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UTILIZATION OF TEXTILE INDUSTRY BY-PRODUCTS TO DEVELOP AND OPTIMIZE GEOPOLYMERIZED MUD CONCRETE FOR SUSTAINABLE CONSTRUCTION

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ABSTRACT

The industrial sector generates large quantities of by-products daily, posing environmental challenges due to disposal issues and global warming. To address this issue, researchers have successfully incorporated these by-products into sustainable building materials. Geopolymerized Mud Concrete is an existing eco-friendly concept that introduced an alternative stabilizer for Mud Concrete by utilizing fly ash, which is generated from the coal combustion process. This study focuses on developing and optimizing the Geopolymerized Mud Concrete mix using textile industry by-products, highlighting its potential as a sustainable alternative to Cement-Based Concrete. The mix design was prepared using soil, wood ash, textile wastewater, and NaCl. Wood ash served as the aluminosilicate source for geo-polymerization, while textile wastewater was used as an alkaline activator instead of commercial NaOH. Both materials were collected from the textile manufacturing industry. The feasibility of textile wastewater as an alkaline activator was assessed through FTIR analysis. Additionally, SEM-EDX was performed to analyse morphology, particle size, and elemental composition of wood ash which affects the strength variation. The study aimed to optimize key parameters, including moisture content, wood ash content, and textile wastewater concentration (pH value) based on the 7, 14, and 28-day compressive strength values of the mix. The results showed that the optimum wood ash content was 20%, and the optimum moisture content ranged from 20% - 22% from the dry weight of the mix. The optimum textile wastewater concentration was shown at pH 12. Furthermore, the findings confirmed that the unconfined compressive strength of the developed concrete mix met the standard requirements for earth-based masonry units.

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Keywords: *Geopolymerized Mud Concrete; Sustainable Construction; Textile Industry; Textile Wastewater; Wood Ash.*

1. INTRODUCTION

The building construction sector has increasingly adopted the concept of sustainability in response to its significant greenhouse gas (GHG) emissions and energy consumption throughout the building life cycle, including material production, transportation, construction, operation, maintenance, and end-of-life stages (Fei et al., 2021; Zuo et al., 2012). However, the construction sector remains the largest emitter of GHGs, accounting for approximately 37% of global emissions, and consuming 40% of global energy (United Nations Environment Programme, 2023;). These challenges are further intensified by factors such as global population growth, rising living standards, and increasing electricity demand (United Nations Environment Programme, 2023; Yan et al., 2010). While improvements in building envelopes and energy systems have reduced operational carbon emissions (those from heating, cooling, and lighting), embodied carbon emissions associated with the production and deployment of materials like cement, steel, and aluminum remain high (Aperador & Bautista-ruiz, 2023; Wang et al., 2019). Therefore, transitioning to a circular economy is critical to reducing the carbon footprint of previously mentioned construction materials. The circular economy involves strategies such as designing buildings for material reuse, optimizing material consumption, and extending the life of buildings and materials through proper maintenance. For example, prefabrication of modular concrete components for reuse can significantly lower emissions, while substituting traditional materials with bio-based and earth-based alternatives can provide sustainable options for decarbonizing the sector (United Nations Environment Programme, 2023). To address these challenges, researchers have been working on developing sustainable building materials incorporating circular economy practices. These materials aim to reduce the environmental impact of construction by using renewable resources, minimizing energy consumption during production, and promoting recycling and reuse (United Nations Environment Programme, 2023). Beyond construction, industrial sectors also contribute to environmental degradation through their by-products, often leading to pollution and economic costs associated with waste disposal (Karunasena& Rathnayake, 2013). Integrating waste management practices and adopting recycling technologies can help mitigate these impacts, while government regulations and incentives encourage industries to adopt more sustainable practices (Ramesh et al., 2014). Incorporating these three concepts, sustainable building materials, circular economy practices, and the efficient use of industrial byproducts, it is possible to develop eco-friendly construction materials. This approach not only reduces industrial waste disposal burdens but also minimizes the environmental degradation caused by conventional building materials.

Geopolymerized Mud Concrete masonry unit is one such alternative for cement-based walling materials, which was developed by Udawattha and Halwatura (2018) by utilizing coal fly ash. It integrates two innovative sustainable building material concepts; Mud Concrete Technology and Geopolymer Concrete Technology. Mud Concrete is a soil-based material composed of soil, cement, and water, whereas Geopolymer Concrete replaces cement with alkali-activated aluminosilicate-rich industrial by-products. Various industrial and agricultural waste materials, such as fly ash, silica fume, wood ash, rice husk ash, industrial slags, and municipal solid waste, can serve as geopolymer precursors due to their high aluminum (Al_2O_3) and silicon (SiO_2) content (Amran et al., 2020;

Sbahieh et al., 2023). Alkaline activation typically involves chemical solutions such as Potassium Hydroxide (KOH), Sodium Hydroxide (NaOH), Potassium Silicate (K_2SiO_3), Sodium Silicate (Na_2SiO_3), or combinations of these compounds. However, industrial by-products with high alkalinity can serve as alternative activators (Ali & Sachan, 2022). These activators facilitate the dissolution of Si and Al atoms, enabling their recombination into a stable geo-polymeric network. The choice of activator significantly influences the microstructure, mechanical properties, durability, setting time, and strength of geopolymer concrete (Sbahieh et al., 2023). Other than replacing cement, these materials also mitigate waste disposal challenges and reduce the carbon footprint of the construction industry.

