Pollution 2021, 7(4): 993-1006
DOI: 10.22059/POLL.2021.320857.1039

RESEARCH PAPER

Production of Eco-Friendly Geopolymer Concrete by using Waste Wood Ash for a Sustainable Environment

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Received: 18 March 2021, Revised: 13 September 2021, Accepted: 15 September 2021

ABSTRACT
Climate change could be exacerbated by waste disposal problems, which destroy the ecosystem. Utilizing waste byproducts in creating eco-friendlier geopolymer concrete was hypothesised to be suitable and sustainable to overcome the negative impacts of wastes. The researchers had missed out on developing an alternate binder due to increasing demand for fly ash, high alkaline activators, and higher curing temperatures. This research used waste wood ash that is readily accessible in local restaurants and has an inherent potassium constituent. It has decided to replace the fly ash with waste wood ash obtained through nearby restaurants at intervals of 10 percent. The fresh and mechanical features have been discovered over long curing periods to assess the impact of waste wood ash. SEM and XRD have been used for characterising the microstructure of selected geopolymer mixes. In terms of setting properties and all mechanical parameters, replacing 30 percent waste wood ash produced enhanced results. The optimised mix could be used in geopolymer to replace fly ash and reduce the cost of alkaline activators while also reducing ecosystem damage.
Keywords: Wood waste ash; Low calcium; Eco-friendly geopolymer concrete; SEM; XRD.

INTRODUCTION

Reusing industrial waste to produce geopolymer could mitigate emissions generated by cement production (Huntzinger and Eatmon, 2009). Geopolymer Concrete (GPC), which uses fly ash as an aluminosilicate binder, is researched (Rangan, 2008). GPC strength parameters have been enhanced by increasing the alkaline solution because silica and alumina are easily dissolved (Chithambar and Muthukannan, 2019). The presence of high Calcium (Ca) promotes earlier strength by generating the reaction with available activator molecules (Amran et al., 2020). However, the interference of chemical reaction has been generated by the calcium that causes the presence of unreacted silica and alumina (Yousefi Oderji et al., 2019). Meanwhile, considering the setting time and workability, it was highly influenced by the calcium present in the binder material (Zhang et al., 2020a). More or less, adding higher amounts of SiO_2 or Al_2O_3 helps shorten the setting time of calcium-rich geopolymers (Wang et al., 2020). For the most part, keeping the SiO_2 and Al_2O_3 ratios constant is a challenging

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one. Either of these methods can provide a solution to this problem: using the binder with lower Ca and higher potassium oxide content (Cheah et al., 2017; Suresh Kumar et al., 2021).

On the other hand, Rice Husk Ash based GPC has less calcium of 0.72percent (Hwang et al., 2015) and high SiO_2, which needs more activators to create the reaction of geopolymer (Nuaklong et al., 2020). It results in lower strength gain and a higher residual of unreacted silica (Liang et al., 2019). Fly ash based GPC produced with FA, which having 1.34percent of CaO, has been investigated (Jiang et al., 2020). Less calcium helps in achieving the later age geopolymerization reaction (Sivasakthi et al., 2021). However, the existing alumina and silica in fly ash need more alkaline activators to diffuse and attain maximum strength (Ganesh et al., 2021b). The POFA based GPC acquires maximum performance when adding slag or fly ash for better performance (Kabir et al., 2017). Furthermore, the ratio of silicate to hydroxide influences the strength gain and proper creation of geopolymeric reaction (Chithambar Ganesh and Muthukannan, 2018). The low calcium content requires more amount of activators for strength gaining in the later ages. A large amount of silica and alumina in the aluminosilicate source material requires high amounts of activators to be applied to dissolve it. Therefore, the source material with less calcium will be suitable while it requires a less alkaline solution.

