

# Effect of Micro Lime on The Ambient Cured Sugarcane Bagasse Ash-Based Geopolymer Concrete

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## ABSTRACT

Geopolymer concrete has been the ideal replacement for Ordinary Portland cement concrete in producing green concrete. The binder in geopolymer concrete is a cementitious paste made from amorphous Aluminosilicate and activated by an Alkaline solution. The geopolymerization process is initiated at elevated temperatures. Thus, the curing requires elevated temperatures. This curing method limits the application of geopolymer concrete in the construction industry. In a geopolymer mix, the presence of Calcium ions allows the formation of Calcium Aluminate Silicate and Calcium Silicate Hydrate gels, allowing ambient temperature curing. Therefore, this study investigates the effect of micro lime on the Sugarcane Bagasse Ash-based geopolymer concrete. The micro lime was added to the geopolymer concrete in 1, 3, 5 and 7% by the Sugarcane Bagasse Ash weight. A mix design was based on a Densified Mix Design Algorithm. The tests carried out included compressive strength and water absorption. Ambient curing of the SCBA-based geopolymer concrete was achieved with 1% of the micro lime. The compressive strength increased with the increase of the micro lime, 10N/mm<sup>2</sup> at 1%, to 18.25N/mm<sup>2</sup> at 7% micro lime. The ambient temperature-cured geopolymer concrete at 3% micro lime had the lowest water absorption rate.

**Kata kunci:** Absorption, Compressive Strength, Geopolymer Concrete, Green Concrete, Micro Lime

*ABSTRAK. Pengaruh Micro Lime pada Beton Geopolimer Berbasis Abu Ampas Tebu yang Diawetkan di Lingkungan Sekitar. Beton geopolymer (geopolymer concrete) telah menjadi pengganti ideal beton Ordinary Portland Cement (OPC) dalam memproduksi green concrete. Bahan pengikat pada beton geopolimer adalah pasta semen yang terbuat dari Aluminosilikat amorf dan diaktivasi dengan larutan Alkali. Proses geopolimerisasi dimulai pada suhu tinggi. Oleh karena itu, proses curing memerlukan suhu tinggi. Metode pengawetan ini membatasi penerapan beton geopolimer dalam industri konstruksi. Dalam campuran geopolimer, keberadaan ion Kalsium memungkinkan pembentukan gel Kalsium Aluminat Silikat dan Kalsium Silikat Hidrat, sehingga memungkinkan proses pengeringan pada suhu sekitar. Oleh karena itu, penelitian ini menyelidiki pengaruh micro lime pada beton geopolimer berbahan dasar Abu Ampas Tebu (Sugarcane Bagasse Ash-Based, SCBA). Micro lime yang ditambahkan pada beton geopolimer sebanyak 1, 3, 5 dan 7% berat SCBA. Desain campuran didasarkan pada Algoritma Densified Mix Design. Pengujian yang dilakukan meliputi compressive strength dan water absorption. Ambient curing pada beton geopolimer berbasis SCBA dicapai dengan 1% micro lime. Compressive strength meningkat dengan bertambahnya micro lime, 10N/mm<sup>2</sup> pada 1%, menjadi 18,25N/mm<sup>2</sup> pada micro lime 7%. Beton geopolimer pada ambient temperature-cured dengan micro lime 3% memiliki tingkat penyerapan air terendah.*

**Keywords:** Penyerapan, Kuat Tekan, Beton Geopolimer, Green Concrete, Micro Lime

## 1. INTRODUCTION

There is evidence of increased concern about global warming; thus, finding sustainable, environmentally friendly methods of infrastructural expansion is critical (Wong, 2022). Concrete is a significant component of diverse infrastructure development, second only to water consumption (Gagg, 2014). Ordinary Portland cement (OPC) is a significant component of cement concrete used as a binder. Concrete will continue to be in demand due to the rising demand for infrastructure development. In engineering history, cement has been the most often used element in concrete as a binding agent for aggregates.