This research investigates the potential of incorporating textile industry by-products to develop sustainable building materials while aligning with circular economy principles. Specifically, wood ash is utilized as an aluminosilicate precursor, and textile wastewater serves as an alkaline activator to produce novel Geopolymerized Mud Concrete mix. The study aims to optimize the moisture content, wood ash content, and textile wastewater concentration to achieve high compressive strength. By embracing these sustainable solutions, the construction sector can significantly lower its environmental footprint and contribute to a more resilient and sustainable built environment.

1.1 RESEARCH SIGNIFICANCE

Currently, Portland-type concrete poses a significant environmental challenge due to its high greenhouse gas emissions. To address this issue, the development of eco-friendly construction materials with enhanced durability and resistance has been proposed. One such innovation is Geopolymerized Mud Concrete, which integrates Geopolymer Concrete technology with Mud Concrete technology and has already shown promise in the development of masonry units.

According to the literature, approximately 780 million tons of fly ash are generated globally each year, yet only about 17–20% of it is utilized. For instance, India alone produces around 220 million tons of fly ash annually, of which only 35–50% is used in construction applications. The remainder is often discarded as waste, occupying vast areas of valuable land (Patankar et al., 2015). In parallel, the textile industry is experiencing rapid growth due to increasing global population and demand. This has led to a substantial rise in industrial waste. The textile sector commonly uses wood as a source of biomass energy, which produces large quantities of wood ash as a by-product. According to recent findings, 4,600 million tons of wood biomass are produced globally each year, with 60% used for energy generation. However, a significant amount of wood ash is still disposed of in landfills, posing environmental and health risks such as airborne dispersion and groundwater contamination due to the presence of heavy metals (Teker Ercan et al., 2023). Moreover, textile manufacturing processes generate large volumes of wastewater containing hazardous chemicals such as NaOH in washing and dyeing (Mohana & Bharathi, 2024). Improper disposal of such by-products can exacerbate environmental degradation and intensify the growing problem of industrial waste management.

This study aims to address these challenges by utilizing wood ash as an aluminosilicate source and textile wastewater as an alkali activator to produce Geopolymerized Mud Concrete. Given the rising environmental concerns surrounding industrial waste disposal, this approach presents an opportunity to incorporate industrial by-products into concrete mixes, contributing to more sustainable construction practices

2. MATERIALS AND METHODS

Figure 1 illustrates the systematic approach followed to develop the novel Geopolymerized Mud Concrete mix.

