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Original Research

EFFECT OF ADDING RED AND YELLOW PIGMENTS TO GEOPOLYMER CONCRETE

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Abstract: This study examined the feasibility of producing colored geopolymer concrete using slag as the binder and investigated the effects of pigment on various properties of geopolymer concrete. The geopolymer concrete was supplemented with two varieties of pigment, namely iron oxide hydroxide in the shades of "red" and "yellow", then the following tests of compressive strength, rebound number, density, and ultrasonic pulse velocity were carried out on it. The highest compressive strength value was achieved when adding 1% of pigments, which increased the red and yellow values from the reference value by 2.7 percent and 1.8 percent, respectively. The best rebound number values can be obtained by adding 1% yellow and 3% red, which increased the red and yellow values from the reference value by 8% and 15%, respectively. The density increases as the proportion of the additional pigment rises. The maximum density values were achieved by incorporating 1% of red and yellow pigment, with a respective increase of 1% and 3% for red and yellow. The highest values of ultrasonic pulse velocity when adding 1% of yellow and red color pigments increased by 1.7% for yellow and 2% for red. The optimal addition is 1.2% as it enhances properties and reduces expenses when utilizing smaller pigments.

Keywords: *Alkaline; colored concrete; compressive strength; solutions; slag*

1. Introduction

In 1978, Davidovits coined the term "geopolymer" to refer to a diverse group of materials characterized by inorganic molecular networks [1]. For silicon (Si) and aluminum mineral supply, geo polymer concrete depends on thermally activated natural minerals such as metakaolin or industrial byproducts such as slag (Al) or fly ash. Alkaline activating solutions have the ability to dissolve these two minerals, causing them to undergo polymerization and form molecular chains, which then serve as the binder. The polymerization process, according to Rangan, "implies a rapid chemical reaction on silicon-aluminium minerals under alkaline circumstances, yielding a three-dimensional polymeric configuration consisting of chains and rings [2, 3].

GPC is a newly developed substance that has the potential to take the role of Portland Concrete Cement. An alkali-activated alumina silicate binder or alkali-activated cement material results from geo-polymerization since the alkali ingredient acting as an activator is a compound of the first unit of the periodic table. Chemical reactions between the atoms of silicon and aluminum result in molecules of the building that are structurally similar to natural

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stone [4]. When used to create geo-polymer concrete, slag has been the subject of numerous research studies. Kumar and Ramesh created geo polymer from "Ground Granulated Blast Furnace Slag" (GGBS), a powder made by combining steel mill blast furnace slag leftovers with industrial metakaolin [5, 6].

Srinivasan looked into how the strength characteristics of slag geo polymer concrete would be affected by the addition of alkali activators (sodium hydroxide) and accelerators (calcium nitrate and sodium sulfate) to the binder [7]. Hadi et al. used the Taguchi technique to identify the ideal mix ratios for geo-polymer concrete using ground granulated blast furnace slag (GGBFS) as an alumina silicate source under ambient curing conditions [8].

To create colored concrete, the pigment must be added to the concrete ingredients as they are mixed. Both synthetic and natural pigments explicitly made for concrete are available, and they are made to achieve the desired hue without entirely changing the mixture's desirable physical qualities [9].

Numerous academics have investigated colored concrete, such as Luo and Lin, who examined how a sludge ash mortar sample's surface color changed under various temperature conditions. It also investigated how temperature affects how quickly mortar surfaces change color [10]. Juan et al. demonstrate the evaluation of white cement with ultramarine blue color. The outcome is clarified by the mineralogical modifications brought about by replacing cement with pigment at a 5, 10, 15, or 20% concentration [11]. Abdulrehman et al. conducted a study on the impact of weather conditions on the distinct mechanical as well as physical properties of colored concrete [12]. This project will tint geopolymer concrete based on slag to produce colored concrete that is more sustainable for the environment.

2. Laboratory Parts and Materials

2.1. Material

2.1.1. slag

This study made use of slag that was brought in from Turkey and is currently being sold on the market in Iraq. Table 1 displays the slag's chemical makeup, while Table 2 clarifies additional physical characteristics. Materials must adhere to ASTM C 989[13].

Table1. Analyses of the chemical composition of slag.