Geopolymer concrete has been the ideal replacement for Ordinary Portland cement concrete in producing green concrete. The binder in geopolymer concrete is a cementitious paste made from amorphous aluminosilicate and activated by an alkaline solution. The geopolymer concrete is mostly cured under elevated temperatures (A. A. Adam & Horianto, 2014; Triwulan et al., 2017; Zahid et al., 2018). The challenges of elevated temperature curing include the high cost of electricity and the limitation of the application of geopolymer concrete in precast members and laboratory work. There is a need to have ambient temperature curing to overcome the challenges and the application of geopolymer concrete for infrastructural development.

Ambient temperature curing was achieved by partially replacing Fly Ash with Grounded Granulated Blast Furnace Slag (Davidovits, 2013a; Puertas et al., 2014). This was achieved due to the high calcium content in slag. The ambient cure GPC has a broader application in the construction industry. The introduction of calcium in GPC for ambient cured concrete results in two reaction mechanisms, polymerization and hydration, related to the development of C-A-S-H and C-S-H (A. A. Adam et al., 2020). The authors discovered that the effective means of curing to accommodate the two processes is wrapping the samples in an airtight container. This facilitates the water trapped for hydration and ambient temperature polymerization.

The studies undertaken on geopolymer concrete in the country used locally available source material, i.e., SCBA. Akbar et al., (2021) incorporated the SCBA in geopolymer mortar. He partially replaced the GBBS with SCBA and showed the potential to be used in geopolymer concrete. With the potential to be used as the only source material, its use in geopolymer concrete has yet to be documented.

This study aims to create ambiently cured SCBA geopolymer concrete while preserving GPC's exceptional qualities, such as high compressive strength and outstanding durability. Micro lime will provide reactive calcium and densify the concrete matrix, boosting the concrete's compressive strength. The ideal dosage of micro lime was suggested based on the findings. This will replace the over-reliance on Portland concrete. The alternative will provide sustainable and green concrete using locally available materials. Additionally, employing SCBA in the production

of geopolymer concrete will create job opportunities through the supplementary activity of processing SCBA in concrete and using a superplasticizer to enhance workability, which is reduced by the alkaline solution's low water content and high molarity.

The study attempts to produce an ambient temperature cured SCBA geopolymer concrete, the gap that is in existence. The specific objectives of the study included; Evaluating the compressive strength of the SCBA-based geopolymer concrete with varying proportions of micro lime and cured at ambient temperature and evaluating the water absorption on the SCBA-based geopolymer concrete with varying proportions of micro lime and cured at ambient temperature.

## **2. METHODOLOGY**

This experimental research was based on a literature study dealing with the collection of references and sources of related studies. The materials used and the experiment conducted.

Some environmental issues caused by cement production include; depleting fossil fuel supplies, lack of raw materials, and escalated environmental concerns related to climate change. OPC production emits significant amounts of Carbon dioxide (CO<sub>2</sub>) during clinker manufacturing. Cement production requires much energy. One metric ton of ordinary Portland cement requires four gigajoules of energy to produce OPC (Naik, 2005).

Incorporating locally available minerals, recycled materials, and wastes (industrial, agricultural, and domestic) as substitutes or, in some cases, replacements in cement has been the focus of many researchers. Fly ash, Ground Granulated Blast Furnace Slag (GGBS), Metakaolin, Rice husk ash, Sugarcane Bagasse Ash, and other cement replacement materials improve binder properties such as long-term strength and durability (Davidovits, 2013b). Industrial by-products rich in aluminosilicate that display cement-like binding characteristics in aqueous alkali-metal solutions can be an alternative to OPC. Amorphous aluminosilicate species quickly dissolve and condense in an alkaline environment to form vast networks of polymeric gels and geopolymer concrete (Nawaz et al., 2020).

