Study of Some Mechanical Properties of Colored Geopolymer Concrete by Using Ultrasonic Pulse Velocity Test

Mohammed H. Mahmud[1] ,Mohammed A. Abdulrehman[2]
1,2 Material department,
College of Engineering,
Mustansiriyah University, Iraq

Abstract

This research study has been done to study dynamic shear modulus, dynamic modulus of elasticity, and dynamic Poisson's ratio of colored geopolymer concrete by using a non-destructive test(ultrasonic pulse velocity)by adding two types of pigments yellow(iron oxide hydroxide) and blue(cobalt) with three additional proportions for each of the listed colors (2, 4, 6% wt), some materials which are available in the native market and other materials imported from outside of the country. Show us that the dynamic young modulus and shear modulus increase with the addition of pigments while the Poisson's ratio decreases.

1. Introduction

Geopolymer concrete is a relatively considered new environmentally friend binder material for partial or total replacement of conventional ordinary Portland cement in concrete which produces a high rate of carbon dioxide. Joseph Davidovits (1978) developed an alkaline liquid that can react aluminum (Al) and silicon (Si) in materials of secondary product such as fly ash, metal slag, or metakaolin(MK). Davidovits coined the term geopolymer to describe this new binder material due to polymerization that occurs in that situation [1].

The first colored concrete was created in the early 1950s by the F.D. Contractors in Southern California were introduced to the concept of introducing synthetic iron oxide, which was then a waste product from chemical processing to their gray concrete mix by the Davis group[2]. Many researchers have studied geopolymer concrete and colored concrete such as Marín-Lópeza had made a comparison between the characteristics of Portland cement concrete as well as metakaolin-based geopolymer concrete [3], Rovnaník was investigated the influence on the strength of compressive and flexural strength of different curing temperatures and times of metakaolin-based geopolymer [4], Cheng et al. had used Geopolymer to study the adsorption of heavy metals. The geopolymer was created by condensing a fixed ratio of MK and alkali solution at a temperature of room and pre-crushing to a constant radius scale[5], Al-Shathr et al. was investigated the influence of various treatment systems on the strength of Metakaolin-based Geopolymer[6],(Sahar et al) had looked into the structural behavior of reinforcement Geopolymer concrete wall[7],Bruce and Rowe had investigated the basic characteristics of (9) pigments commonly used in concrete block paving [8], Hyun-soo et al. had looked into iron oxide pigments' effects on the characteristics of interlocking blocks of concrete [9], Fujii, et al. had looked into the dosage and form of pigment affect the color of concrete [10], Hospodarova et al. had studied some of the physical and mechanical characteristics of the pigment compounds (liquid case) in the first alternative, with the study of pigment in the liquid case with fly ash (the second alternative) [11]. In this study, we will consider the addition of some pigments to geopolymer concrete and study some of the mechanical properties by using the UPV test.

2.Important of the work

Since geopolymer produces carbon dioxide less 80% of ordinary cement, according to previous researches[12]. Through this research, we were concluded that it is possible to use geopolymer as an alternative to concrete when applying colored concrete.

3.Materials and Experimental work

3.1 Materials

Colored geopolymer concrete materials include (metakaolin, fine aggregate, coarse aggregate, alkaline solution (Na_2SiO_3+NaOH), HRWR, Additional water, and pigments.

3.1.1 Metakaolin(MK)

Kaolinite's chemical structure is $Al_2Si_2O_5(OH)_4$; MK is a dehydroxylated mineral clay kaolinite type linked to the reaction [12]

$$Al_2Si_2O_5\,(OH)_4 \rightarrow Al_2Si_2O_7 + 2\,H_2O$$

The synthetic investigation, Metakaolin's real characteristics, and the necessities of Chemical of Pozzolan ASTM C 618 [13] are represented in Tables (1), (2), and(3).

Table (1) Metakaolin chemistry analysis

oxides	Content, percent %
K_2O	0.27
Na_2O	0.22
MgO	0.15
L.O.I	0.71
TIO_2	0.8
Fe_2O_3	0.92
CaO	1.37
SO_3	0.45
Al_2O_3	39.00
SiO_2	54.2
	Σ= 98.09

* done by Geological Survey of Iraq, department of central laboratories

Table (2) Metakaolin physical characteristics

Physics properties	Result
Color	Off-white
Physical	Powder
Specific gravity	2.64
Surface area, m^2 /g	13.3