The hybrid geopolymer concrete using GGBS (Suresh Kumar et al., 2020), Pulverized fly ash and High Calcium Wood Ash (HCWA) was produced (Cheah et al., 2015). More calcium concentration in the aluminosilicate material interrupts the geopolymeric reaction, which causes a decrease in the ability to reach ultimate strength (Amran et al., 2020). As well, this calcium-rich solution used the alkaline solution to dissolve from an early age itself (Suresh Kumar et al., 2020). A series of highly concentrated activators had to be used to dissolve silica and alumina (Mehta and Siddique, 2018). Studies have been conducted on the self-activating technique of HCWA in geopolymer concrete, in which no activator was used (Ban et al., 2017). According to the study, replacing 50 – 60 percent of HCWA enhanced the performance of GPC at earlier ages (Ban and Ramli, 2012). Meanwhile, geopolymerization did not occur at the later ages because calcium was present and used the activators to dissolve on earlier ages itself (Zhang et al., 2020b). The source material with low calcium and high alkaline properties could improve the long-term strength development of geopolymerization. Geopolymer concrete has been produced in limited quantities due to the limited availability of sources. The implementation of GPC has less than a 7% probability globally (Assi et al., 2020). Therefore, the investigations have to be concentrated on finding alternate activators or an alternate solution for the activator usage.

Hence, the binder with lower calcium content and high alkaline composition have to be chosen to solve the aforementioned problems. The Low Calcium Waste Wood Ash (LCWWA) has been adopted as a substitute binder for the enlargement of eco-friendly geopolymer concrete. The binder material with low calcium and high K_2O could be employed in this research. Accordingly, the optimization of binder ratios has been performed in this research by replacing the fly ash with LCWWA from 0 to 100 percent. The study examined the influence of LCWWA on consistency, setting time and mechanical properties that are relied on long term investigation. Further, the study focused on defining the microstructural changes of selected GPC mixtures by using SEM and EDX.

MATERIALS AND METHODS

Materials: This research employed Fly Ash (FA) as a primary binder with a specific gravity of 2.82, a loss of ignition of 1.79 percent, and a surface area of 325 square meters per kilogram

(Chithambar Ganesh and Muthukannan, 2019). This research adheres to ASTM C618 (ASTM C618, 2010), and fly ash is permitted as a binder in this study, which will allow it to create GPC. According to the EDX chemical analysis, the FA has low in calcium (Arunkumar et al., 2021a). Low Calcium Waste Wood Ash (LCWWA) is a residual derived from hotels that are readily accessible (Arunkumar et al., 2021b). The LCWWA was filtered through a 90µm sieve to remove massive powder particles and carbonaceous components. LCWWA has been found to have a surface area of 567 m2/kg and a specific gravity of 2.43 (Arunkumar et al., 2020). The elemental composition of LCWWA and FA have shown in Table 1. An activator like hydroxide or silicate has required to create GPC. In this study, sodium-based activators have been used. NaOH pellets in this study had a specific gravity of 1.47. It has been decided to use Na_2SiO_3 (sodium silicate) with a specific gravity of 1.70 as the activator. In order to dissolve NaOH pellets, the amount of water was calculated (Rajamane N. P and Jeyalakshmi R., 2014). The research employed river sand with a specific gravity of 2.62, the maximum particle size of 1.18 mm, and fineness modulus of 2.42 as fine aggregates. Before using the fine aggregate, it has been dried on a dried surface (Arunachalam et al., 2021). The study used a coarse aggregate with a size of 10mm and a fineness modulus, and specific gravity of 7.59 and 2.89, respectively. In order to obtain soluble sodium hydroxide, it was necessary to add water. This research computed the water required to obtain soluble sodium hydroxide (NaOH) using this study (Pavithra et al., 2016).

Table 1. Fly ash and LCWWA Chemical Compounds in % by Mass (Arunkumar. et al., 2021)

Chemical compound	Si	Al	K	Ca	Mg	C	Gd	Ti	Fe
FA	23.6	17.4	0.8	0.7	70	3.1	-	1	2.1
LCWWA	7.25	0.4	14.5	2.61	2.95	10.22	0.48	-	-

Mix proportioning and curing: During GPC production, the fly ash to wood ash ratio has been optimized from 0 to 100%, every 10% interval. The authors previously discovered the optimal activator to binder ratio and sodium hydroxide molarity (Arunkumar et al., 2020). As a result, the ratios of alkaline solutions to the binder and sodium silicate to hydroxide were kept constant at 0.45 and 2.5, respectively (Ganesh et al., 2021a). Similarly, it has been found that the optimal molarity of sodium hydroxide is 10M. (Arunkumar. et al., 2021). Modified Indian standards for geopolymer concrete were used to create the design mix and then implemented (Anuradha, 2011). Calculations for water required for mixing have been made in relevance (Pavithra et al., 2016). As indicated in Table 2, the geopolymer concrete mixture proportions for optimizing the fly ash and wood ash ratio has been presented. When it came to

