

EFFECT OF ALKALI - ACTIVATED NATURAL POZZOLAN ON MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE

Zainab M. MOHAMMED^{1,*}, Ali A. ABDULHAMEED², Hamid K. KAZIM³

¹ Ministry of Education, Baghdad, Iraq.

² University of Baghdad, Dept. of Reconstruction and Projects, Baghdad 10071, Iraq.

³ Middle Technical University Technical Institute in Balad, Iraq.

* corresponding author: zanmsh@gmail.com

Abstract

As an alternative to Ordinary Portland Cement (OPC), the alkali-activated binders have been developed with better technical characteristics and more extended durability. The Alkali-Activated Iraqi Natural Pozzolans (AANP) could produce geopolymer cementation building materials and make them ecologically acceptable. The primary advantage of geopolymer cement is that it has a lower environmental effect that contributes to it. The engineering characteristics of geopolymer concrete produced using activated Iraqi natural Pozzolan are summarized in this research. The mechanical properties, modulus of elasticity, and ultrasonic pulse velocity of various concrete mixes were determined via experimental study. The impact of essential variables like water/binder ratios w/b % and curing conditions on the characteristics of geopolymer concrete have been identified using test data. The findings indicate that concrete and mortar produced with alkali-activated natural pozzolans have flexibility and moderate to high strength.

Keywords:

Geopolymer concrete;
Activated natural pozzolana;
Compressive strength;
Tensile strength;
Modulus of elasticity.

1 Introduction

A significant building material used around the world is Portland cement concrete. Unfortunately, massive CO₂ amounts are emitted into the environment through the manufacture of Portland cement, which contributes greatly to the greenhouse effect and the Earth's global warming. Portland cement manufacturing is expected to generate approximately 7 % of world CO₂ emissions, lowering greenhouse gas emissions. The carbon dioxide emissions generated by alkali-activated cement are about 50 - 80 % lower than those produced by OPC. Environment-friendly construction materials must be developed. Sustainable development principles necessitate the development of novel construction materials. Geopolymer cement is an alternative used to manufacture precast concrete, structural and non-structural components, stabilize hazardous waste and process heat-resistant concrete products [1, 13, 17].

The chemical processes that make up the concrete geopolymer replacement don't need high temperatures for processing, producing carbon dioxide, unlike standard concrete. The term geopolymer refers to a group of metal binders made up of silicon, oxygen, and aluminium that have a polymeric nature. Dissolution, transport, orientation, and multiple condensations, are all possible mechanisms for geopolymer polymerization, an exothermic process [2, 18, 19].

The numerous preparation routes for synthetic geopolymers, including the sequence in which the raw ingredients are applied, show the various improvements in material compressive strength. The simplest method is to prepare an alkaline solution by combining MOH, water, and stirring for two minutes, then adding Pozzolan to the alkaline solution in a mixer for 15 minutes. Then add sodium silicate and mix for 15 minutes. The geopolymer paste helps bind fine and coarse aggregates and any non-reactive material for preparing the geopolymer concrete. Hard paste with high viscosity is the core of modern geopolymer concrete, so it appears to have poor workability [3].

By changing the components of the mixture, the timing of the geopolymer mixture can be set to adjust either quickly or slowly. Depending on the installation circumstances, in a short time, satisfactory structural integrity and density were achieved, less than sixty minutes. With the inclusion of methacholine, granular slag was used as a source of the material; it was found that the processing temperature, alkaline activator shape, and source material composition influenced the geopolymer paste setting time. At 60 °C, they claimed the geopolymer paste took 15 - 45 minutes to cure [4]. Pozzolans with a greater silicate and aluminate content may slow down the setting time of alkali-activated Natural Pozzolan, which lowers as the curing temperature and alkaline hydroxide rise [16].