Oxides	% Content
Fe_2O_3	1.9
AL_2O_3	14.5
SiO_2	38.2
Sulphide sulphur	0.38
CaO	37
Cr_2O_5	0.02
TiO_2	0.8
MnO	3.1
MgO	8.1

Table 2. Physical characteristics of slag

Characteristics	Outcomes
Specific weight	3.2
Surface area, cm^2/g	5338
Nature of material	Powder
Color	Light grey

2.1.2. Sodium hydroxide

According to ASTM E 291[14], sodium hydroxide is readily available in flake form and is highly pure (greater than 98 percent). The NaOH solution characteristics are summarized in Table 3.

Table 3. Sodium hydroxide characteristic*

Appearance	Unit	Specification ASTME291	Outcomes
Copper as Cu^{+2}	ppm	≤ 4.0	0.1
Iron oxides (Fe_2O_3), max	Percent	≤ 0.01	0.005
Manganese as Mn	ppm	≤ 4.0	0.02
Silicate as SiO_2	Ppm	≤ 20	14
Sodium chloride (NaCl)	Percent	≤ 0.15	0.07
Sodium carbonate (Na_2CO_3)	Percent	≤ 0.40	0.36
Sulphate as Na_2SO_4	ppm	≤ 200	70
Sodium hydroxide (NaOH)	Percent	≥ 97.5	98.14
Water Insoluble	ppm	≤ 200	60

*As indicated by the manufacturer

2.1.3. Sodium silicate

The United Arab Emirates imports the sodium silicate employed in the current research, which is readily accessible in the Iraqi market. Table 4 presents the characteristics of the sodium silicate employed.

Table4. Properties of Sodium Silicate

Description	Value
SiO_2 / Na_2O	2.4 ± 0.05
Na_2O wt. %	13.10 – 13.70
H_2O wt. %	55.1
SiO_2 wt. %	32– 33
Specific Gravity	1.534 – 1.551
Density - 20°	51 ± 0.5
Viscosity (CPS) 20°C	600 – 1200
Appearance	Vaporous

*As indicated by the manufacturer

2.1.4. Fine aggregate

As a fine aggregate, conventional sand from the Ekhedir region is used. Moreover, it turns out that the fine aggregate conforms with IQS No. 45/1984[15] standards based on its chemical and physical characteristics. Tables 5 and 6 present the fined aggregates' physical, grades, and chemical features.

Table 5. Natural Fine Aggregates Grading*

Size of Sieve, mm	cumulative % passing	IQS45.1984, zone2
100	100	100
4.75	90	90-100
2.36	75	75-100
1.18	59.7	55-90
0.6	39.3	35-59
0.3	12.4	8-30
0.15	2.28	0-10

* Graduation analyses were performed in the materials laboratories of Mustansiriyah University's Engineering College.

Table 6. Characteristic of Naturals Fine Aggregates

The Characteristic	results	IQS45-1984
Gravity specifics	2.7	---
Modulus of fineness	3.04	---
Absorption (%)	0.69	---
SO_3 content (%)	0.114	0.5(%) max

* The tests were conducted by the National Center for Construction Laboratories.

2.1.5. Coarse aggregate

The mixtures for this investigation were made using traditional gravel from the Al-Nabai zone as the coarse aggregate. The examination's findings demonstrated their conformance to IQS 45/1984[15]. Tables 7 and 8 provide a detailed description of the physical and chemical characteristics of coarse aggregate.

Table 7. Inspection of Coarse natural aggregates *

Size of Sieve in mm from % IQS No.45-1984	%Passing	IQSNo.45.1984
20	100	100
14	95	90-100
10	87	85-100
5	8	1-10
2.36	3	0-5
1.18	0	---

* Graduation analyses were performed in the materials laboratories of Mustansiriyah University's Engineering College.

Table 8. Natural coarse aggregates Characteristics *

The Characteristics	results	IQS No.45-1984
Gravity specifics	2.6	---
Absorption%	0.56	---
percent content of Sulfate	0.04	0,1 max

* The tests were conducted by the National Center for Construction Labs.

2.1.6. High-range superplasticizer admixture (HRSPA)

Following ASTM C494, a naphthalene formaldehyde plasticizer was employed to raise the workability. Table 9 displays the plasticizer's characteristics.

Table 9. Characteristics of plasticizer.

Technical Properties	Descriptions
Density	1.181± 0.01 @ 20 °C
Color	A dark brown liquid
Basis, kg/l	Naphthalene Formaldehyde Sulfonate
Value of pH	7-11
Chloride content	Nil

2.1.7. Additional water.

Colored geopolymer concrete was prepared by incorporating tap water as an additional water source, which proved to be compatible with the concrete mixture.

