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Study of Curing Time Impact on Geopolymer Concrete and Mechanical Properties

Oliver Johns, Lily Taylor*

University of Nottingham, Nottingham NG7 2RD, UK

*Corresponding Author: taylor.lilyun@gmail.com

Abstract. Geopolymer concrete has the potential to replace traditional concrete as a viable material choice. The purpose of this research was to determine how long the geopolymer concrete examples needed to cure before they reached their final mechanical qualities. We measured the density, drying shrinkage, compressive strength, splitting tensile, flexural strength, poisson's ratio, elastic modulus, rebound strength, and ultrasonic pulse velocity of the specimens after they had been cured in the oven at 600C for 4 hours to 72 hours. The results of the experiments reveal that the compressive strength, splitting tensile strength, and flexural strength all increase dramatically during the first 24 hours of curing but then level off. The specimens cured for 72 hours had the highest elastic modulus, whereas those cured for only 4 hours had the lowest. Specimens cured for 4 hours had the highest density, while those cured for 72 hours had the lowest. Similar trends may be seen in the specimens' compressive strength, rebound strength, and ultrasonic pulse velocity.

Keywords: Geopolymer Concrete; Curing Time, Curing Conditions; Mechanical Properties; Compressive Strength.

INTRODUCTION

In the present day and age, geopolymer concrete may be superior to regular concrete made with portland cement. Because of its utilisation of industrial solid wastes including flyash, GGBFS, rice husk ash, and sugarcane bagasse ash, etc., geopolymer concrete is sustainable, cheap, high-performing, and long-lasting. The GPC could employ as bidding materials any of the pozzolanic materials that are high in alumina and silica [1]. The alkaline solution used to activate the pozzolanic materials consists of a specified ratio of sodium or potassium hydroxide and sodium or potassium silicate compounds. The geopolymerization reaction involves several stages in the creation of geopolymer concrete, beginning with a fresh condition and ending with a hardened state. The geopolymerization mechanism is depicted graphically in Figure 1 below. The geopolymerization reaction is affected by many variables, including the pozzolans minerals' composition, particle size, the molarity of the sodium or potassium hydroxide used, the alkaline ratio, the liquid to binder ratio, the type of superplasticizer used, the curing type, and the curing duration. [2].

Davidovits used the term "geopolymer" in 1978 to describe a type of material in which bonding takes place only after a reaction has taken place [3,4]. When it comes to high performance, geopolymer concrete benefits most from a superplasticizer based on SNF [5, 6],

while self-compaction in conventional concrete benefits most from a superplasticizer based on PCE [4, 7]. The geopolymerization reaction is extremely sensitive to the molarity of sodium hydroxide. Therefore, the strength of the specimens grows proportionally with the increase in molarity, but only up to a certain limit. The reaction and the strength and performance of the specimens are also affected by the alkaline ratio, which consists of the ratio of sodium silicate to sodium hydroxide [7]. Due to the increased content of GGBFS presence forming the C-S-H bonds in the concrete, the mechanical properties of the GPC specimens change depending on the flyash to GGBFS ratio, whereas the geopolymer bonds are Na-A-S-H or other comparable. Long-term viability also depends on striking the ideal ratio of GGBFS to flyash. or long-lasting qualities [8]. It is not obvious that decreasing the concrete's water content will increase the specimen's strength, yet this is what happens with geopolymer concrete. Geopolymerization reactions benefit greatly from a high ratio of liquid to binder. Therefore, a certain amount of liquid is crucial for the specimens to grow strength. In the case of geopolymer concrete made from flyash and slag, the ideal liquid-to-binder ratio is determined to be 0.6 [9]. Mechanical strength and characteristics are closely related to the rate at which the geopolymerization reaction is induced and cured. Early ages of oven-cured specimens were stronger than those of ambient-cured specimens [10,11].