Laboratory experience shows that fresh geopolymer concrete can be cured for at least 120 minutes with no indication of tuning in compressive strength and degradation after mixing. This is mostly determined by the chemicals found in the source material; for example, the greater the CaO concentration, the quicker the environment. Other chemicals in the source material, such as Al_2O_3 and SiO_2 , may further delay preparation. The first setting time of PFA-based geopolymers is quicker at high temperatures, and the ultimate setting time of these mortars is 15 – 25 minutes after the initial setting [4].

Hydrothermal curing treatments at 40 - 90 °C are commonly used to improve the mechanical performance of early age alkali-activated materials AAMs because of their predominantly semi-crystalline nature and low CaO and reactive Al_2O_3 contents. Increasing the curing time led to a decrease in porosity and thus promoted strength development in both concrete, regardless of their natural state [14].

There are many distinct viewpoints on the major variables influencing the mechanical characteristics of geopolymer concrete. Compressive strength is influenced by the kind of alkaline activators used, the curing periods, and the processing temperatures. According to other researchers, the relative amounts of Si, Al, K, and Na in solution, the molar ratio of Si to Al in solution, the ratio of alumina silicate mineral to kaolin, the form of alkaline activator, water content, and treatment temperature are all important factors in achieving satisfactory polymerization. The addition of silicate ions to the aqueous solution substantially increases mechanical strength and modulus of elasticity values. Still, it has a little detrimental effect on the matrix/aggregate and matrix/steel links, otherwise quite strong [3]. Compared to conventional concrete, this new kind of concrete may provide several advantages, including increased early strength, increased temperature resistance, and improved chemical resistance in hostile settings. Many concrete buildings, particularly those constructed in corrosive settings, begin to degrade after 20 to 30 years, prompting researchers to investigate the endurance of conventional Portland cement concrete [15].

Compared to OPC manufacturing, geopolymer concrete manufacturing is expected to reduce CO_2 emissions by 22 - 72 %, depending on the materials used. This article describes how to make geopolymer concrete from Natural Pozzolan and the laboratory findings experiments performed on the materials. The study results provided in this article help understand the engineering characteristics of geopolymer concrete. Weakening the (matrix/steel) bond is otherwise extremely strong [5].

2 Experimental studies

2.1 Material and mixing procedure

CaO/ SiO_2 ratio is 0.19. It was chosen because it's the most reactive natural pozzolana found in Iraq, and it is used to make Portland Pozzolan Cement. The presence of feldspar (Sodic plagioclase includes alpine and hornblende), amphibole, quartz, and biotite in pozzolan cement was discovered using a light microscope. The chemical analysis of Portland cement, coarse aggregate, and activated pozzolana is presented in Table 1.

Table 1: Chemical composition of Portland cement, coarse aggregate, and activated natural pozzolana.

	Compound composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	TiO ₂	K ₂ O	Na ₂ O	SO ₃	L.O.I.
Portland cement	Percentage by weight	61.65	15.92	4.3	7.55	2.03	0.437	2.13	3.2	2.25	2.84
	IQS.5, 2019 limits [6]	--	--	--	--	Max 5 %	--	--	--	Max 2.8 %	Max 4 %

	Property	Results	Iraqi specifications limits [7]
Coarse aggregate	Apparent specific gravity	2.6	-
	Absorption	2.5	-
	Apparent specific gravity	2.6	-
	Absorption	2.5	-
	Bulk density [kg/m ³]	1600	-
	% SO ₃ content	0.09	Max. 0.1 %

	Compound composition	SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃ [min %]	SO ₃ [max %]	Moisture content [max %]	L.O.I [max %]
Activated natural pozzolana	Percentage by weight	76	3.6	2.0	8
	ASTM C 618 [8]	70.0	4.0	3.0	10.0

Potassium hydroxide KOH pellets have been dissolved in water to produce alkaline solutions to produce geopolymer concrete. Sodium silicate solution was supplied as glass water. The resultant solution's chemical makeup was 8.4 % Na₂O, 26.7 % SiO₂ and 63 % water pH 11.5.