2.1.8. Pigments

For this inquiry, two varieties of powdered pigment were utilized: red (Fe_2O_3) and yellow (Fe_2O_3). Imported from China in varying weight percentages of the mixes' slag content (0, 1, 2, 3). The surface area values of the pigment used in this study are displayed in Table10.

Table 10. Surface area Value of pigments.

Pigment	Fineness
Red Fe_2O_3	6580 (cm^2/g)
Yellow Fe_2O_3	(cm^2/g)

2.2. Geopolymer Concrete Mixtures Made with Various Colors

In Fig. 1, Tables 11 and 12, the colored geopolymer concrete combinations are displayed.

***Table 11.** Colored geopolymer concrete mixes

Mix.	Slag(kg)	Alkalinesolution (Kg)	Added water (Kg)
So	18	6.3	3.6
SR1	17.82	6.3	3.6
SR2	17.64	6.3	3.6
SR3	17.46	6.3	3.6
SY1	17.82	6.3	3.6
SY2	17.64	6.3	3.6
SY3	17.46	6.3	3.6

*Where So: without pigments, SR: Geo polymer concrete with red iron oxide hydroxide, and SY: Yellow iron oxide hydroxide is used in the production of geopolymer concrete.

Table 12. Mixtures Colored Geo Polymer Concrete

Coarse Aggregate Kg	Fine Aggregate Kg	Pigment Kg	HRSP A Wt% of slag	Na_2SiO_3/NaOH
54	26.47	0	2	1:2.5
54	26.47	180	2	1:2.5
54	26.47	360	2	1:2.5
54	26.47	540	2	1:2.5
54	26.47	180	2	1:2.5
54	26.47	360	2	1:2.5
54	26.47	540	2	1:2.5

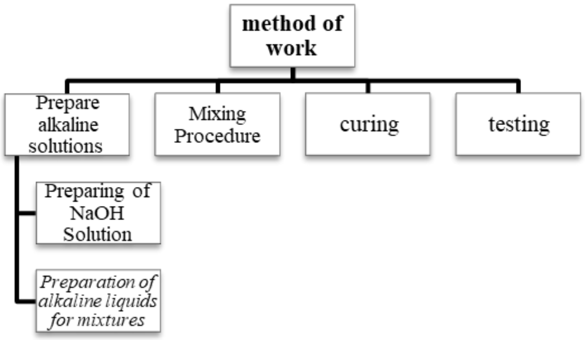

Figure1. Geopolymer concrete mixtures

2.3. Prepare Alkaline Solutions of Geo Polymer Concrete Mixes

2.3.1. Preparing of NaOH Solution

314 g of sodium hydroxide are dissolved in 686 g of water to produce 1 kilogram of a sodium hydroxide solution at a concentration of 10 molarity [16].

2.3.2. Preparation of alkaline liquids for mixtures

To create the alkaline liquid, the sodium hydroxide solution and sodium silicate solution were mixed in a ratio of 1:2.5 while taking into account the solution's earlier preparation (24 hours before the components of the mixture were combined) [17].

2.4. Colored Geopolymer Concrete Mixing Procedure

Utilize a 200L electric mixer to blend the dry components, including pigments, slag, coarse aggregate, and fine aggregate for a minimum of two to three minutes before adding the produced alkaline liquid, plasticizer, and extra water (4 - 5 minutes) [17, 18].

2.5. Curing

The specimen is taken outside the lab and exposed to direct sunlight for curing after 28 days of demolding**.**

2.6. Tests of Colored Geopolymer Concrete

Table 13. Tested samples

Test	Size and shape	No. of samples
Compressive strength,	Cube(100*100*100)mm	21
Rebound Numbers	Cubes(150*x150*x150)mm	21
Density	Cube(100*100*100)mm	21
UPV	Cube(100*100*100)mm	21

2.6.1. Compressive strength (fc)

This test was conducted in line with (BS.1881: Part 116: 1989) [19], using three cubic samples from each mixture with measurements of 100 * 100 * 100 mm and determining its average, as shown in Table 13. Fig. 2 depicts the examination of the samples (28 days later) using a hydraulic machine with a capacity of 2000 KN.

Figure 2. Compressive strength test.

2.6.2. Rebound number test

This test (Fig. 3) was conducted for each mixture of colored geopolymer concrete following ASTMC 805[20]**.**

Figure 3. Rebound number test.