The most critical components of geopolymer are the source material and the alkaline liquids. Alumina and silica-rich source material should be used to make geopolymer. Natural minerals like kaolinite, clay byproducts including fly ash and silica fumes, ground granulated blast furnaces (GGBS), rice husk ash, and sugarcane bagasse ash (SCBA) are a few examples. The decision is made based on the product's accessibility, price, type of application, and unique end-user requirements. The sodium- or potassium-based soluble alkali metals are the source of the alkaline liquids. The most typical alkaline solution contains sodium silicate, potassium silicate, or sodium hydroxide. Because of the stable cross-linked aluminosilicate polymer structure-property, the sodium hydroxide-prepared material has the best sulfate attack resistance

(Ariffin et al., 2013; Bakharev, 2005; Kantarcı, 2022). In dissolving the source materials, (Hydrogen ions) OH ions aid in breaking the aluminosilicates (Waqas et al., 2021). Therefore, it is crucial to ensure enough OH ions are in the geopolymer matrix for the geopolymerization process. Additionally, (Waqas et al., 2021) deduced that the NaOH solution's molarity affects the geopolymer matrix's compressive strength.

Calcium ions in microparticles would promote Calcium Silicate Hydrate (C-S-H) nucleation in the pore space. Calcium Silicate Hydrate (C-S-H) is the major hydrated byproduct that results from the chemical interaction involving SCBA and calcium oxide (Payá et al., 2018). The ambient temperature curing of concrete results from two reaction mechanisms, polymerization and hydration, related to the development of C-A-S-H and C-S-H (A. A. Adam et al., 2020). Using the calcium ion from the micro lime would allow ambient curing of the SCBA-based GPC, thus avoiding elevated temperature curing.

The mineral analysis of SCBA from various countries shows a varying percentage of Calcium Oxide ranging from 1.69% to 10.07% (Abdalla et al., 2022). SCBA has a lower calcium oxide percentage (41.37%) than GGBS (Puertas et al., 2011). The Sugarcane bagasse ash obtained from the West Kenya sugar company is pozzolanic without further treatment (Abdalla et al., 2022; Arasa et al., 2017).

This study intended to use SCBA as the source material for geopolymer concrete. Since sodium hydroxide and sodium silicate are considerably more viscous than water, their application in GPC makes them more cohesive and stickier than regular concrete. A superplasticizer was employed to improve workability. Calcium ions were introduced to the mix using micro lime.

Since SCBA, industrial waste from sugar processing factories, is a locally available source material, it can produce green sustainable concrete cured at ambient temperature.

## **2.1. Material**

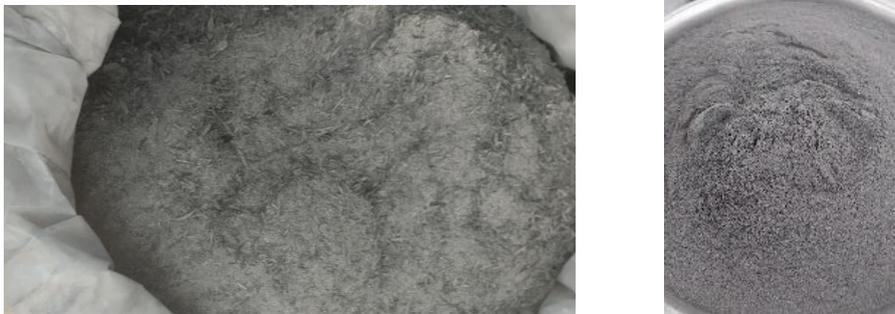
The materials used in the study were SCBA, natural crushed aggregate, river sand, superplasticizer and potable water from Nairobi County water supplies.

## **2.2. Material Preparation and Preliminary Tests**

### **2.2.1. Sugarcane Bagasse Ash**

The sugarcane bagasse ash was collected from West Kenya Sugar Company, Kakamega County. It was dried in the oven for 24 hours at 105°C to remove moisture. The SCBA was then sieved through a 150 µm sieve and stored in a polythene bag to remain dry. The physical image of the SCBA before and after sieving is shown in Figure 1. The chemical composition of the SCBA was determined using an X-ray fluorescence (XRF) machine at the Kenya State

Department of Mining Laboratory in Nairobi. The Loss on Ignition (LOI) was determined at the Chemistry Department at The Technical University of Kenya and tabulated in Table 1.