This study obtained the aggregate from river sediments and consisted of 14 mm and 4.75 mm coarse aggregate and sand. The fineness coefficient of the aggregate was 2.07; the grading analysis of the coarse and fine aggregate is in Table 2.

Table 2: Grading analysis of coarse aggregate and fine aggregate.

	Size of sieve 14.5 mm	Passing [%]	Iraqi specifications limit No. 45 / 1984*
Coarse aggregate	20	100	100
	14	100	90-100
	10	60	50-85
	5	5.3	0-10
	Size of sieve [mm]	Accumulated passing [%]	Iraqi specifications limit No. 45 / 1984*
Fine aggregate	9.50	100	100
	4.75	90	90-100
	2.63	71	60-95
	1.18	51	30-70
	0.60	30	15-34
	0.30	9	5-20
	0.15	1.2	0-10

* Limit of Iraqi specification No. 45/1984 [7]

Table 3: Mix proportion of geopolymer cement concrete.

Materials	kg/m ³
Fly ash (Class F)	204
Cement	204
Fine sand	531
Coarse aggregate	1266
Sodium silicate solution	105
Sodium hydroxide solution	39

Table 4: Mix proportion of ordinary Portland cement concrete.

Materials	kg/m ³
Cement	408
Fine sand	531
Coarse aggregate	1266
Sodium silicate solution	105
Sodium hydroxide solution	39

As shown in Tables 3 and 4, there are two kinds of mix proportions with and without fly ash. The BRE technique was used to calculate the set concrete mixture ratio, which resulted in compressive strength of 45 MPa 28 days and a 55 mm slump. The cement and the particles in the water glass and the alkali solution were replaced with the same amount of Iraqi natural Pozzolan; however, no more water was added since the activators were already in the solution. For all mixtures, the KOH [ml] / Na₂SiO₃ [ml] ratio was 7.7, and the solids in the water glass and the alkaline solution to total binder ratio by mass for the AP1 and AP2 blends, respectively, were 25 and 30 %. The following is a list of how to write down downmixing procedures:

- MC1: PC mix control $w/c = 0.40$,
- MC2: PC mix control $w/c = 0.50$,
- AP1: Activated pozzolana $w/b = 0.40$,
- AP2: Activated pozzolana $w/b = 0.50$.

Compressive strength was measured using Pozzolan activated mixes with w/b 0.4 and 0.5 wt. The testing required that concrete samples be poured in a variety of sizes. The liquids were poured three layers into pre-oiled moulds and then vibrated to eliminate any trapped air using a vibration table. The vibe test was used to determine the flow of the mixes, and the vibe timings for the AP1 and AP2 mixtures were 30 and 15 seconds, respectively. The adherence of geopolymer concrete to the mould is problematic, and mould lubrication is crucial for sample ejection.

After 24 hours of casting and curing, samples are formed in two processing systems at three temperature levels:

1) Closed treatment: To evaluate tensile and compressive strength. Three sets of samples were wrapped in impermeable plastic wrap that had been evaluated and kept at 30 ± 2 , 50 ± 2 , and 70 ± 2 °C in a controlled environment.

2) Vapor treatment: To evaluate tensile and compressive strength, the treatment was modified for three series of samples put in a vapour chamber at 30 ± 2 , 50 ± 2 , and 70 ± 2 °C. The static modulus of elasticity was tested using vapour curing at 50 ± 2 °C.

2.2 Methods of examination

2.2.1 Compressive strength

To determine the compressive strength of geopolymer concrete, each mixture was prepared in cubes of 10 x 10 x 10 cm, and These samples were evaluated for compressive strength according to BS EN 12390-3:2009 [9]. Section 3.1 goes through the casting and processing procedures. Each formulation was tested with three samples at 3, 7, 28, and 90 days, and the findings were presented as average compressive strength values.