2.6.3. Density

Using the electronic balance in Fig. 4, the density of the specimens was calculated following BS 1881- 114:1983 [21].

Figure 4. Measuring of weight unit

2.6.4. Test for ultrasonic pulse velocity

Based on ASTM C 597 [22], the test was conducted in three cube dimensions of 100 x 100 x 100 mm for each colored geo polymer combination (Fig. 5). It primarily measures the duration (time) of an ultrasonic pulse (54 kHz) that is generated and tested on one side of a colored geopolymer concrete member using an electro-acoustic transducer. The same information is obtained using a similar transducer in contact with the opposite side.

Figure 5. Ultrasonic Pulse Velocity direct test

3. Results and Discussion

3.1. Compressive strength (fc) result

Table 14 displays the results of the compressive strength (fc) tests performed on samples of geo-polymer concrete.

Table 14. The compressive strength of various mixtures of geopolymer concrete samples.

Mixes	Compressive Strength (N/mm^2)
So	33.4
SR1	33.3
SR2	32.5
SR3	32.4
SY1	34.6
SY2	33.1
SY3	32.6

Yellow and red pigments were added in the following percentages: 0, 1, 2, and 3. The results are shown in Fig. 6 and Fig. 7. Adding 1 percent of pigment with both colors produced geopolymer concrete with the highest compressive strength value; however, as more pigment was applied, the compressive strength value steadily decreased. This behavior can be elucidated by:

- The inclusion of red and yellow pigment in geopolymer concrete decreases the extent of water interaction with slag due to the higher surface area of the pigment compared to the slag. Consequently, the pigment has a greater affinity for water molecules than the slag. This helps to get a higher compressive strength because when more water molecules interact with the binder, the bonds between the molecules of the binding material become weaker[23].
- The incorporation of color can be used to fill the voids in the geopolymer concrete. However, augmenting the

quantity of pigment can lead to the aggregation of pigment particles, resulting in the formation of segregated areas that compromise the strength of the geopolymer concrete [24].

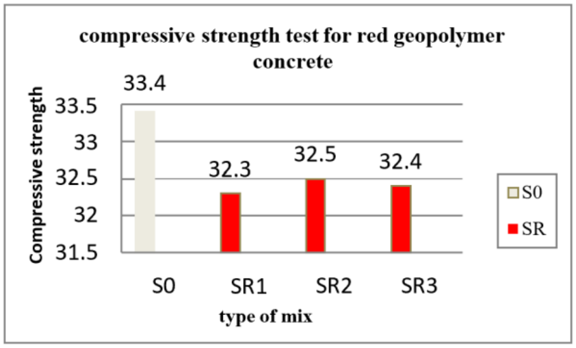

Figure 6. Evaluation of the Red Geopolymer concrete's compressive strength.

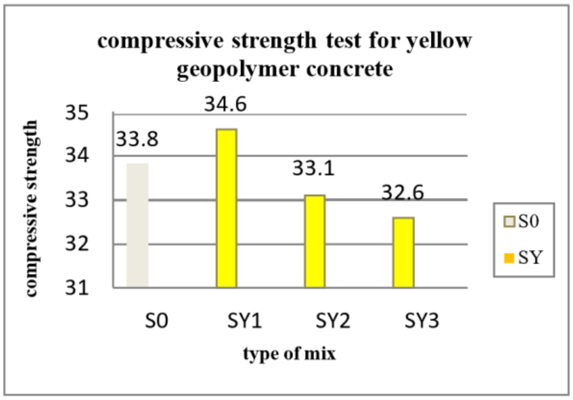

Figure 7. Results of yellow Geopolymer concrete's compressive strength.

3.2. Rebound Number Result

Generally, the quantity of values that rebound rises when colors are added to geo-polymer concrete. The pigment fills the pores and spaces in the samples' outer surface, including the subsurface pores, which causes the surface roughness of the samples' internal and surface pores (close to the surface) to decrease, leading to an increase in values. The highest values of the rebound number were discovered when using red pigment at 3 percent and yellow pigment at 2 percent. Contrarily, when the percentage of adding this color grows, the roughness of the sample surface increases as the percentage of adding this color increases, as shown in Fig. 8 and Fig.9.