**Figure 1.** Physical image of SCBA before and after sieving

**Table 1.** Chemical composition of SCBA

Element	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Fe	Ti	P <sub>2</sub> O <sub>5</sub>	Mn	Others	LOI
%	76.786	8.828	3.957	2.947	3.328	3.013	0.385	0.654	0.222	0.48	7.70

### 2.2.2. Fine Aggregates

River sand of Fineness Modulus (FM) 2.71 was used as the fine aggregates and was obtained from a local supplier in Nairobi. River sand was washed and sieved to remove any dust and humus particles. The river sand was oven-dried at 105°C for 24 hours to remove moisture. The physical properties are given in Table 2. The particle size distribution curve is shown in Figure 2.

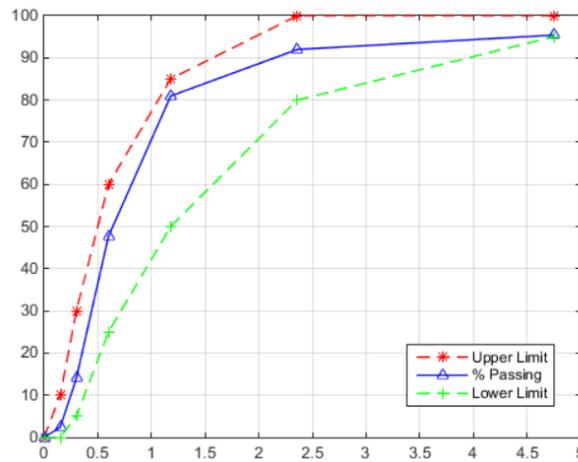
### 2.2.3. Coarse Aggregates

Coarse aggregates were obtained from a local supplier in Nairobi of a Maximum Aggregate Size (MAS) of 12.7mm. The aggregates were washed through a sieve size of 3.18mm to eliminate the fine particles. It was oven-dried for 24 hours at 105°C. After cooling, the aggregates were sieved into the following categories: 3.18 mm - 6.35 mm, 6.35mm - 9.35 mm, and 9.35mm - 12.70mm, as shown in Figure 3. The Densified Mix Design Algorithm (DMDA) method was adopted to proportion the quantities used in the mix. The 6.35mm - 9.35mm aggregates were progressively packed into the 9.35mm – 12.7mm aggregates while plotting the packing curve until a maximum dry density (MDD) was obtained. With the new MDD, the 3.18mm - 6.35mm aggregates are packed to combine the two while plotting the packing curve until a new MDD is achieved.

**Table 2.** The physical properties of the aggregates

Types of aggregates	Specific gravity	Water absorption (%)	FM	AIV (%)	ACV (%)
Fine aggregates	2.65	1.37	2.71		
Coarse aggregates	2.70	2.90		12.04	17.23

FM= Fineness Modulus, AIV=Aggregates Impact Value, ACV= Aggregates Crushing Value



**Figure 2.** Particle Size Distribution for Fine Aggregates



**Figure 3.** Physical images of aggregates

#### 2.2.4. Alkaline Activator

One part of 16M Sodium Hydroxide and two parts of Sodium Silicate were used as the alkaline activator, bought from a local supplier in Nairobi.

#### 2.2.5. Micro Lime

The micro lime was obtained from Loba Chemie, supplied by a local supplier in Nairobi.

#### 2.2.6. Superplasticizer

A Sodium Naphthalene Formaldehyde (SNF) based superplasticizer was used in the study. A dark brown tint and a specific gravity of 1.20 characterized the superplasticizer.