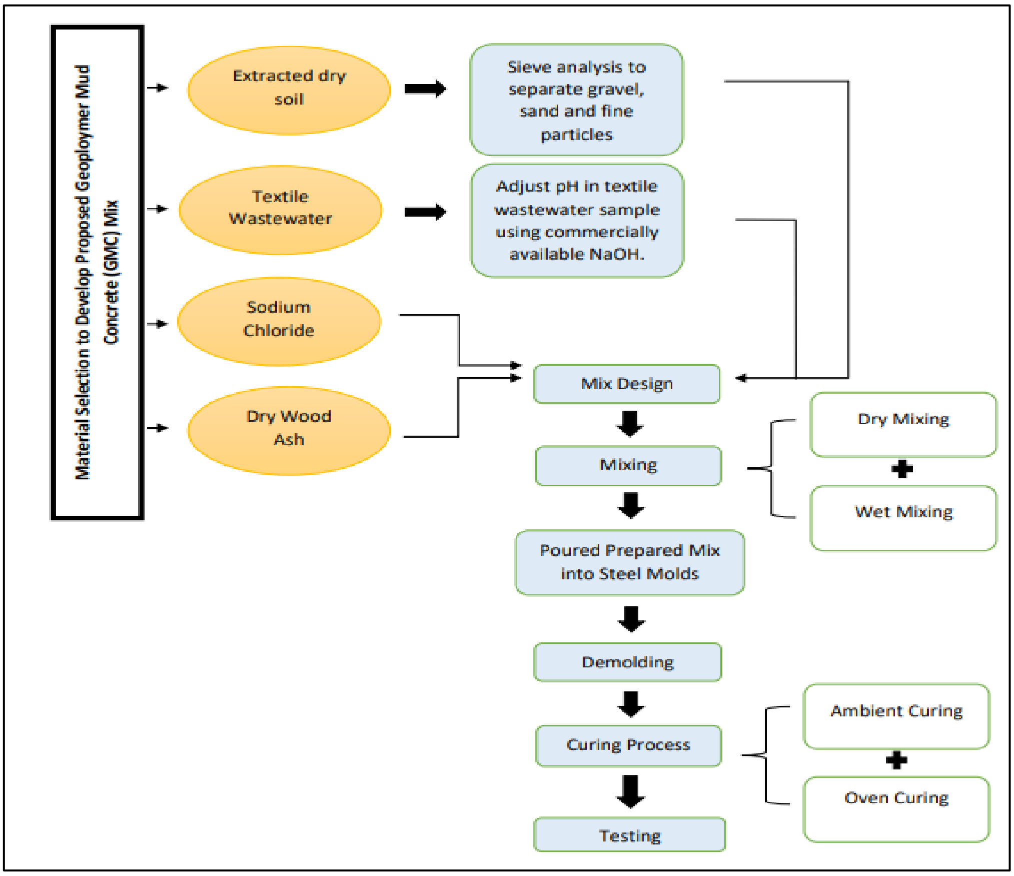

Figure 1: Experimental setup

2.1 MATERIAL SELECTION AND PREPARATION

The materials used to produce novel geopolymer mud concrete mix include mainly soil, wood ash, textile wastewater, and NaCl. The soil for this experiment was taken from the University of Moratuwa premises, a homogeneous layer at a 600 mm depth below the existing ground level and removed the organic matter. The soil was then sun-dried, or oven-dried to remove moisture. After that, dried soil was subjected to sieve analysis to meet standardized requirements for each fine (sieve sized below 0.425 mm), sand (sieved sized 0.425 mm – 4.75 mm), and gravel (sieved sized 4.75 mm – 20 mm) particles to make the proposed concrete mix. Dry sieve analysis and grading curves were prepared according to the BS 1377-2:1990 standard. Figure 2 shows a visual representation of the particle size distribution of soil, showing the percentage of particles that pass through each set of sieve sizes. For the analysis, the weight retained on each sieve was recorded. Then cumulative percentages were calculated. Finally, these values were plotted on a graph of a particle size (X axis- log scale) against cumulative percentage passing (Y axis- linear scale), creating a gradation curve. Here, sand and gravel particles were typically more stable and better suited for use in proposed Geopolymerized Mud Concrete. Fine particles may have higher compressibility and lower strength. The sample "A" was selected for the study from among the soil samples on the following graph (Figure 02).

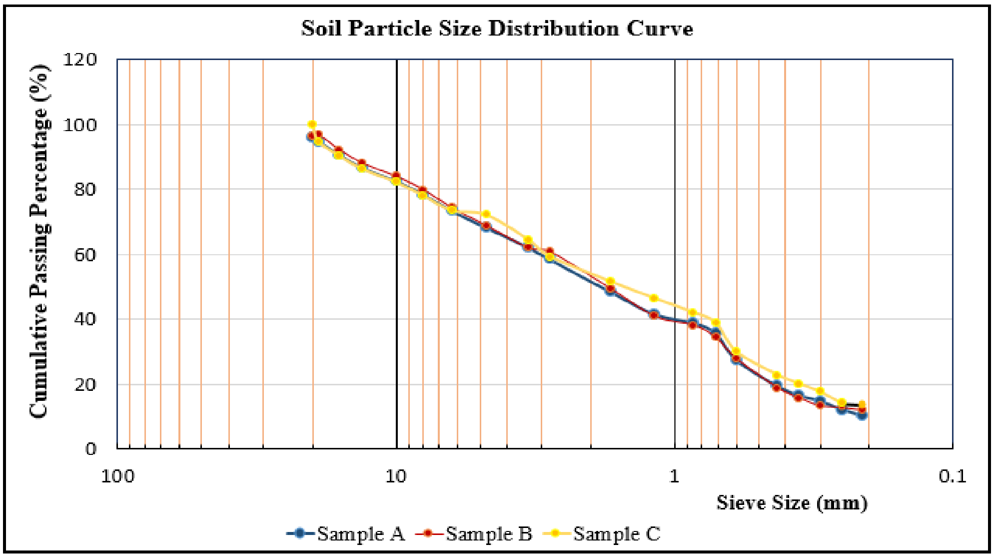

Figure 1: Particle size distribution of soil

Wood ash contains a high amount of silica and alumina compounds, which makes this suitable as an aluminosilicate source material for the proposed mix. Due to its high pH and potential to act as a catalyst in the geopolymerization reaction, textile wastewater was chosen as an alternative alkaline activator for this study. Both wood ash and textile wastewater were obtained from the textile manufacturing industry in Sri Lanka. The pH of the textile wastewater sample was measured using a pH meter. However, due to variations in the factory's production process during the experimental period, the pH of the wastewater fluctuated slightly, ranging between 9 and 10. Therefore, the pH of the textile wastewater was adjusted to the desired value by adding commercially available NaOH. The pH value in the received textile wastewater samples was measured every day before casting the cube.

Additionally, NaCl was used to increase the ionic strength of the alkali solution. This ionic environment may help to dissolve silica (SiO_2) and alumina (Al_2O_3) from wood ash. Also, it helps to speed up the setting time of geopolymer concrete, enhancing the durability of the resulting matrix and potentially improving its compressive strength.