Table (3) Natural Pozzolan Chemical Requirements under ASTM C618

Composition of Oxide	Pozzolan (Class N)	MK
Loss on ignition, (max %)	10	0.71
SO_3, (max %)	4	0.45
$SiO_2+Al_2O_3+Fe_2O_3$, (min %)	70	94.12

3.1.2 sodium hydroxide

NaOH is commercially available 98 percent pure sodium hydroxide in flake shape solids should be dissolved in water purified to provide the quantity required in a solution. The solution of colored geopolymer concrete is made using sodium hydroxide. To prepare sodium hydroxide used dissolution of flakes of caustic soda in water may help. Cooling of the solution is advised by exposure to air for a while (two hours at least). The descriptions of the NaOH solution used in the analysis by ASTM E 291 can be found in the table (4).[14]

Table (4) Characteristics Sodium Hydroxide*

Appearance	Unit Measuring	Specification ASTM E291-09[53]	Results
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
Ni^{+2}	Ppm	5.0≤	2.42
Silicate as SiO_2	Ppm	20≤	14
Sodium carbonate (Na_2CO_3), max.	Percent	0.40	0.36
Sodium chloride (NaCl), max.	Percent	0.15	0.07
Sodium hydroxide (NaOH), min.	Percent	97.5≥	98.14
Sulphate as Na_2SO_4	Ppm	200≤	70
Water Insoluble	Ppm	200≤	60

* According to manufacturer

3.1.3 Sodium Silicate

Na_2SiO_3 concentration is relying upon the proportion of Na_2O to SiO_2 and H_2O. This sort of Na_2SiO_3 which was utilized in the current examination was made in the UAE. The qualities of the sodium silicate used shows in table (5).

Table (5) Sodium Silicate's Properties *

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

* According to Manufacturer.

3.1.4 Coarse Aggregate

Coarse aggregate (Al-Nebai quarry) natural gravel was used and examine the gradation, specific gravity, sulfate content, absorption. The outcomes show that it adapts to Iraqi standard IQS 45/1984[15]. Examining, characteristics of coarse aggregate (chemical and physical) are shown in Tables, (6) and (7) respectively.

Table (6) Natural Coarse Aggregate Examining *

Sieve Size(mm)	Passing %	IQS No.45- 1984
14	100	90-100

10	99	85-100
5	8	1-10
2.36	3	0-5
1.18	0	----

* Gradation studies were carried out at the material laboratory Al-Mustansiriyah University, College of Engineering.

Table (7) Natural Coarse Aggregate Characteristics *

Characteristics	Test Result	IQS No.45-1984
Absorption%	0.62	----
Gravity specifics	2.6	----
Sulfate content%	0.09	0.1 percent maximum

* Tests were conducted in the University of Baghdad's directorate of construction science

3.1.5 Fine Aggregate

Fine aggregate(Al-Ekadir region/ Karbala Governorate) with maximum size (4.75mm) was used as part of this work, so it is necessary to clean it before use. Tables (8) and (9) show the grade, physical and chemical characteristics of fine aggregates conforming to Iraqi standard specifications IQS (No. 45/1984) [15].

Table (8) Grading of Natural Fine Aggregate*

Size of Sieve (mm)	Cumulative Percentage Passing	IQS 45-1984, zone 2
10.0	100	100
4.75	92.23	90-100
2.36	79.41	75-100
1.18	66.71	55- 90
0.6	44.02	35-59
0.3	15.35	8-30
0.15	0.08	0- 10

* The substance laboratory, the College of Engineering, the University of Al-Mustansiriyah, carried out graduation examinations.

Table (9) Natural Fine Aggregate characteristic *

Characteristics	Result of Test	IQS 45-1984
Absorption (%)	0.71	----
Fineness modulus	3.022	----
Gravity specifics	2.7	----
Sulfate content%	0.36	maximum 0.5 %

* The test was done in the University of Baghdad Construction Study Directorate

3.1.6 HRWRA

To improve the workability of geopolymer concrete, The high range water reducer based upon the modified condensate of the sulfonated naphthalene formaldehyde has been used. The name of the product KUT PLAST SP400 has been provided by the local supplier. KUT PLAST SP 400 complied with the specification of the ASTM C494 type F. Table(10)illustrates the basic characteristics of the KUT PLAST SP 400[16].

Table(10) Super plasticizer characteristics (KUT PLAST SP 400)*

Properties	Descriptions
Specific gravity	1.220 – 1.240 at 20^{o}C
Colour	Light Brown
Chloride content	Nil
Air entrainment	< 1.0%
Calcium Chloride content	Nil

* According to manufacturer

3.1.7 Additional Water

Additional water is the tap water from the water delivery grid for the concrete mix design.