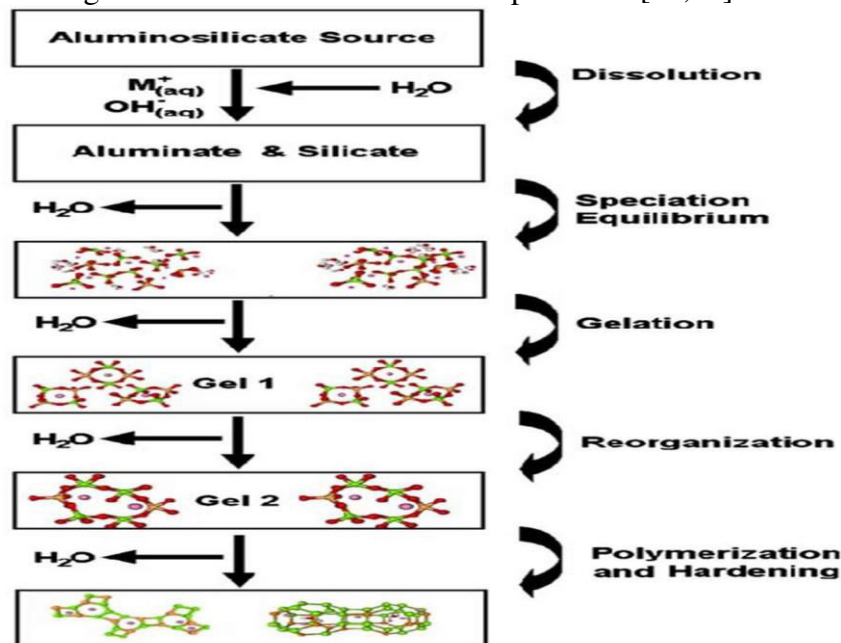


Figure 1 Mechanism of geopolymerisation reaction

Curing time has a significant impact on the mechanical strength of GPC specimens; however, this effect is minimal after 48 hours [12-14]. When cured in an oven, compressive strength improves over time; nevertheless, the effects of curing for longer than 12 hours become negligible [15]. Better strength growth can be achieved by securing at room temperature with a relative humidity of more than 95% for a longer time before applying heat [16]. Curing time is affected by temperature. However, longer treatment significantly accelerated the reaction rate and boosted early-age strengths [17], while curing at a higher temperature for 1 hour had no discernible effect on strength development. Nanomaterials, such as calcium carbonate, can improve the GPC's (or alkali-activated concrete's) mechanical qualities [18]. A longer curing time improved the geopolymerization process, leading to greater compressive strength. The rate of strength development was rather rapid during the first 24 hours of curing, but slowed significantly afterwards. This means the heat-

curing process can be completed in less than 24 hours [19]. There is a greater percentage of absorption in fog-cured samples [20,21]. Because of the geopolymer matrix's capacity to retain water, the microstructure of this type of concrete is more porous, which may explain these events [22]. Compressive strength can be developed early in the geopolymerization process thanks to heat curing, which helps speed up the process [23]. Although the ambient curing specimens only reached 57-82% of the 28-day compressive strength after 3 days, their ultimate strength was somewhat more impressive than that of the corresponding oven-drying cured specimens after 28 days [24,25]. Compressive strength in oven-cured specimens does not significantly improve after 7 days [26].

The elastic modulus of alkali-activated concrete changes depending on the curing temperatures. There was an apparent upper bound on the static modulus of elasticity that was related to the water-to-binder ratio in the early ages of curing. If water is lost due to evaporation during curing at a higher temperature before full strength is obtained, the static modulus of elasticity decreases [27,28]. Because of the delay in the beginning of the setting process, curing at room temperature is not possible. Increasing the temperature promoted the dissolution of reactive species, leading to a massive increase in strength [29]. A longer cure time improved the geopolymerization technique. Sample failure occurred at a later age [30] when curing was performed at a higher temperature for a longer period of time, causing partial water evaporation and microcavities. Similar to the compressive strength, the flexural strength of GPC treated at room temperature increased over time. The flexural strength of a mixture was improved by up to 10% when GGBFS, 6% OPC, and 2% CH were added to it. Geopolymer concretes outperformed OPC concrete of similar compressive strength in flexural strength. Ambient cured GPC flexural strength can be predicted with some degree of caution using the AS 3600-2009 computation [31]. Fly ash and GGBFS interact to drive geopolymerization at 600C. The C-S-H and A-S-H gel present in the reaction products lends credibility to this partnership. The addition of slag increases compressive strength, which may be due to the formation of gel phases (C-S-H and A-S-H) and the tightening of the microstructure [32]. When exposed to acids, sulphates, and salt water, GPC samples fare better [33].

EXPERIMENTAL PROGRAM

Experimental program includes the materials preliminary testing, mixing, casting, curing and tests setups.