2.2 CHARACTERIZATION OF MATERIALS

2.2.1 Characterization of Wood Ash

Scanning Electron Microscopy with Energy-Dispersive Spectroscopy (SEM-EDX) analysis was performed to characterize the morphology and elemental composition of the wood ash sample. This analysis helps to understand the microstructural and chemical properties essential for its application as a precursor in geo-polymer concrete. SEM micrographs of wood ash showed diverse particle sizes with shapes (Figure 3). Wood ash particles also showed higher porosity. These particle shapes can influence to the mechanical properties of geo-polymer concrete and may also reduce the workability of the concrete mix. Larger particles could indicate unburned carbon, which could impact the geo-polymer concrete workability, reactivity, and strength development. Smaller particles, especially those with a large surface area, are important for enhancing reactivity in geopolymerization, because they provide more chances for chemical reactions.

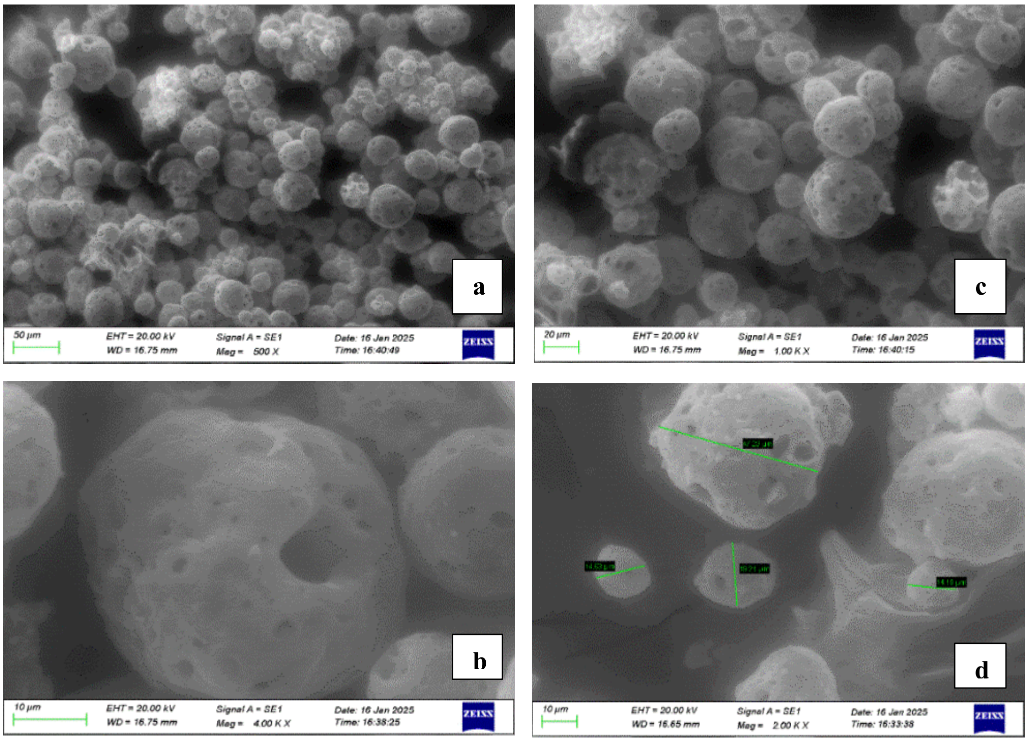

Figure 2: Surface morphology of wood ash (a)- 50 µm size, 500× magnification, (b)- 20 µm size, 1.00 K × magnification, (c) 10 µm size, 4.00 K × magnification, (d)- 10 µm size, 2.00 K× magnification

According to SEM/EDX analysis (Figure 4), the present wood ash sample has contained higher weight of carbon (42.74 wt%) content when compared to other elements, indicating a significant amount of unburned organic matter. It may reduce the compressive strength of geopolymer concrete and inconsistent strength development. Furthermore, in this sample show low silicon (0.35 wt%) by weight and aluminium (0.56 wt%) by weight content.