3.1.8 Pigments

Two types of pigment were used in this research (yellow iron oxide hydroxide, and cobalt blue) of Chinese origin (granular size ≤ 45 micron)and used with different percent (0, 2, 4, 6) %wt. of metakaolin.

3.2 Colored Geopolymer Concrete Mixes

Table (11) Colored Geopolymer Concrete Mixes

Mix.	MK, kg/m^3	The alkaline solution, by MK weight	additional Water, by MK weight	Coarse Aggregate kg/m^3	Fine Aggregate kg/m^3	Pigments Kg/m^3	HRWR, By weight of MK %	NaOH molarity	Na_2SiO_3/ NaOH
Mo	400	0.65	0.12	1200	650	0	3.5	16	1:2.5
MY 2	392	0.65	0.12	1200	650	8	3.5	16	1:2.5
MY 4	384	0.65	0.12	1200	650	16	3.5	16	1:2.5
MY 6	376	0.65	0.12	1200	650	24	3.5	16	1:2.5
MC 2	392	0.65	0.12	1200	650	8	3.5	16	1:2.5
MC 4	384	0.65	0.12	1200	650	16	3.5	16	1:2.5
MC 6	376	0.65	0.12	1200	650	24	3.5	16	1:2.5

***Where Mo: Geopolymer concrete without pigments, MY: Geopolymer concrete with Yellow iron oxide hydroxide, and MC: with Blue cobal**

3.3 Solution for Geopolymer

3.3. 1 Preparing NaOH Solution Alkaline

The alkali solution of Geopolymer concrete has been constituted of two Ingredients (Na_2SiO_3 and NaOH). The NaOH flakes with a high 98% purity can be made into a solution by dissolving them in distilled water. The mass of NaOH in the final solution varies depending on the NaOH solution's concentration. For eg, a 10 molar solution of NaOH contains 10 x 40 = 400 g of NaOH solids per liter, where 40 denotes the molecular weight of NaOH, O = 16, Na = 23, and H = 1. The NaOH solid mass in this work has been evaluated as 262g for each kilogram of the sodium hydroxide solution with an 8 M concentration. Similarly, NaOH solid mass for each kilogram of solution for other concentration values has been measured as 10M: 314g, 12M: 361g, 14M: 404g, and 16M: 444g, based on the ASTM E291-09[14] and (Hardjito and Ranga) [1].

3.3.2 Preparation of the Alkaline Liquid

Sodium silicate solution is available commercially in different degrees and has a SiO_2 to Na_2O relationship of 2.4 in the sodium silicate solution used in this analysis. The weight of components is proportionally water = 55.1%, SiO_2 = 32.5% and Na_2O = 13.4%. After preparing NaOH as a solution, the Na_2SiO_3 solution will be added. The mixture of a solution of (NaOH) and a solution of Na_2SiO_3 is alkaline fluid. The alkaline fluid should be prepared at least 24 hours before use, by combining solutions[1].

3.4 Mixing Procedure for colored Geopolymer Concrete

First, in dry form, the coarse and fine aggregate has been mixed for 2-3 min using a 200-litter mixer. The pigments have been added into the dry mixture then metakaolin, prepared alkali liquid, superplasticizer, and additional water. for 4min-5min final mixtures were carried out to reaching the homogeneity of the mixture[17][18].

3.5 Curing

This treatment procedure means positioning the specimen outside of the laboratory under direct sunlight for 28 days after demolding. Models have been poured over temperatures of 32° to 36°, which are dependent on the previous studies[6] and which are positioned under ambient temperature.

3.6 Dynamic Modulus of Elasticity, Shear Modulus, and Poisson Ratio

UPV has been carried out with each mixture based on the ASTM C-597 of colored geopolymer concrete [19] mainly consists of the measurement's duration, T (second) of the ultrasonic pulse (50kHz - 54kHz), by the electro-acoustic transducer is generated and put under testing on one side of the concrete member, and the same is gained from the similar transducer in contact with the other side. The pulse

Velocity (V=L/T) can be calculated with measured travel time T (sec) and distance between two props L (m). The transducers can be arranged, as can be seen from figure(1) in 3 potential configuration types. Those are (a) direct (b) indirect, (c) semi-direct transmission

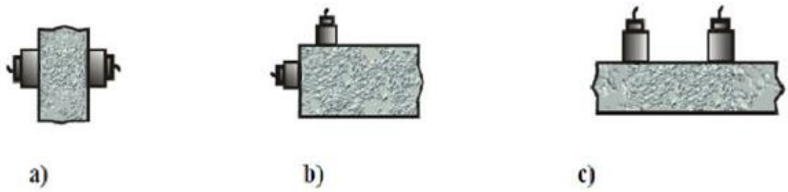


Figure (1) Methods of the transmission of pulse velocity ultrasonic

In this work, a direct test approach was used to the samples of colored geopolymer concrete, Figure (2).

