production, properties and applications. *Journal of Cleaner Production*: 125, 253-267