2.2.2 Ultrasonic pulse velocity

According to BS EN 12504-4:2004, Ultrasound pulse velocity was measured by ultrasound. Measurement was performed on the 100 x 100 mm end face of a 500 mm prism [10] At 7, 28 and 90 days, two sets of duplicate samples were examined.

2.2.3 Tensile strength

100 x 200 mm cylinders were used to test the tensile strength of all the mixes BS EN 12390-6: 2002 [11]. At 7, 28, and 90 days, samples were examined in duplicate groups, with average findings reported.

2.2.4 Modulus of elasticity

By BS1881-121:1983, the static modulus of elasticity by uniaxially compressing a 100 x 200 mm cylinder sample and measuring deformation with disc gauges placed between specified measurement lengths [12]. The pressure is calculated by dividing the demand gauge reading by the scale length, and the applied load is divided by the cross-sectional area. The stress-tension connection was discovered after a series of readings. The modulus of elasticity constant has occurred as a result of real loading at 7, 28 and 90 days.

3 Discussion of the results

3.1 Compressive strength

In Figs. 1 and 2 the logarithmic X-axis displays the results of the compressive strength of the concrete utilizing activated Iraqi natural pozzolana and regulating Portland cement mixtures. Concrete's strength grew with age in all instances. The pace of strength development is fast in the early years and then slows down as you become older. Early on, geopolymer concrete mixes had lower strength than OPC control mixtures, but following long-term ageing, they had the same or even greater strength as OPC mixes. After 365 days, the activated pozzolana with $w/b = 0.40$ AP1 had the greatest pressure resistance of 42 MPa, while the activated pozzolana with $w/b = 0.50$ AP2 had the higher pressure resistance of 38 MPa, which was greater than the OPC control mixture.

The strength of concrete is significantly influenced by the curing process. The impact of various processing temperatures in two treatment states: closed and vapour-cured, is seen in Figs. 1 and 2. Overall, the closed condition and the OPC control concrete produced the greatest outcomes in the long-term. However, there isn't much of a difference between the two situations. This effect may be explained by the water being retained in the pores of vapour-cured samples, resulting in a more open microstructure.

The findings showed that the optimum temperature for treating alkaline activated pozzolana was 70 °C for achieving high early strength, but the greatest long-term strength was achieved at 50 °C under airtight circumstances.

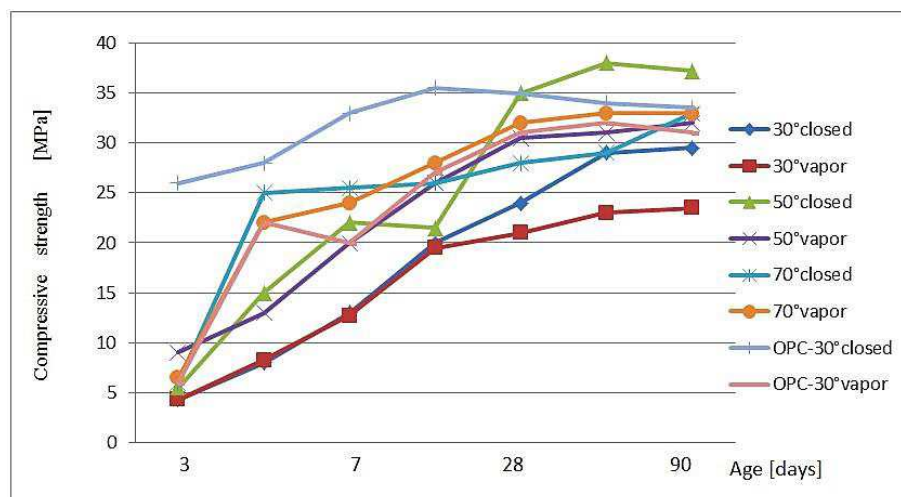


Fig. 1: Compressive strength of activated and OPC control mixtures in the long-term $w/b = 0.50$.