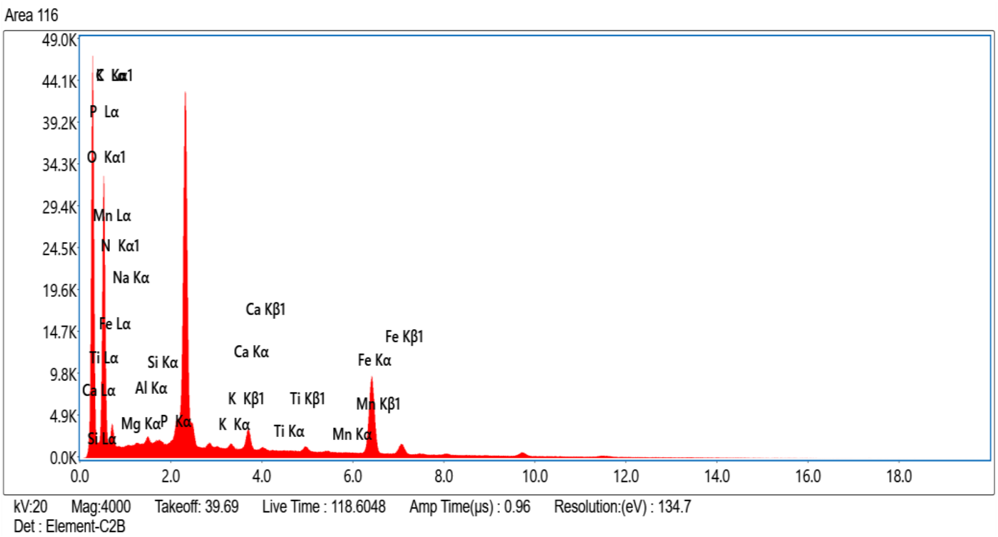

Figure 3: Elemental composition spectrum of wood ash

2.2.2 Functional Groups of Textile Wastewater

Fourier Transform Infrared Spectroscopy (FTIR) analysis was conducted to identify the functional groups present in the textile wastewater sample and assess its suitability as an alkaline activator for geo-polymerization. Key functional groups that affect its chemical reactivity and alkalinity, such as hydroxyl (-OH), carbonyl (C=O), sulfate ($-SO_4^{2-}$), and silicate (Si-O) groups, were detected by the FTIR spectrum (Figure 5). A large quantity of free hydroxyl (-OH) groups is shown by a significant absorption peak in the 3800–3900 cm^{-1} region, indicating that textile wastewater has strong alkaline characteristics. These hydroxyl groups play a crucial role in geopolymerization by promoting the dissolution of aluminosilicate precursors, which is essential for the formation of geopolymer bonds. Furthermore, a peak at about 1630 cm^{-1} that is associated with C=O stretching suggests the existence of carbonyl compounds, which could be the result of chemicals used in textile manufacturing. The presence of sulfate ($-SO_4^{2-}$) groups in the 1100–1200 cm^{-1} range suggests possible interactions with aluminosilicate materials during the activation process.

The functional groups present in the textile wastewater sample confirm its suitability as an alternative alkaline activator for geopolymer mud concrete. Its high hydroxyl (-OH) content enhances the breakdown of silica (SiO_2) and alumina (Al_2O_3), facilitating the geopolymerization reaction.

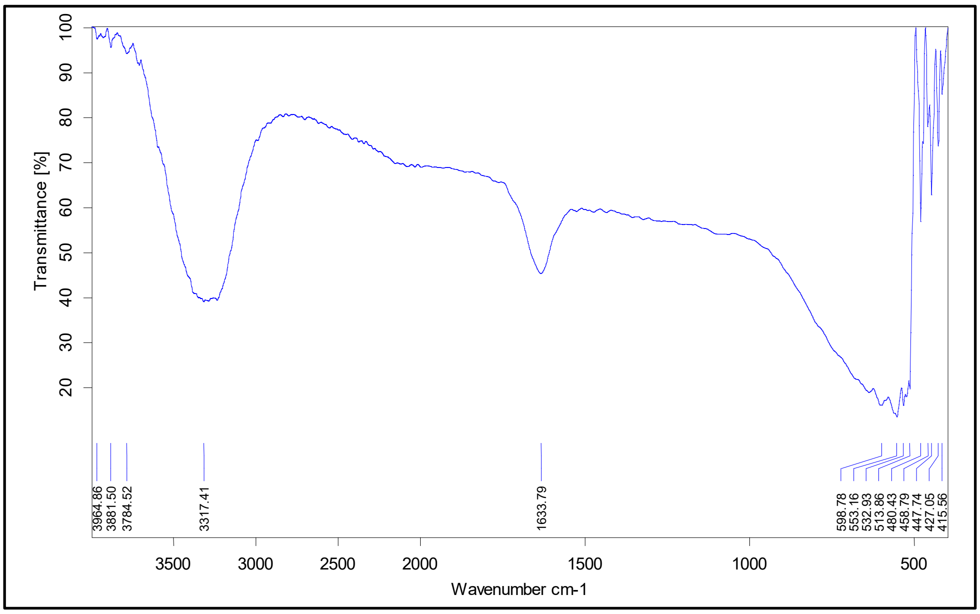

Figure 5: FTIR spectrum for textile wastewater

2.3 MIX DESIGN

There are currently no proper standard guidelines or norms for developing a geopolymer concrete mix. Because geopolymer concrete is still developing with multiple alternative materials. However, we can gain some idea from the literature by referring about previous studies conducted by multiple researchers. In the absence of standardized guidelines, researchers have developed and tested various mix proportions through multiple studies. For example, as shown in Table 1, the literature suggests an optimum mix proportion for coal fly ash-based geo-polymerized mud concrete that has demonstrated success in maintaining strength, workability, and durability.

Table 1: Mix design of coal fly ash-based geopolymerized mud concrete
Source: (Udawattha & Halwatura, 2018)

Material	Optimum Percentage
Coal Fly ash	20%
NaOH	5%
NaCl (Common salt)	2%
Soil	
Fine	5%
Sand	50%
Gravel	45%
Water	20% (from dry mix)

The soil and NaCl content of the mix were kept constant when casting cubes throughout this study. The soil proportion was set at 5 % fine, 45 % sand, and 50 % gravel from the total soil percentage. 2 % NaCl (Common Salt) was used for each set of cubes to increase the ionic strength of the mixture. Also, curing temperature & curing time were maintained at 100˚C and 24 hrs., respectively.