Table 2. Mix proportioning in kg/m^3 (Arunkumar et al., 2020)

Mix id	GC	GCW10	GCW20	GCW30	GCW40	GCW50	GCW60	GCW70	GCW80	GCW90	GCW100
FA %	100	90	80	70	60	50	40	30	20	10	0
WWA %	0	10	20	30	40	50	60	70	80	90	100
FA	550	495	440	385	330	275	220	165	110	55	0
WWA	0	32	64	96	128	161	193	225	257	289	321
Sodium Hydroxide	110	110	110	110	110	110	110	110	110	110	110
Sodium silicate	276	276	276	276	276	276	276	276	276	276	276
Fine Aggregate	667	667	667	667	667	667	667	667	667	667	667
Coarse Aggregate	993	993	993	993	993	993	993	993	993	993	993

creating a homogeneous mix, the standard mixing procedure has also been followed (Chithambar Ganesh et al., 2019). Before the specimens have to be tested, they were kept at room temperature for curing.

Setting and mechanical characterization: Consistency, initial and final setting times of geopolymer mixtures have been measured with the standard procedures given in BS EN 196-3:2005 (British Standard, 1999). For conducting each mechanical characterization test, a total of 165 specimens has been cast for each test on the standard recommended size such as cube, cylinder and prism. The cube and prism specimen sizes were 150 mm X 150 mm X 150 mm and 150 mm X 500 mm. Mechanical characteristics such as compressive and flexural strength of GPC made with low calcium materials have been identified in compliance with ASTM C109 (ASTM C109/C109M-02., 2002) and ASTM-C293 (ASTM-C293, 2015) procedures. The compressive and flexural strength of the GPC mixes has been carried out by testing the cube and prism specimens on the compressive testing machine. The size of the cylindrical specimen was 150 mm X 300 mm. The elastic modulus has also been found in accordance with ASTM C215 (ASTM C215, 1991) procedure by testing the cylindrical specimen. Three samples were tested in all ages and an average was applied to the results. Scanning electron microscope furnished with EDX has been used to examine the microstructure of the selected mixtures chosen for further investigation. The morphological and elemental composition changes in the chosen mixtures have been evaluated using the SEM.

RESULT AND DISCUSSION

Consistency: The research focused on the influence of LCWWA on the consistency of eco-friendly geopolymer paste, and the results have been illustrated in figure 1. The water required for attaining the standard consistency of geopolymer paste has increased with increasing the replacement of LCWWA. From figure 1, it was understood that the mix without LCWWA grasps its standard consistency at a water to binder ratio of 0.36. In the meantime, the water to binder ratio increased from 0.38 to 0.49, increasing the LCWWA replacement from 0 to 100 percent. The result revealed that increased water to binder ratio meant to increase of water requirement. LCWWA addition to the GPC mix has a substantial influence on the need for water for standard consistency because of its surface area ($558m^2$/kg). Depending on the surface area of the aluminosilicate material, the amount of water required to achieve its consistency has been influenced (Zhang et al., 2021). However, the replacement of LCWWA up to 30 percent required less water, whereas the mix with 100 percent LCWWA required a higher amount of water to attain the standard consistency (Arunkumar. et al., 2021). The lower water requirement was due to the specific surface area of fly ash ($324m^2$/kg), which was highly present in the mixes up to 30 percent replacement (Yousefi Oderji et al., 2019). 10 percent to 70 percent fly ash reduced water requirements by 18%. The shape of particles presents in the aluminosilicate materials also influenced the requirement of water for attaining normal consistency, whereas fly ash (spherical shape particles) has less water demand (Assi et al., 2020) and LCWWA (angular particles) has higher water demand (Cheah and Ramli, 2012). In the meantime, the friction between molecules has also been created with the alkaline activators, which adhere to the fluidity effect on the geopolymer paste (Cheah and Ramli, 2011).