Table 1 Chemical Composition

Minerals	Flyash	GGBFS
Silica (SiO ₂)	45.8	34.52
Alumina (Al ₂ O ₃)	21.4	20.66
Lime (CaO)	13.7	32.43
Iron Oxide (Fe ₂ O ₃)	12.6	.57
Magnesia (MgO)	1.3	10.09
Sulphate (SO ₃)	1.9	0.77
LOI*	0.1	0.3

LOI*- Loss of Ignition

Materials

After some preliminary testing, the qualities of the raw materials are detailed here. The primary components of the GPC mix were flyash, GGBFS, coarse aggregates, fine aggregates, sodium hydroxide, sodium silicate, superplasticizer, and water. The mineral make-up of the flyash and GGBFS is shown in Table 1. In an x-ray fluorescence analysis, the mineral oxides contained in the flyash and GGBFS were identified. The construction mix included class-c flyash. SEM images of flyash and GGBFS particles are shown in Figures 1a and 1b, respectively. Flyash is described as hollow and spherical, while GGBFS is described as uneven. The XRD graph in Fig.1c demonstrates the amorphous character of both flyash and GGBFS. Both sodium hydroxide and sodium silicate, produced by CDH pvt ltd. Delhi, are employed as alkaline activators in GPC's mix design. While sodium silicate is acidic, sodium hydroxide has a minimum purity of 98%. Fosroc chemicals' mix designs incorporate the SNF-based superplasticiser. You may also know it as SP Conplast 430.

The GPC's mix design called for coarse aggregates in the 10mm and 20mm sizes, while the fine aggregates were made from locally sourced stone dust. Both types of aggregates were subjected to the preliminary tests to ensure their quality. Preliminary examinations on the stone dust indicate that it is located in zone 2 and is of a high quality grade. The gradation curves of coarse and fine aggregates are shown in Fig.2d, demonstrating that both types of aggregates are properly graded. The stone-dust has a fineness modulus of 2.756, a specific gravity of 2.62, an absorption rate of 1.21%, a silt content of 6%, and a bulk density of 1610kg/m³. Coarse aggregates have values of 7.29, 2.79, 2%, 23%, 22%, 24%, 30%, and 8% for fineness modulus, specific gravity, water absorption, crushing value, impact value, flakiness index, and elongation index, respectively.

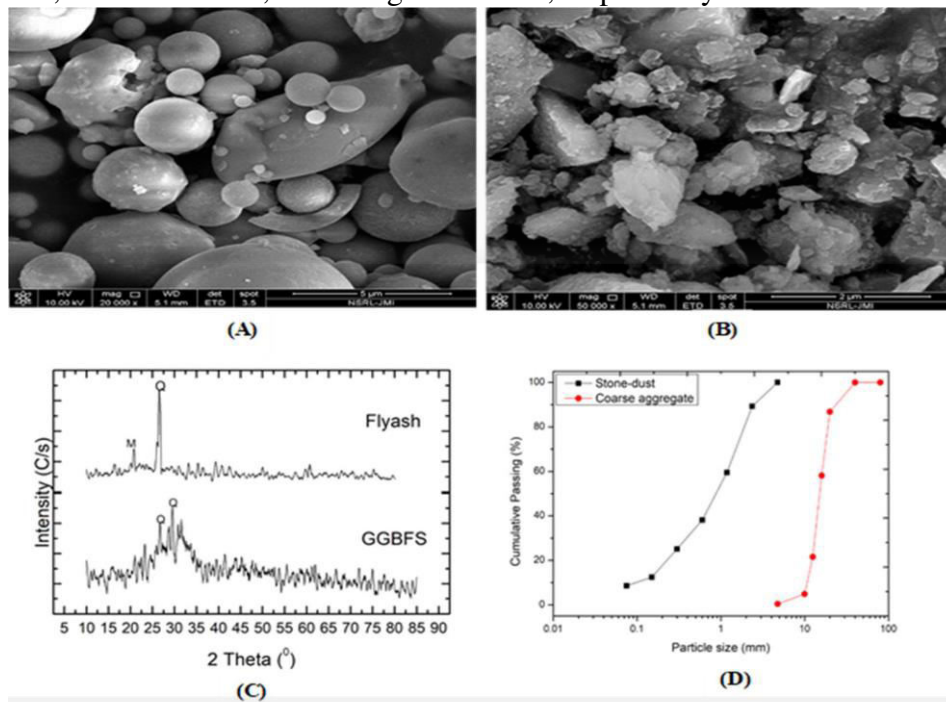


Figure 2 SEM image of a) flyash; b) GGBFS; c) XRD graph of flyash and GGBFS; and d) gradation curve of coarse aggregates and fine aggregates