In this study, the moisture content was optimized first. As the first step, a workable concrete mix was developed for various wood ash contents (10 %, 20 %, 30 %, 40 %). For each wood ash content, five different concrete mixes were prepared by varying the moisture content. Then slump diameter vs. moisture content and compressive strength vs. moisture content graphs were obtained. Based on these two graphs, optimum wood ash content and optimum moisture content were determined. In the second step, textile wastewater concentration was optimized. For that textile wastewater samples with four different pH values (pH 10, pH 11, pH 12, pH 13) were prepared while keeping the previously optimized constituents at a constant.

2.4 MIXING PROCEDURE

A small-scale material mixture was used to mix materials in the laboratory. Initially, dried materials were mixed thoroughly for 10 minutes to ensure even particle distribution and avoid material segregation. After that in the wet mixing, the prepared alkaline solution was gradually added into the mixture. This gradual addition ensures that the mix does not become too fluid, which could affect workability. The total mixing duration was 20 minutes, while mixing, the mix was checked from time to time for consistency and homogeneity.

2.5 CASTING TEST SPECIMENS, CURING, AND TESTING FOR COMPRESSIVE STRENGTH

Three test specimens for each concrete mix were prepared according to the BS EN 12390-2:2019 standard by using 100mm×100mm×100mm steel moulds. Then two heat-curing techniques were followed for the prepared test specimens. In the ambient curing process, prepared specimens were kept at room temperature inside the laboratory, while in the oven curing, prepared specimens were kept inside the oven for 24 hours under 100^{0}C. Finally, the compressive strength test was conducted at 7, 14, and 28 days in accordance with the BS EN 12390-3:2002 standard.

3. RESULTS AND DISCUSSION

3.1 WORKABILITY

For this study, a flow table test for fresh concrete was conducted according to the BS EN 12350-5:2009 standard. First, specimens were cast to determine the optimum moisture content of the workable mix by using a slump diameter for five different moisture contents in four different fly ash percentages. As literature includes, due to sticky characteristics of the alkaline activator solution, the workability of geopolymer concrete is lower than the conventional concrete.

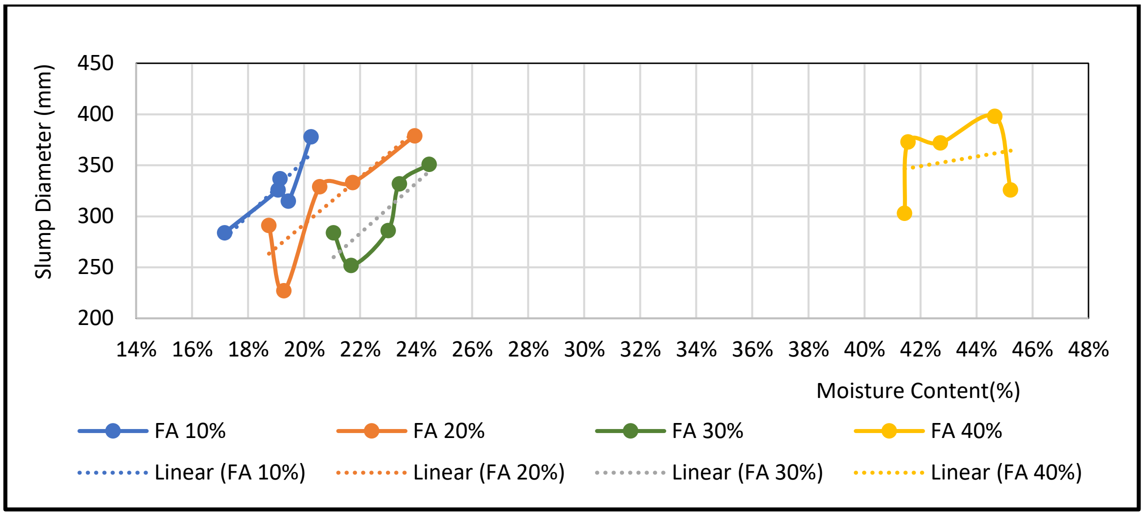

Figure 6: Slump diameter vs moisture content graph

As shown in Figure 6, the slump diameter was measured to evaluate the workability of the mix. Fly ash 20% showed higher and optimum workability. The researchers have stated, that the reduction in workability of concrete containing wood ash particles, irregular shape, and higher specific surface area.

3.2 DETERMINE OPTIMUM MOISTURE CONTENT AND OPTIMUM WOOD ASH CONTENT

Four different wood ash contents (10%, 20%, 30%, 40%) were subjected to study with 05 different moisture contents. Moisture content was varied while keeping the curing temperature at 100 ^{0}C for 24 hr and pH 13 in wastewater concentration at the same value (Figure 7, Figure 8, and Figure 9).

According to test results, 20 % of wood ash content by dry weight showed the highest compressive strength. A comparable result was obtained by literatures showed that higher wood ash contents may hinder workability, because of increased particle interactions. Excessively high percentages can result in poor bonding within the matrix (Ma et al., 2022). It was observed that the moisture content of around 20 % - 22 % provided optimal results to cast the proposed concrete cube.