Table 15. Rebound Number Results for Colored Geopolymer Concrete Mix

Mixes	Results
So	35.79
SR1	36.40
SR2	38.54
SR3	38.95
SY1	41.51
SY2	39.95
SY3	37.78

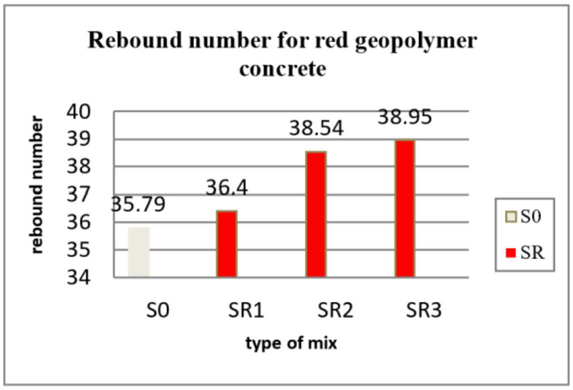

Figure 8. Rebound number tests for red Geopolymer concrete cubic

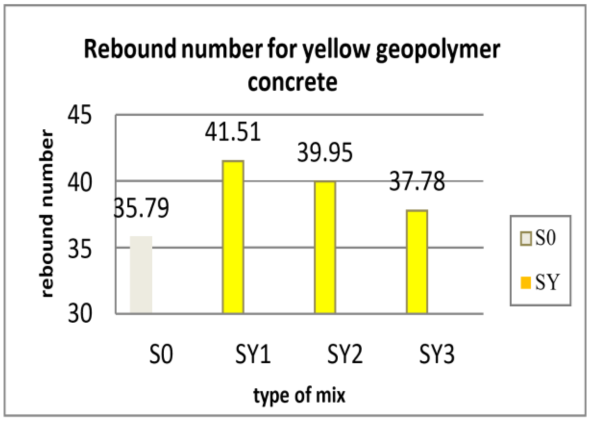

Figure 9. Rebound number tests for yellow Geo polymer concrete cubic

3.3. Density Result

Table 16 shows that as the pigment percentage rises, the density values also rise. The pigment's finer particle size compared to the slag's coarser particle size causes the pore content to drop, which is why. The colored geopolymer concrete's density rises to a point (1%) before starting to decline as the pigments fill in the spaces. As the samples achieve saturation, the pigment molecules start agglomerating inside the material and occupying a bigger area than slag. Because their density is smaller than slag, the density declines. This is why it gets lower as the proportion of adding color grows, as seen in Fig. 10 and Fig. 11.

Table 16. Outcomes of the density of colored geopolymer mixes

Mix.	Density(kg/m^3)
S0	2289
SR1	2311
SR2	2308
SR3	2284
SY1	2363
SY2	2338
SY3	2277

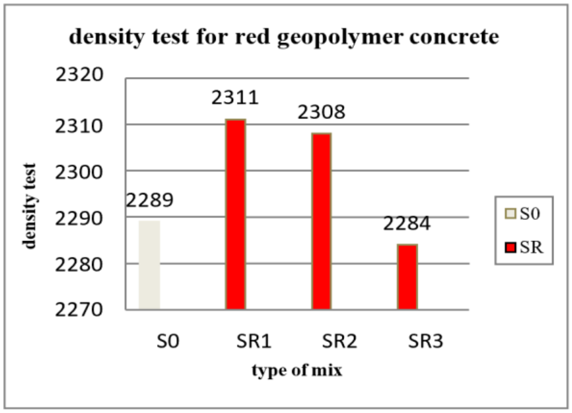

Figure 10. The density of red Cubic geopolymer concrete.

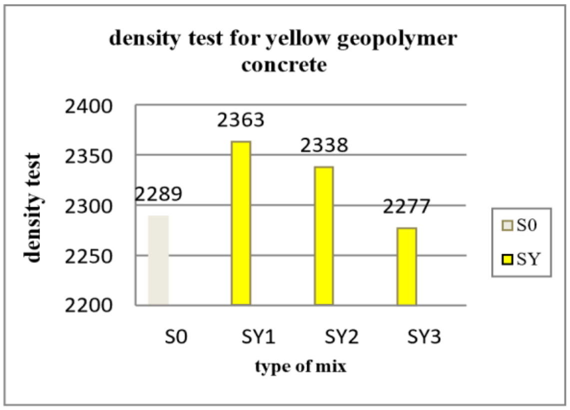

Figure 11. Density for yellow Geopolymer concrete cubic.