## 2.3. Mix Design

### 2.3.1. Mix Proportions

The mix proportion was achieved through a literature review mix design by (Pavithra et al., 2016) and a Densified Mix Design Algorithm. The DMDA method is based on the premise that the concrete comprises aggregates of different sizes bound together by a cementitious paste. The composition of the aggregates is determined from the relative amounts of the different sizes, making up the Maximum Dry Density (MDD) (Koteng', 2019). The mix proportion is as shown in Table 3 for 1 m<sup>3</sup>.

**Table 3.** Concrete Mix Proportion

Mix	CA 1	CA 2	CA 3	Fine aggregates	SCBA	Na <sub>2</sub> SiO <sub>3</sub>	NaOH	H <sub>2</sub> O	SP	Micro Lime
Mix 1	847.92	282.05	200.45	435.26	400	133.34	66.67	128.65	12	0
Mix 2	847.92	282.05	200.45	435.26	400	133.34	66.67	128.65	12	4
Mix 3	847.92	282.05	200.45	435.26	400	133.34	66.67	128.65	12	12
Mix 4	847.92	282.05	200.45	435.26	400	133.34	66.67	128.65	12	20
Mix 5	847.92	282.05	200.45	435.26	400	133.34	66.67	128.65	12	28

CA 1- 9.35-12.7mm, CA 2- 6.35-9.35mm, CA 3- 6.35-3.18mm, FA-Fine Aggregates, SP- Superplasticizer

### 2.3.2. Preparation and Curing Samples

Paste-solids mixing method of mixing was employed. The SCBA was added to a 0.02m<sup>3</sup> paddle mixer Katerina model B200A made in China, Figure 4, followed by the liquids (Sodium Hydroxide, sodium silicate, mixing water and the Superplasticizer) fine and coarse aggregates from the smallest to the largest. The micro lime was added by percentage weight of SCBA in 0, 1, 3, 5, and 7%, with 0% addition as the control sample. Once a consistent and uniform mix was achieved, it was poured into a metallic tray. Cube moulds of 100 mm x 100 mm conforming to BS EN 12390-1:2021 were used, and the specimen was cast to BS EN 12390-2:2019. Ninety cubes were cast and left in the moulds for twenty-four hours before being demoulded.



**Figure 4.** Mixer

## 2.4. Compressive Strength

The compressive strength was tested using a universal compressive testing machine with a 150-kilonewton (kN) load, as shown in Figure 5. Compressive tests conforming to BS EN 12390-4:2019 were undertaken at 7,14, 28, and 56 days. Three cubes were used for each testing age and mix to examine the compressive strength. The average compressive strength of the three samples was reported and plotted against age.



**Figure 5.** Compressive Strength Test

## 2.5. Water Absorption

The water absorption test was carried out at 28 days by BS 1881-122(2011). A total of 15 cubes and the specific percentage addition of the Micro lime were prepared. The average water absorption rate was tabulated and plotted.

## 3. RESULTS AND DISCUSSION

### 3.1. Compressive Strength

The average compressive strength for the various mixes was recorded and plotted, as shown in Figure 6. It shows the test samples' compressive strength for different periods of ambient curing and the 0% micro lime.

The 0% geopolymer concrete was cured under elevated temperature and achieved a compressive strength of  $11.25\text{N/mm}^2$ , which was constant over time. The ambient temperature curing was achieved by adding 1%-7% of the micro lime as an admixture to the SCBA-based GPC. The compressive strength increases with time for Mix 2, 3, 4, and 5. The compressive strength increased with the increase in curing time in days. There was slow strength development over the early days (7 days) but significant strength development over the 14 and 28 days. The optimum compressive strength at day 28 was achieved at 7% addition of micro lime, which agrees with the finding (A. Adam et al., 2019).