When compared to 7 days, 14 days, and 28 days' dry compressive strength for the 40% wood ash, the maximum load wasn't shown in the test machine (Since max load ≤ 1kN).

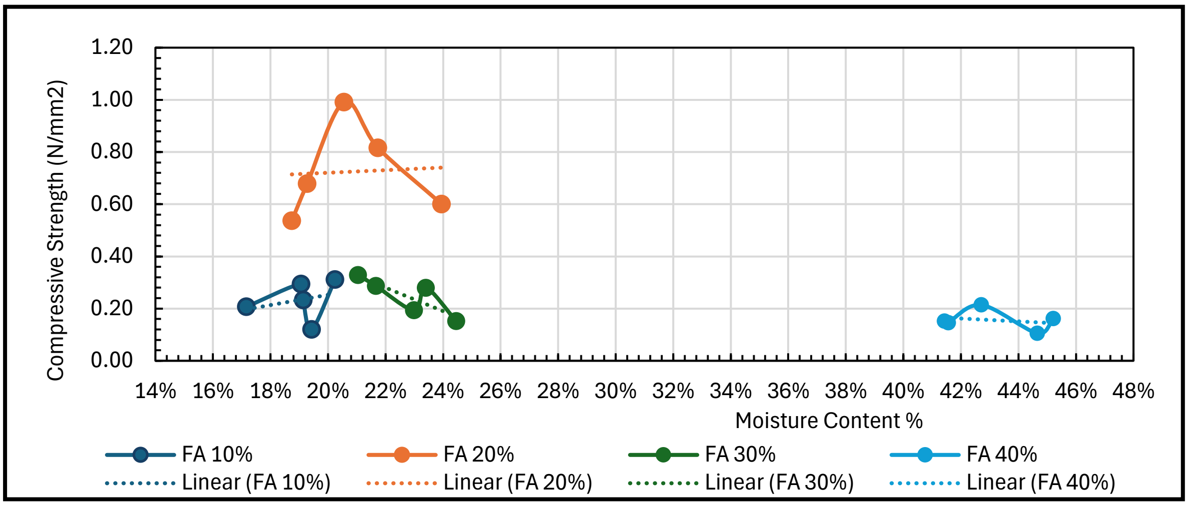

Figure 7: The effect of moisture content on dry compressive strength of various wood ash percentages after 07 days

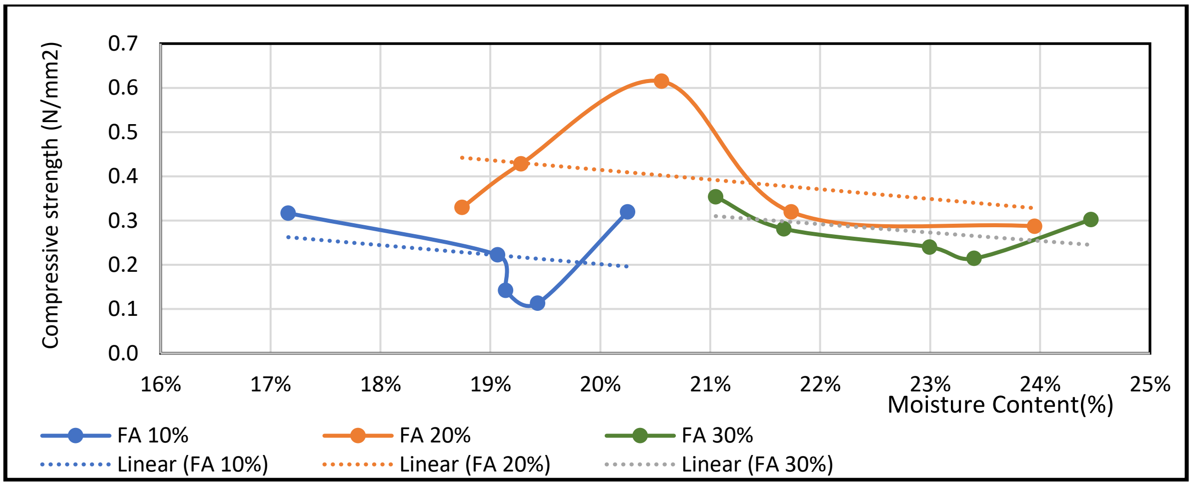

Figure 8: The effect of moisture content on dry compressive strength of various wood ash percentages after 14 days