Mixing, Casting, and Curing

This section explains how to mix the materials, cast the samples in various moulds, and detail the curing process. The blending of the ingredients in the pan for ten to fifteen

minutes. The proportions of the individual raw materials utilised in the GPC's mix design are shown in Table 2. It takes 20-24 hours from the time the alkaline solution is made until it is mixed. Testing the fresh concrete's workability after mixing, the samples were then cast in the various moulds. According to the Indian Standard, the three different types of specimens used to measure mechanical strength are cubes, cylinders, and prisms. The samples were baked at 600 degrees Celsius for anything from four to seventy-two hours to cure any moisture.

Tests Setups

The concrete laboratory performs all investigations on fresh or hardened GPC mix. GPC mix density determines chemical characteristics. Before the 28-day destructive examination, cube samples are weighed to test mix design density. After water evaporates from the mix or end products form, the length comparator of the concrete or mortar specimens at the micron reading level shrinks. The compressive strength of 150mm*150mm*150mm GPC mix samples is tested. At 5.2kN/sec, a Universal Testing Machine axially loaded the samples. The splitting tensile strength of 150mm and 300mm cylindrical samples is measured. To assess GPC cylinder specimens' splitting tensile strength, the Universal testing machine applies transverse loads. For testing GPC mix design flexural strength, the beam sample is 100mm wide, 100mm high, and 500mm long. The beam specimen was tested for GPC mix flexural strength using the flexural testing equipment using a two-point load or flexural tensile test. The 150mm-by-300mm cylindrical samples would assess the GPC mix design's modulus of elasticity and poisons ratio.

Table 2 Mix Design of GPC

Material	Quantity (kg/m ³)
Fly ash	303.75
GGBFS	101.25
Coarse Aggregates (20mm)	761
Coarse Aggregates (10mm)	508
Fine Aggregates/Stone dust	683
Sodium Hydroxide	46.28
Sodium silicate	115.72
Superplasticiser	4.05
Water	20.25

The universal testing equipment applies axial load to the cylinder to assess the vertical and horizontal strain of the GPC cylinder specimen to measure modulus of elasticity and poisons ratio. Non-destructive lab and field tests measure strength and quality without destroying them. The rebound test checks surface hardness on cube samples 7 days, 14 days, 28 days, 42 days, and 56 days after casting. It measured combined sample strength on all sample cubes and cylinders.

UPVT passes ultrasonic pulse waves through the sample. GPC specimen strength and efficiency increase with UPV. Research equipment uses two transducers, an electrical pulse generator, an amplifier, and an electronic timing device. Transducers and electronic timing machines send ultrasonic pulse waves.

RESULTS AND DISCUSSION

The curing time varies from 4 hours to 72 hours on the identical mix design specimens.