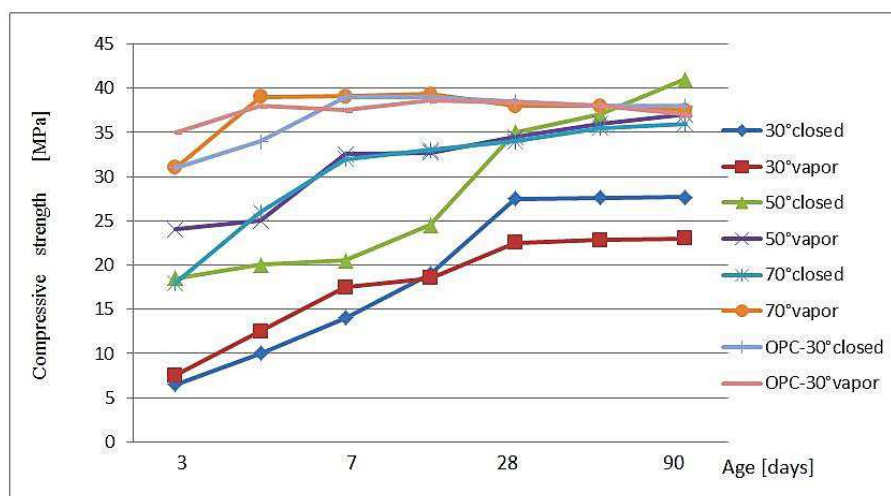


Fig. 2: Compressive strength of activated and OPC control mixtures in the long-term $w/b = 0.40$.

The impact of the quantity of water is shown in Fig. 3, which plots the compressive strength over 28 days versus the water to geopolymer particles by mass ratio. The results in Fig. 3 indicate that when the ratio of water to geopolymer particles by mass increased, the compressive strength of the geopolymer concrete dropped, resulting in free water in the geosynthetic concrete and a porous microstructure. Fig. 3 shows that increasing the curing temperature improved the compressive strength of concretes.

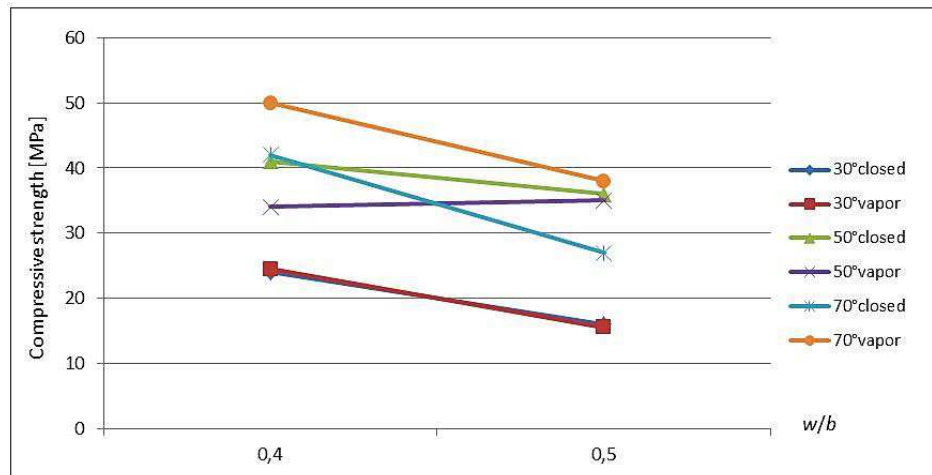


Fig. 3: Compressive strength of alkali-activated Pozzolan after 28 days against w/b % at various curing temperatures.

3.2 Ultrasonic pulse velocity

Fig. 4 displays the ultrasonic pulse velocity test results for all mixes. The greatest values were obtained by AP1, followed by AP2, which has the highest weight. Even with the same compressive strength or greater, all geopolymer concrete mixes had lower ultrasonic pulse velocities than OPC concrete mixtures.