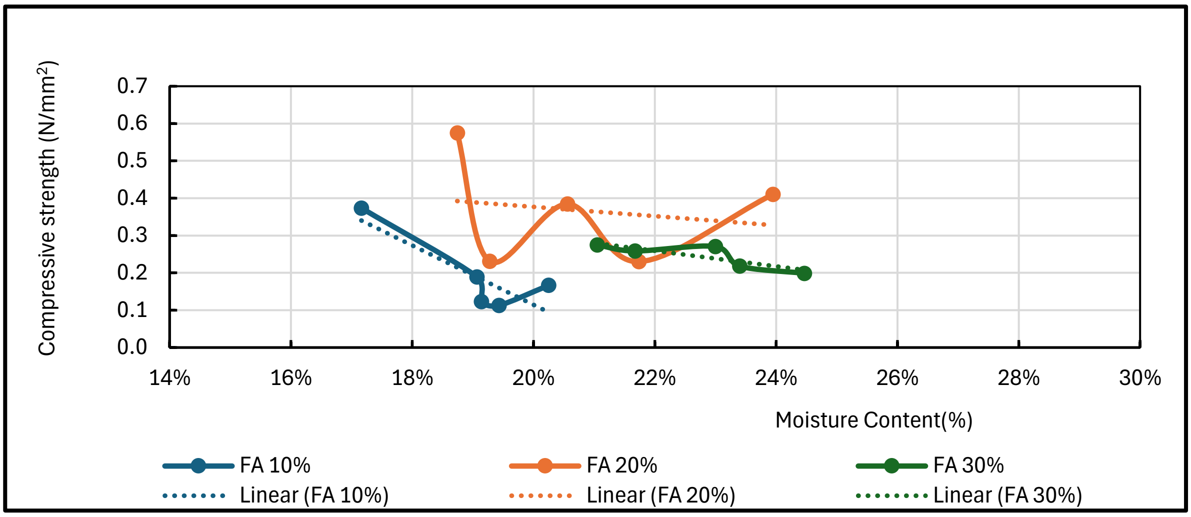

Figure 9: The effect of moisture content on dry compressive strength of various wood ash percentages after 28 days

3.3 DETERMINE THE OPTIMUM TEXTILE WASTEWATER CONCENTRATION

The concentration of the activator affects the strength properties of concrete and setting time (Tennakoon et al., 2017). Four different pH values (pH 10, pH 11, pH 12, pH 13) were used to optimize the textile wastewater concentration (Figure 10). Cubes were cast while keeping optimum moisture content at 20% - 22%, optimum wood ash content at 20 %, and curing temperature at 100˚C for 24 hrs. According to the results shown in Figure 10, pH 12 shows the highest dry compressive strength, and after this value strength decreased.

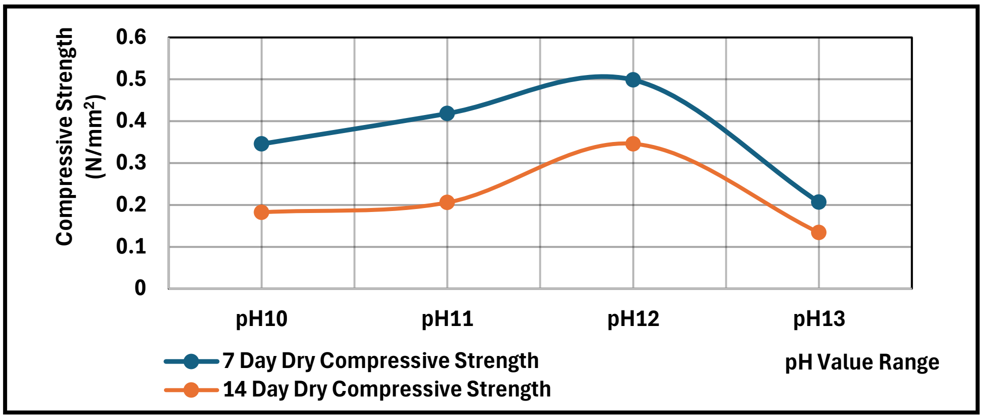

Figure 10: Dry compressive strength variation with different pH value

The obtain results, show that textile wastewater and wood ash can be effectively used to produce Geopolymerized Mud Concrete for sustainable construction. Based on this study, the optimum mix-20% wood ash, 20-22% moisture and pH 12 wastewater achieved higher compressive strength. FTIR analysis confirmed the suitability of textile wastewater as an alkaline activator. The SEM/EDX results showed that the wood ash sample consisted of a higher amount of unburned carbon content and various sizes of particles with higher porosity. Those are may also affect inconsistent strength development and increase water requirements

4. CONCLUSION

This study was conducted to develop existing Geopolymerized Mud Concrete as an eco-friendly alternative to cement-based concrete by using textile industry by-products. Results highlighted the wood ash content, textile wastewater concentration, and moisture content significantly influence the compressive strength of the developed material. The optimal mix- 20% wood ash, textile wastewater at pH 12 (replacing commercial NaOH) and 20% - 22% moisture (with a slump diameter 329mm) achieved a 7-day dry compressive strength of 0.9917 N/mm^2, which satisfied the minimum strength requirements for non-load bearing wall. This experimental result showed inconsistent strength development due to higher porosity and high carbon content of wood ash, which also minimized the mix from achieving wet compressive strength. These finding reflect the need for improve materials consistency to use industrial by-product to sustainable construction. Hence this research study supports the global transition towards low carbon waste-based building materials to prevent global emissions and waste minimization. Future research should be focused on optimizing materials properties and finding alternative methods to strength development of geopolymer mud concrete as a sustainable by product.

5. ACKNOWLEDGEMENTS

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