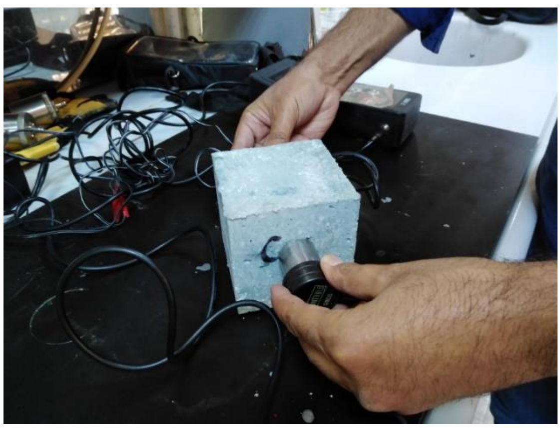


Figure (2) Ultrasonic Pulse Velocity direct test

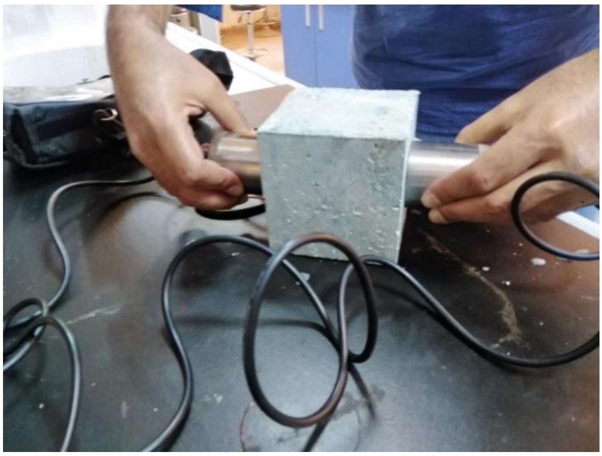
As a non-destructive testing method, ultrasonic testing is often used to other discontinuities and detect cracks in solids. Elasticity moduli (E), Poisson ratio (v), and shear moduli (G), which are mechanical properties are also present. The following relationships can be used to measure elastic properties by calculating the (V_T) is transverse speed and (V_L) is the longitudinal speed of ultrasonic waves[20]

$$E = \frac{\rho V_T^2 (3V_L^2 - 4V_T^2)}{V_L^2 - V_T^2} \qquad (1)$$

$$G = V_T^2 \rho \qquad (2)$$

$$v = \frac{\left(V_L/V_T\right)^2 - 2}{2\left[\left(V_L/V_T\right)^2 - 1\right]} \qquad (3)$$

in which ρ, the density of the samples.The transverse wave velocity can be calculated by used (S-wave transducers)as shown in figure (3).



Figure(3) UPV with S-wave transducers

Table 12 shows the outcomes of the Dynamic young modulus, shear modulus, and Poisson's ratio results of colored geopolymer concrete mix.

Table (12) Dynamic young modulus, shear modulus, and Poisson's ratio results of colored geopolymer concrete mix

Mix.	Dynamic young modulus(Gpa)	Shear modulus(Gpa)	Poisson's ratio
Mo	28	11.85	0.1831
MY2	28.67	12.14	0.1809
MY4	29.1	12.33	0.1802
MY6	29.8	12.64	0.1796
MC2	28.39	12	0.1829

MC4	28.7	12.15	0.1817
MC6	29.09	12.32	0.1806

From table (1), it can be seen that the young modulus and shear modulus increase with the addition of pigments while the Poisson's ratio decreases.

Conclusions

The value of the Dynamic young modulus increased by adding the pigments. The highest value was when adding (6%) yellow, and blue pigments, as the young modulus value increased to (6.42% and 3.89 %) by adding the yellow, and blue pigments, respectively. the shear modulus behavior similar to the young modulus by increased(6.67% and 3.96%) for the yellow and blue

pigments, respectively. The Poisson ratio decreases with the addition of pigment, with the lowest values being achieved upon addition (6%) by (1.9% and 1.36%) for yellow and blue pigments, respectively.