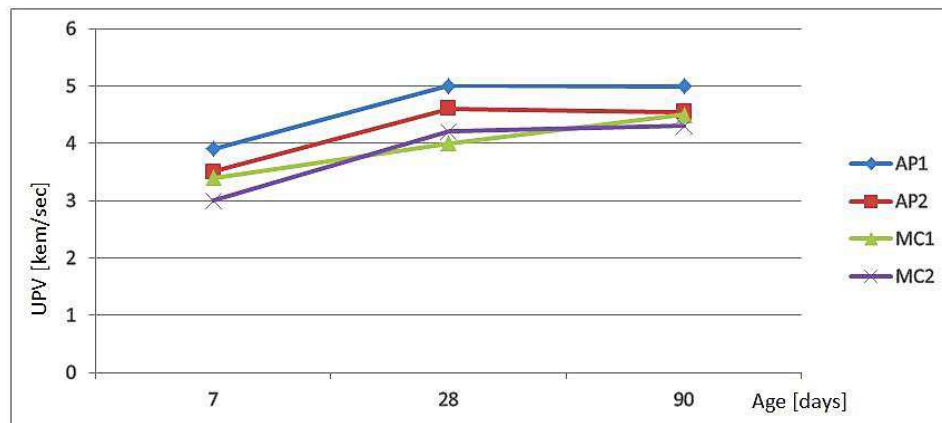


Fig. 4: Ultrasonic pulse velocity for various blends.

3.3 Indirect tensile strength

Figs. 5 and 6 show the results of 90 days of indirect tensile strength testing and the impact of temperatures and curing conditions on the tensile strength of concrete. Tensile strength follows a similar pattern as compressive strength. Fig. 5 depicts the development of tensile strength of various combinations. Compared to control OPC mixes, activated natural pozzolan-based geopolymer concrete mixtures had better tensile strengths at longer ages. AP2 exhibited poorer tensile strength performance at an early age than the OPC control mix of 1.7 MPa vs 2.03 MPa.

After 28 days, the tensile strength of the AP1 blend was greater than that of the OPC control combination. Compared to MC1 and MC2, the tensile strength of activated geopolymer concrete mixtures was greater than that of (ordinary Portland cement) control mixtures. The tensile strength of activated natural geopolymer concrete, like OPC concrete, is more susceptible to over curing than the

compressive strength. The impact of curing conditions and temperatures on the tensile strength of concrete is shown in Fig. 5. The optimal processing temperature was 50 °C, which coincided with the compressive strength temperature. Also, a greater water-to-binder ratio resulted in decreased tensile strength, consistent with the trend seen with OPC blends.

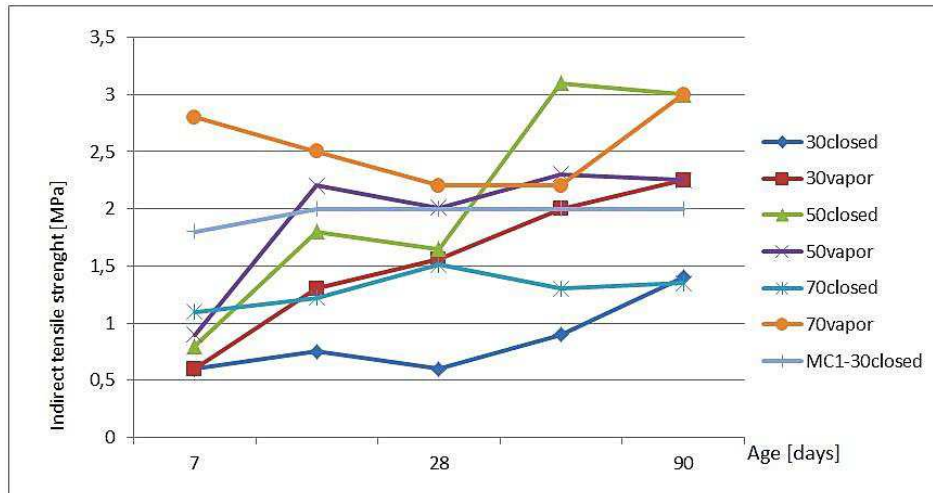


Fig. 5: Tensile strength of AP1 and MC1 mixes.