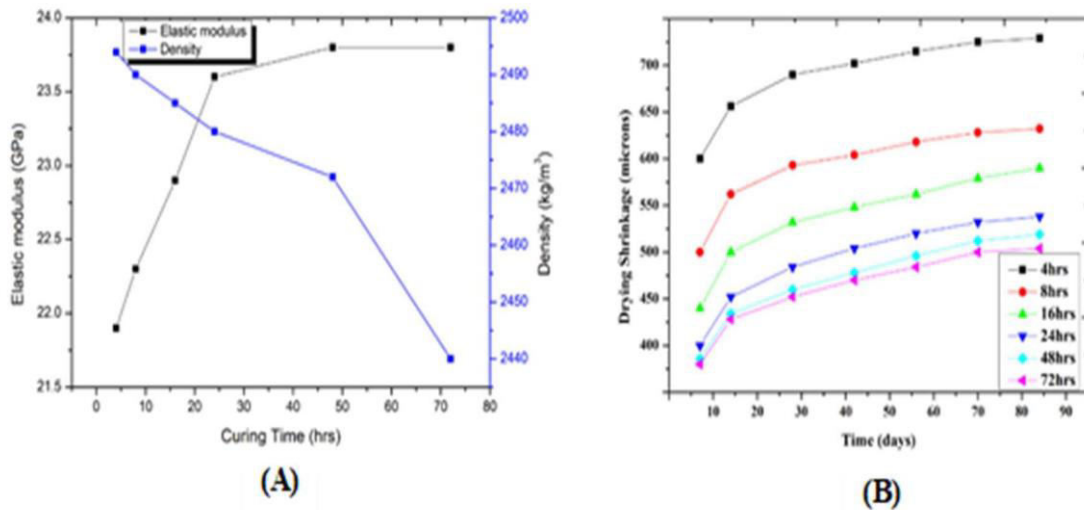


Figure 3 a) Density and elastic modulus variation; b) Drying shrinkage variation with the curing time

Density

Oven curing period decreases GPC specimen density. Fig.3a shows density fluctuation over curing times. 4hour specimens had the highest density, whereas 72hour specimens had the lowest.

Drying Shrinkage

GPC specimens were examined for drying shrinkage at 7, 14, 28, 42, 56, 70, and 84 days. The oven curing period reduces drying shrinkage. 4hour-cured specimens have the highest drying shrinkage, while 72hour specimens have the lowest. Fig.3b depicts drying shrinkage behaviour under different curing periods.

Compressive Strength

Oven curing enhances GPC specimen compressive strength. Compressive strength of cured specimens at different testing days is shown in Fig.4a [34]. 7-, 14-, 28-, 42-, and 56-

day specimens were tested. From 4 to 24 hours of curing, compressive strength grows significantly, but after that, it increases somewhat. One day before, the NaOH-Na₂SiO₃ mix was utilised to activate the geopolymer paste with 8.5-11.5% fly ash. Geopolymer paste specimens with 8.5 percent Na₂O demonstrated better residual compressive force than those with more Na₂O [35]. 50 percent fly ash and 50 percent slag activated with 10 M NaOH produced 50 MPa compressive mechanical strengths after 28 days [36].

Splitting Tensile

Indirect tensile strength is splitting. The splitting tensile of GPC specimens increases from 4 hours to 24 hours but decreases after 24 hours. Fig.4b shows splitting tensile behaviour variation with curing time. All specimens cured at different times were tested at 7, 14, 28, 42, and 56 days. From 4 hours to 24 hours, the splitting tensile rapidly increases, then decreases after 24 hours. At 28 days, all curing specimens had 95% splitting tensile.

Flexural Strength

Modulus of rupture is flexural strength. Flexural testing on prism-shaped specimens can determine it. Flexural strength resembles indirect tensile strength. Flexural strength diminishes after 24 hours and increases before 4 hours. Fig.4c shows flexural strength behaviour fluctuation over curing durations. All specimens cured at different times were tested at 7, 14, 28, 42, and 56 days. At 28 days, all curing specimens had 95% splitting tensile. 24-hour curing is best.

Elastic Modulus and Poisons ratio

In the UTM, cylindrical objects were loaded longitudinally to determine elastic modulus and poisons ratio. In Fig.3a, the elastic modulus of GPC specimens increases with the curing period from 4 to 72 hours. 28-day specimen tests reveal elastic modulus and poisons ratio. 72-hour specimens had the highest elastic modulus, while 4-hour specimens had the lowest. Poison ratio specimens is 16 of 4hours, 8hours, and 16hours curing period specimens and 15 of 24hours, 48hours, and 72hours specimens.

CONCLUSIONS

After the experimental investigation in the laboratory, the following conclusions are as follows:

- 4hour specimens had the highest density, whereas 72hour specimens had the lowest. 4hour-cured specimens have the highest drying shrinkage, while 72hour specimens have the lowest.
- From 4 to 24 hours of curing, compressive strength grows significantly, but after that, it increases somewhat. Splitting tensile and flexural strength first rapidly increase with the curing duration from 4 to 24 hours, however it decreases after 24 hours.
- 72-hour specimens had the highest elastic modulus, while 4-hour specimens had the lowest. The poisons ratio is 16 for 4hours, 8hours, and 16hours specimens and 15 for 24hours, 48hours, and 72hours specimens.
- Rebound strength follows compressive strength. UPV increases as cure time increases from 4 to 72 hours. UPV rapidly grows from 4 to 24 hours, but it barely increases after 24 hours.

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