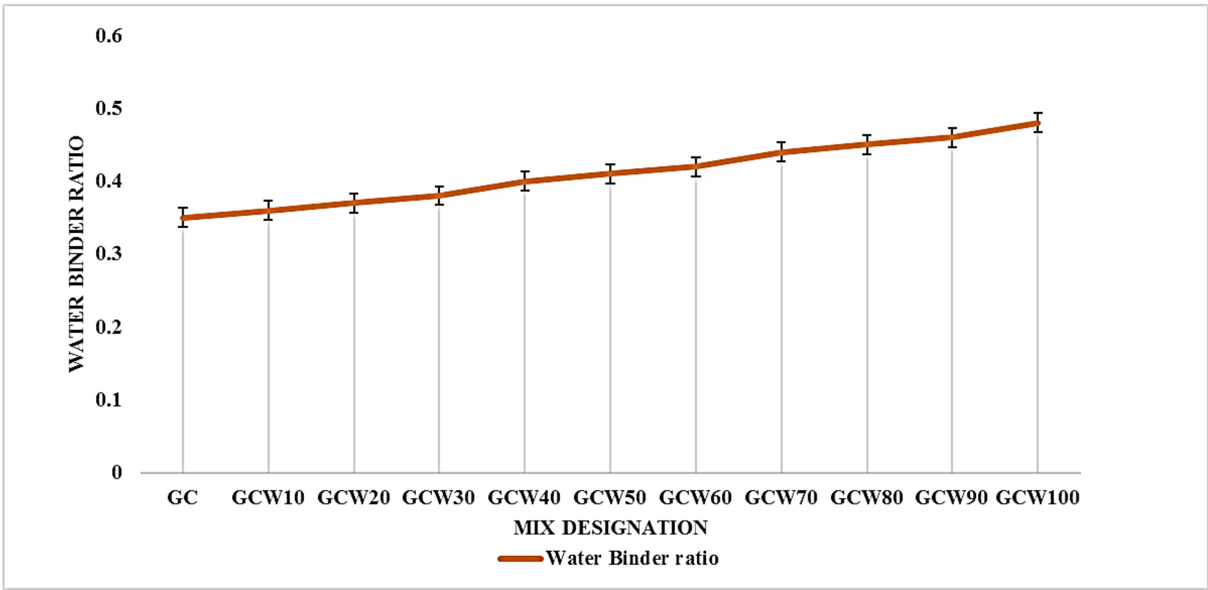

Figure 1. Influence of LCWWA on consistency

Setting times: The influence of LCWWA on the initial and final setting time of geopolymer paste has illustrated in figure 2. Generally, fly ash-based geopolymer has required extended time for setting (Malkawi et al., 2016), and it adversely affected the use of fly ash-based geopolymer concrete in civil engineering applications. This research focused on adding LCWWA in the geopolymer mixture to reduce both setting times to a concern. The mix only with fly ash required 240 and 450 minutes for the initial and final set of the mixtures (Ganesh and Muthukannan, 2021). In contrast, the mix only with LCWWA required 50 and 150 minutes for the initial and final setting. The reason behind this small quick setting was due to the presence of calcium in LCWWA (Cheah and Ramli, 2011). The setting times has been expanded due to the binder materials have less calcium. Due to the absence of calcium in the