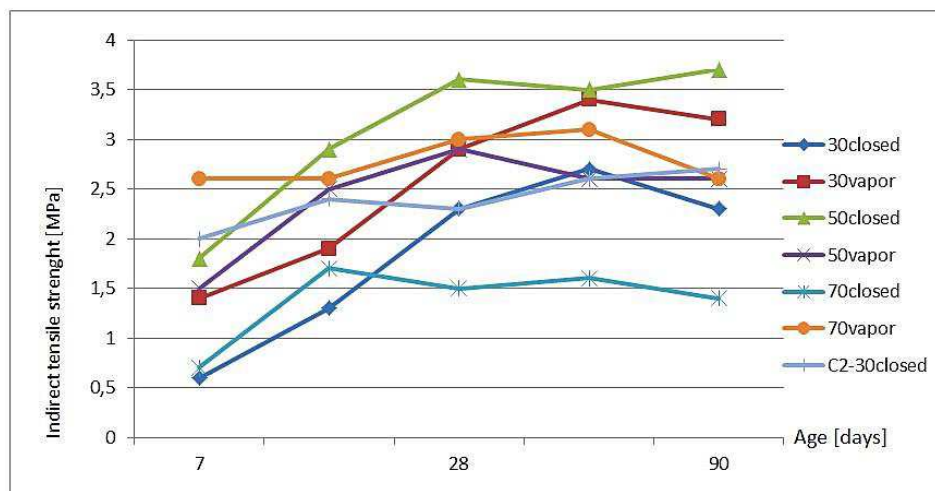


Fig. 6: Tensile strength of AP2 and MC2 mixes.

3.4 Modulus of elasticity

Figs. 7 and 8 show the findings of the static modulus of elasticity. The constant modulus of elasticity rose with age, similarly to the compressive modulus findings. This progress was fast in the first 28 days, with most of the total parameter value attained during this time. Except for the AP1 mixture, mixes composed mainly of activated natural Pozzolan had a lower constant modulus of elasticity during the first 14 days than OPC concrete mixtures.

Long-term findings indicate that certain alkaline activated natural pozzolans, such as AP1, have a constant modulus of elasticity of 5 – 20 % greater than OPC mixes. AP1 and AP2 mixes have a lower long-term constant modulus of elasticity than OPC concrete mixtures. Curing temperature has an impact on the modulus of elasticity.

At a young age, raising the curing temperature raised the constant modulus of elasticity to the degree that appears to be linked to the w/b %, Fig. 7. With a w/b % of 0.40, the curing temperature was increased to 50 °C for AP1, and the modulus of elasticity rose but dropped when the curing temperature was increased up to 70 °C. The temperature rose as the greatest constant modulus of elasticity was achieved at 70 °C for AP2 mixes with a w/b % of 0.50. However, with time, the outcomes deteriorate to the same level as the treated mix at 50 °C Fig. 8.