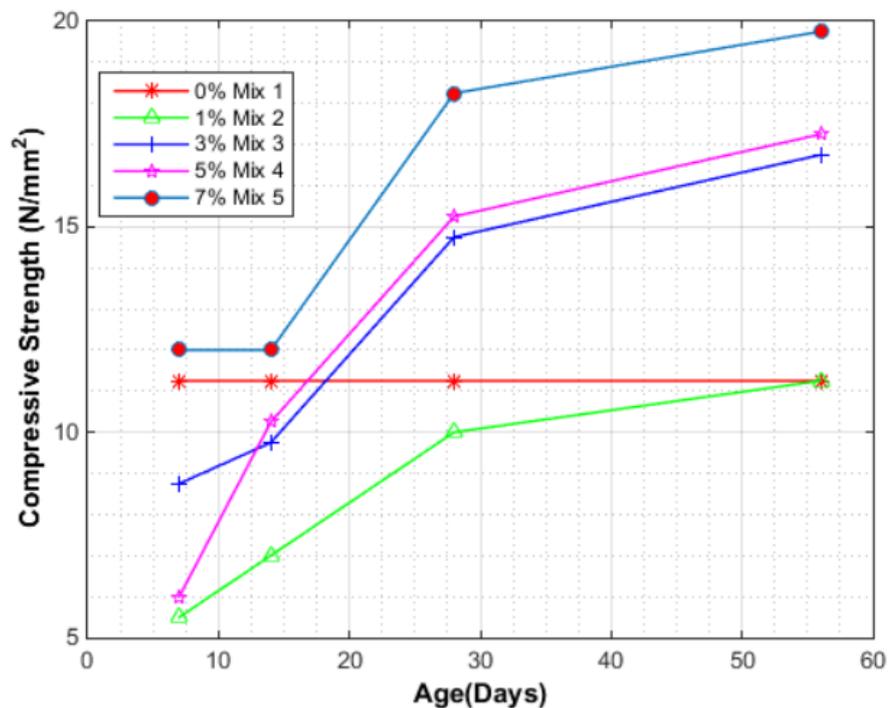


Figure 6. Compressive strength Vs. Age in days

The compressive strength at 28 days, for 3, 5, and 7%, was more significant than the compressive strength of the controlled sample, cured at elevated temperatures. The compressive strength achieved at 3, 5, and 7% was more significant than the ones found by (A. Adam et al., 2016) with fly ash as the source material,  $12\text{N/mm}^2$  at day 28. It can be seen from Figure 6 that the 28-day compressive strength increased from  $10\text{N/mm}^2$  to  $18.25\text{N/mm}^2$ , indicating an 82.5% increase from the 1% mix to the 7% mix. This is due to the increased quantities of reactive calcium ions in the alkaline solution, converting the N-A-S-H to C-A-S-H, thus increasing the compressive strength. According to a study (Temuujin et al., 2009), the inclusion of calcium will enhance the geopolymerization reaction by enhancing the source material's ability to dissolve in the alkaline medium and precipitate calcium silicate hydrate or calcium silicate aluminate hydrate.

The GPC mix 3, 4, and 5's 28-day strength were acquired at room temperature, and it was discovered that hydration and polymerization contributed to the increase in strength (Parveen et al., 2018). There was little compressive strength development to 56 days.

### 3.2. Water Absorption

The water absorption rate is shown in Figure 7. The water absorption rate for the 0, 1, 3 and 7 % mixes was relatively higher than the 5% for the first 60 minutes, after which the rate reduced from the 1% mix. The best performance for the absorption rate among the ambient and elevated temperature cured concrete was achieved by the 0% cured geopolymer concrete, which

had a water absorption rate of 3.8% for the first 30 minutes and 4.7% for 120 minutes. The ambient cured geopolymer concrete with the lowest water absorption rate achieved at 3% addition of micro lime.