3.4. Ultrasonic Pulse Velocity result

As illustrated in Table 17, Fig. 12, and Fig.13, the percentage of pigment increases the ultrasonic pulse velocity, which indicates a reduction in pore content and an increase in density. This is because pigments significantly contribute to the filtration of pores, thereby accelerating the ultrasonic pulse velocity.

Table 17. The outcomes of UPV test colored geopolymer concrete mixes

Mixes	UPV(m/s)
S0	3593
SR1	3518
SR2	3412
SR3	3307
SY1	3654
SY2	3558
SY3	3457

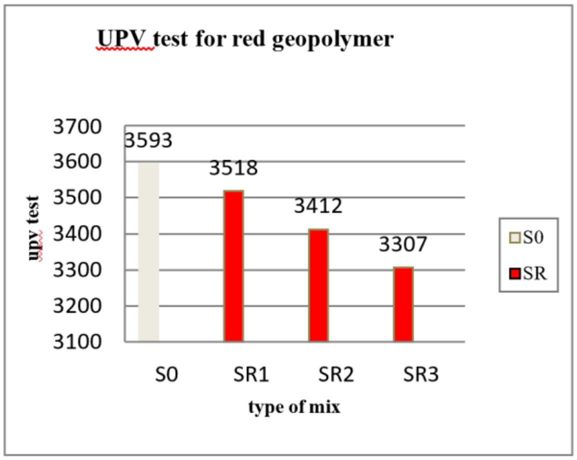

Figure 12. UPV tests for red Geopolymer concrete cubic

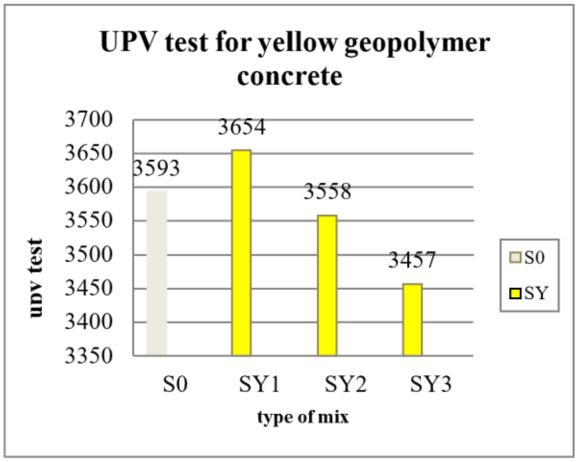

Figure 13. UPV tests for yellow Geopolymer concrete cubic.

4. Conclusions

The red and yellow values increased from the reference value by 2.7 percent and 1.8 percent in the compressive strength test when both colors were combined with 1 percent of the pigment. If pigments are introduced at higher percentages than specified, the outcome will be the opposite (a decrease in compressive strength). The red and yellow values were elevated from the reference value by 8% and 15%, respectively, when applying red pigment at 3% and yellow pigment at 1%, which produced the highest values of the rebound number. The density increases as the added pigment’s fraction increases. The maximum density values were obtained with 1% red and yellow pigment additions, which led to 1% and 3% density increases for red and yellow, respectively. The highest values of ultrasonic pulse velocity rose by 1.7% for yellow and 2% for red when pigments of the colors yellow and red (1% each) were added.

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Conflict of interest

There is no conflict of interest in the current project.

Author Contribution Statement

Rusul Abdul Rahim Ghadban is a master's student and Mohammed Ali Abdulrehm is the thesis supervisor.

References

1. Geopolymer.Org (2012). *What is a geopolymer? Introduction*. [cited 2022; Available from: http://www.geopolymer.org/science/introduction/.
2. Hardjito, D., et al., (2004). *On the development of fly ash-based geopolymer concrete*. Materials Journal. Vol. 101, Isuue 6, pp. 467-472.
3. Mohammed, A. Al-Jaberi, Z., L. A. and Shubber,A. N. (2021). *Effect of Polypropylene Fiber on Properties of Geopolymer Concrete Based Metakaolin.* Journal of Engineering and Sustainable

Development. Vol. 25, Isuue 2, pp. 58-67. https://doi.org/10.31272/jeasd.25.2.7.

4. Khale, D. and R. Chaudhary, (2007). *Mechanism of geopolymerization and factors influencing its development: a review*. Journal of Materials Science. Vol. 42, Isuue 3, pp. 729-746. DOI: https://doi.org/10.1007/s10853-006-0401-4.