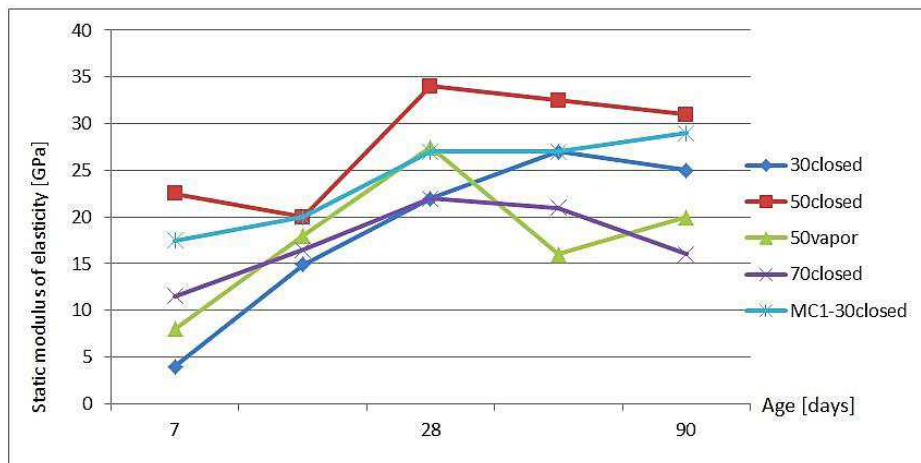


Fig. 7: Static modulus of elasticity of AP1 and MC1 mixes.

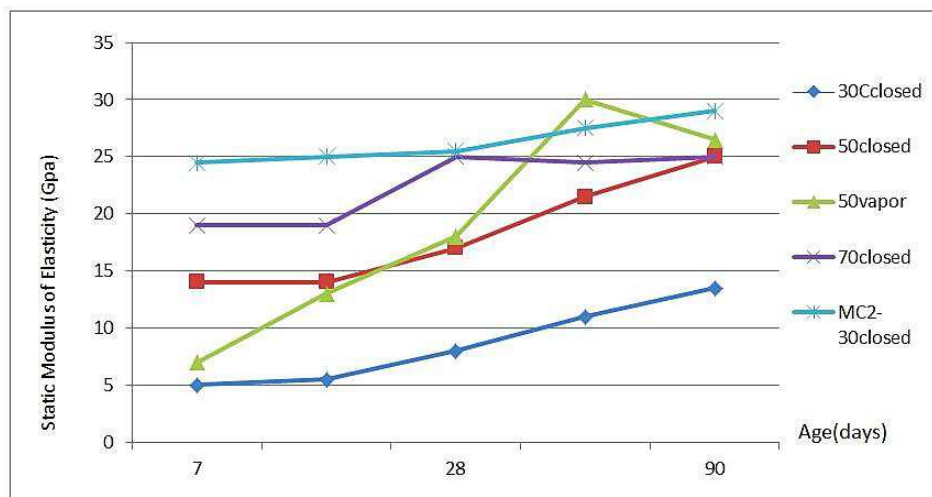


Fig. 8: Static modulus of elasticity of AP2 and MC2 mixes.

4 Conclusion

The major findings of this study on the engineering characteristics of geopolymer concrete produced with natural pozzolan activation AANP are as follows:

- 1) Early on, activated natural pozzolan geopolymer concretes have lower strength than ordinary Portland cement mixes. Still, they have the same or even greater strength as ordinary Portland cement mixes after curing.
- 2) Increases in the mass ratio of water to geopolymer particles reduce the strength of geopolymer concrete. More water is retained inside the geopolymer paste, resulting in a more flexible microstructure in this kind of concrete.
- 3) Geopolymer concrete seems to have a lower ultrasonic pulse velocity than ordinary Portland cement concrete of the same compressive strength.
- 4) Pozzolan Activated Natural Concrete mixes exhibit a lower constant modulus of elasticity than ordinary Portland cement concrete mixes during the first seven days. According to long-term findings, the static modulus of AANP concrete is usually approximately 5 - 20 % greater than that of ordinary Portland cement mixes.
- 5) Curing temperatures affect the modulus of elasticity of AANP concrete. The modulus of elasticity constant rose with the increase of curing temperatures at a rate that seemed to be linked to the w/b % at an early age. If water is lost due to evaporation during processing at a higher temperature before full strength increases, the modulus of elasticity decreases.

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