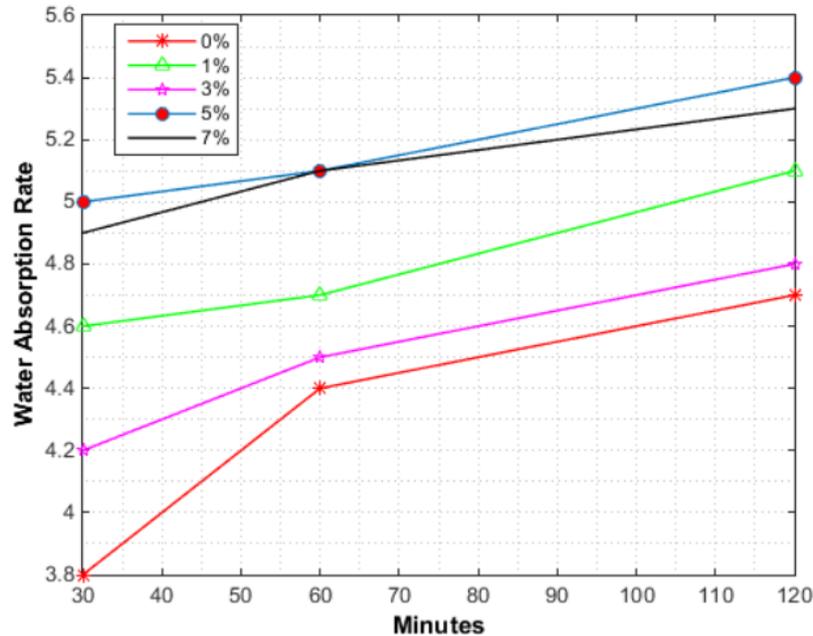


Figure 7. Water absorption rate (%)

A study by (Abdullah et al., 2017) asserts that the water absorption properties of geopolymer concrete substantially impact the structure's endurance. The structure's concrete will spall off if water penetrates the geopolymer concrete. When it comes to steel-reinforced concrete, the water corrodes the embedded steel bars, shortening the lifespan of the concrete construction.

The water absorption rate is at least 3% when micro lime is added to allow ambient curing. As the amount of micro lime increases, the rate of absorption rises. Due to the C-S-H and C-A-S-H gel created when the reactive calcium was added with the micro lime, densification of the concrete is at its best at 3%. The least water absorption rate at 3% indicates that the concrete matrix holds a homogenous dense microstructure with fewer voids.

The associated pores account for 1, 5, and 7% of high permeability. Concrete is a porous substance that interacts with its surroundings and permits water to travel through concrete structures, which affects how long SCBA-based geopolymer concrete will last.

Because sodium is soluble in water, the 1% micro lime mix contained insufficient calcium ions to prevent N-A-S-H conversion to C-A-S-H. As a result, inadequate hydration and polymerization occurred, leading to pores (Garcia-Lodeiro et al., 2011). The more calcium ions there are, the more stable and soluble C-A-S-H is created. The extra calcium ions cause the pores in the concrete to hydrate by absorbing water from the matrix.

Sorptivity is a technical indicator of the microstructure and properties of a material that is essential for endurance. It refers to a substance's ability to draw water into itself by capillary action and absorb it. A more popular method of measuring concrete resistance to exposure to hazardous environments is sorptivity. A study (Zhang & Zong, 2014) describes the process of water absorption in terms of internal and surface sorptivity. Surface sorptivity occurs immediately when a specimen is submerged in water, whereas interior sorptivity develops over time. However, they could not discover any apparent correlation between sorptivity and compressive strength. This explains the high compressive strength in the 5 and 7% mix, yet with a higher water absorption rate than that of the 3% mix. The authors concluded that the capillary suction of water via the pore spaces within solid concrete particles, not the strength of concrete, influences sorptivity.

#### **4. CONCLUSION**

The results from this study have shown that ambient temperature-cured geopolymer concrete would be achieved at 1% of micro lime by weight of SCBA. The compressive strength increased with the increase of the micro lime,  $10\text{N/mm}^2$  at 1%, to  $18.25\text{N/mm}^2$  at 7% micro lime, indicating an 82.5% strength increase. The geopolymer concrete with ambient curing at 3% micro lime had the lowest water absorption rate compared to the other percentage of micro lime. The 3% micro lime as an additive was optimal, as determined by compressive strength and water absorption.

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