5. Kumar, B.S.C. and K. Ramesh, (2017). *Durability studies of GGBS and metakaolin-based geopolymer concrete*. Technology. Vol. 8, Isuue 1, pp. 17-28.

6. Jabbar Alserai, S., W. Kadhim Alsaraj, and L. Abdulbari Aljaberi, (2020). *Bearing Load Capacity of Geopolymer Concrete Thin Wall Panels Under Eccentric Compression*. Journal of Engineering and Sustainable Development. Vol. 24, Isuue 1, pp. 1-14.

7. Srinivasan, K., (2017). *Durability studies on the slag-based geopolymer concrete strengthened with steel fibers*. International Journal of Civil Engineering and Technology (IJCIET). Vol. 8, Isuue, pp. 239-250.

8. Hadi, M.N.S., N.A. Farhan, and M.N. Sheikh, (2017). *Design of geopolymer concrete with GGBFS at ambient curing conditions using the Taguchi method*. Construction and Building Materials. Vol. 140, Isuue, pp. 424-431. https://doi.org/10.1016/j.conbuildmat.2017.02.131.

9. Allan, J.D. (1994). *A manufacturer's opinion on the cause or effect of coloring concrete*. in *Proc. 2 nd Int. workshop on concrete block paving*.

10. Luo, H.L. and D.F. Lin, (2007). *Study the surface color of sewage sludge mortar at high temperatures*. Construction and Building Materials. Vol. 21, Isuue 1, pp. 90-97. https://doi.org/10.1016/j.conbuildmat.2005.06.053.

11. Gutiérrez, J.C.R., O.J.R. Baena, and J.I. Tobón, (2009). *Evaluación Del Desempeño Mecánico Del Cemento Blanco Coloreado Con Pigmento Azul Ultramar*. DYNA: revista de la Facultad de Minas. Universidad Nacional de Colombia. Sede Medellín. Vol. 76, Isuue 157, pp. 225-231. https://doi.org/10.24850/j-tyca-14-1-1.

12. Abdulrehman, M.A., (2012). *Studying Mechanical and Physical Properties of Colored Concrete*. Materials Engineering Department, Mustansiriyah University Baghdad, Iraq.

13. ASTM C989/C989M-12a, (2012). *Standard Specification for Slag Cement for Use in Concrete and Mortars*. West Conshohocken, PA, USA.

14. ASTM E291-18, (2009). *Standard Test Methods for Chemical Analysis of Caustic Soda and Caustic Potash (Sodium Hydroxide and Potassium Hydroxide)*. West Conshohocken, PA, USA.

15. IQS No. 45, (1984). *Aggregate from Natural Sources for Concrete and Construction. Central Agency for Standardization and Quality Control*. Baghdad, Iraq.

16. Hardjito, D. and B.V. Rangan, (2005). *Development and properties of low-calcium fly ash-based geopolymer concrete*. Curtin University of Technology. Issue, pp. 103.

17. Lloyd, N. and V. Rangan. (2010). *Geopolymer concrete with fly ash*. in *Proceedings of the Second International*

Conference on Sustainable Construction Materials and Technologies. UWM Center for By-Products Utilization.

18. Sanni, S.H. and R. Khadiranaikar, (2013). *Performance of alkaline solutions on grades of geopolymer concrete.* International Journal of Research in Engineering and Technology. Vol. 2, Isuue 11, pp. 366-371. https://doi.org/10.15623/ijret.2013.0213069
19. B.S. 1881, part 116, (1989). *Method of Determination of Compressive Strength of Concrete Cubes.* The UK.
20. ASTM C805-02, (1993). *Test for Rebound Number of Hardened Concrete.* West Conshohocken, PA, USA.
21. BS 1881-114, (1983). *Testing Concrete-Methods for determination of density. British Standard.* The UK.
22. ASTM C597-02, (2003). *Standard Test Method for Pulse Velocity through Concrete.* West Conshohocken, PA, USA.
23. Al-Kharabsheh, B., (2007). *An Experimental Study on Colored Concrete Using Pigments from Raw Local Materials.* Departamento de Engenharia Civil. Issue.
24. Hospodarova, V., J. Junak, and N. Stevulova, (2015). *Color pigments in concrete and their properties.* Pollack Periodica Pollack Periodica. Vol. 10, Isuue 3, pp. 143-151. https://doi.org/10.1556/606.2015.10.3.15.