References

[1] D. M. J. Sumajouw, D. Hardjito, S. E. Wallah, and B. V Rangan, “Fly ash-based geopolymer concrete: An application for structural members,” *World Congr. GEOPOLYMER 2005 Geopolymer; Green Chem. Sustain. Dev. Solut.*, 2005.

[2] B. A.-K.-D. de E. Civil and undefined 2007, “An Experimental Study on Colored Concrete using Pigments from Raw Local Materials.”

[3] C. Marín-López *et al.*, “Synthesis and characterization of a concrete based on metakaolin geopolymer,” *Inorg. Mater.*, vol. 45, no. 12, pp. 1429–1432, Dec. 2009.

[4] P. Rovnaník, “Effect of curing temperature on the development of hard structure of metakaolin-based geopolymer,” *Constr. Build. Mater.*, vol. 24, no. 7, pp. 1176–1183, Jul. 2010, doi: 10.1016/j.conbuildmat.2009.12.023.

[5] T. W. Cheng, M. L. Lee, M. S. Ko, T. H. Ueng, and S. F. Yang, “Applied Clay Science The heavy metal adsorption characteristics on metakaolin-based geopolymer,” vol. 56, pp. 90–96, 2012, doi: 10.1016/j.clay.2011.11.027.

[6] B. Al-Shether, T. Al-Attar, and Z. A. Hassan, “Effect of Curing System on Metakaolin Based Geopolymer Concrete,” *J. Univ. Babylon - Eng. Sci.*, vol. 24, no. 3, pp. 569–576, 2016.

[7] Sahar Jabbar M. AL-Serai, “Structural Behavior of Fiber Reinforced Geopolymer Concrete Wall Panels,” *M.Sc. Civ. Eng. / Al-Mustansiriyah Univ.*, 2019.

[8] S. Bruce, G. R.-P. of the 4th I. C. on, and undefined 1992, “The influence of pigments on mix designs for block paving units.”

[9] H. S. Lee, J. Y. Lee, and M. Y. Yu, "Influence of iron oxide pigments on the properties of concrete interlocking blocks," *Cem. Concr. Res.*, vol. 33, no. 11, pp. 1889–1896, Nov. 2003, doi: 10.1016/S0008-8846(03)00209-6.

[10] T. Fujii, A. Fujiki, H. Tanaka, and T. Ayano, "Effect of dosage of pigment on the surface color of concrete," *Zair. Soc. Mater. Sci. Japan*, vol. 54, no. 8, pp. 810–815, Aug. 2005, doi: 10.2472/jsms.54.810.

[11] V. Hospodarova, J. Junak, and N. Stevulova, "Color pigments in concrete and their properties," *Pollack Period.*, vol. 10, no. 3, pp. 143–151, Oct. 2015, doi: 10.1556/606.2015.10.3.15.

[12] S. Salvador, "Pozzolanic properties of flash-calcined kaolinite: A comparative study with soak-calcined products," *Cem. Concr. Res.*, vol. 25, no. 1, pp. 102–112, Jan. 1995, doi: 10.1016/0008-8846(94)00118-I.

[13] A. S. for T. and materials Materials, "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete," 2002.

[14] *ASTM E291, "Standard Test Methods for Chemical Analysis of Caustic Soda and Caustic Potash (Sodium Hydroxide and Potassium Hydroxide) ", American Society for Testing and Materials, 2009*. .

[15] *IOS No.45, Iraqi Specification, "Aggregate from Natural Sources for Concrete and Construction", Central Agency for Standardization and Quality Control, Baghdad, 1984*. .

[16] *ASTM C494 "Standard Specification for Chemical Admixtures for Concrete", Annual Book of American Society for Testing and Material Standards, 2004*. .

[17] N. A. Lloyd and B. V. Rangan, "Geopolymer concrete with fly ash," *2nd Int. Conf. Sustain. Constr. Mater. Technol.*, vol. 7, pp. 1493–1504, 2010.

[18] M. A. Abdulrehman, "Studying Mechanical and Physical Properties of Colored Concrete," 2012.

[19] *ASTM C597-02 Standard Test Method for Pulse Velocity through Concrete", American Society for Testing and Materials, 2003*. .

[20] I. H. Sarpün, V. Özkan, and S. Tuncel, "Ultrasonic determination of elastic modulus of marbles relation with porosity and CaO %," *10th Int. Conf. Slov. Soc. Non-Destructive Test. Appl. Contemp. Non-Destructive Test. Eng.*, pp. 119–125, 2009.