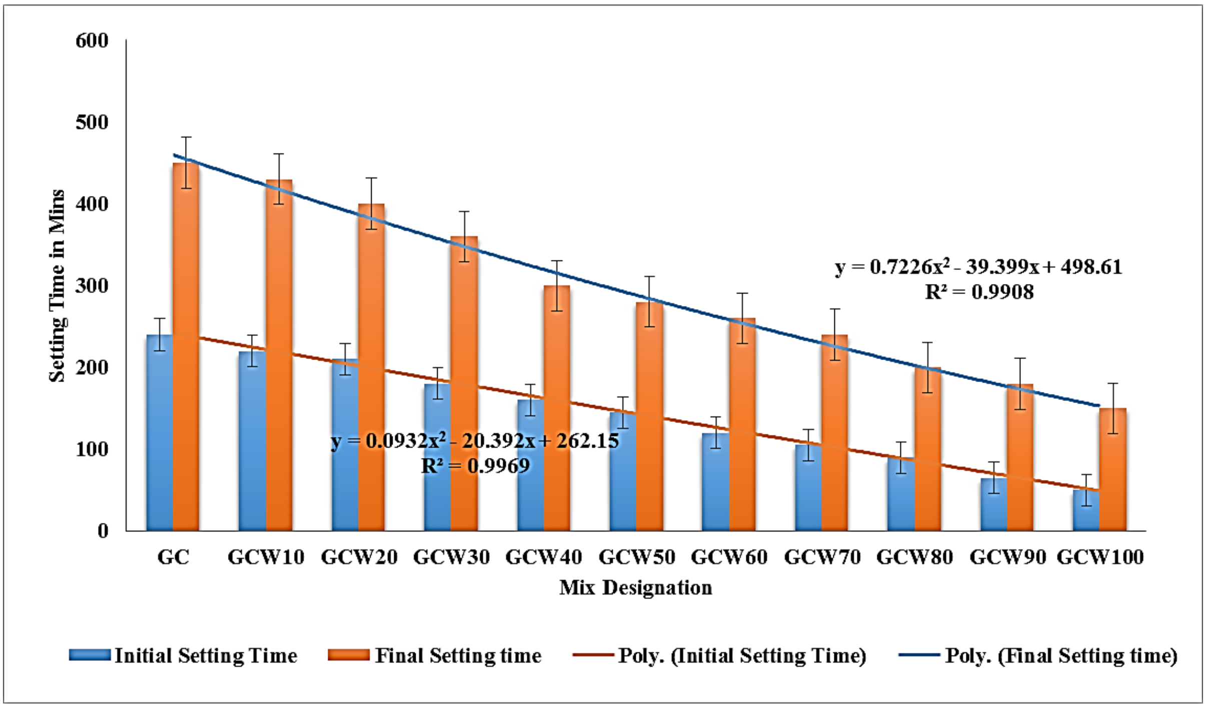

Figure 2. Influence of LCWWA on setting time

mixture when 100 percent LCWWA was replaced with fly ash, the setting times have been lowered between 50 and 150 minutes (Ban et al., 2017). As a result of ambient curing conditions, longer setting times have been observed. Whereas the mixtures cured at elevated temperatures, the setting times have been improved further. However, the study aims to achieve the better performance of the GPC mixtures incorporated with LCWWA at ambient curing conditions alone (Chithambar Ganesh and Muthukannan, 2019). Due to the higher calcium content, the mix with 80% LCWWA sets faster at room temperature than other mixes (Ban et al., 2017). The incorporation of high calcium wood ash quick the setting time, mentioned by (Samsudin and Ban, 2015).

Compressive strength: The research has been employed to find the influence of LCWWA on the compressive strength of eco-friendly geopolymer concrete mix that cured at 3, 7, 28, 56 and 90 days under ambient curing conditions. The results have been illustrated in figure 3. As stated in previous studies (Winnefeld et al., 2010), the presence of high calcium led to left the unreacted Al and Si. In this research, the unreacted alumina and silica dissolute from binders have been eliminated because the binder has less calcium content and is easily reacting with the alkaline solutions (Hamidi et al., 2016). Geopolymer structure homogeneity and early age strength have been enhanced with the help of LCWWA replacement (Ban and Ramli, 2012). As a result of the polysialate precipitation and the massive dissolution of the amorphous phase of the binder materials, earlier strength has been achieved (Chithambar Ganesh et al., 2020). When LCWWA is replaced by up to 30%, the compression strength has been significantly increased at all age of curing (Cheah and Ramli, 2013). In the meantime, the replacement of LCWWA more than 30 percent of LCWWA led to a decrease the strength (Arunkumar. et al., 2021) due to the unreacted elements of fly ash (Jiang et al., 2020). Over the 28, 56, and 90-day curing durations, LCGPC strength attainment has continued. As a result of the perfect geopolymerisation reaction, the later age strength was gradually achieved (Sivasakthi et al., 2021). At 3, 7, 28, 56, and 90 days, the GCW30 concrete reached compressive strengths of 21,68MPa, 28,98MPa, 38.9MPa, 41.63MPa, and 44.25MPa respectively. Because calcium levels were low and alkaline solution was not required for dissolution, the strength has been increased as a result of this (Thakur and Ghosh, 2009).

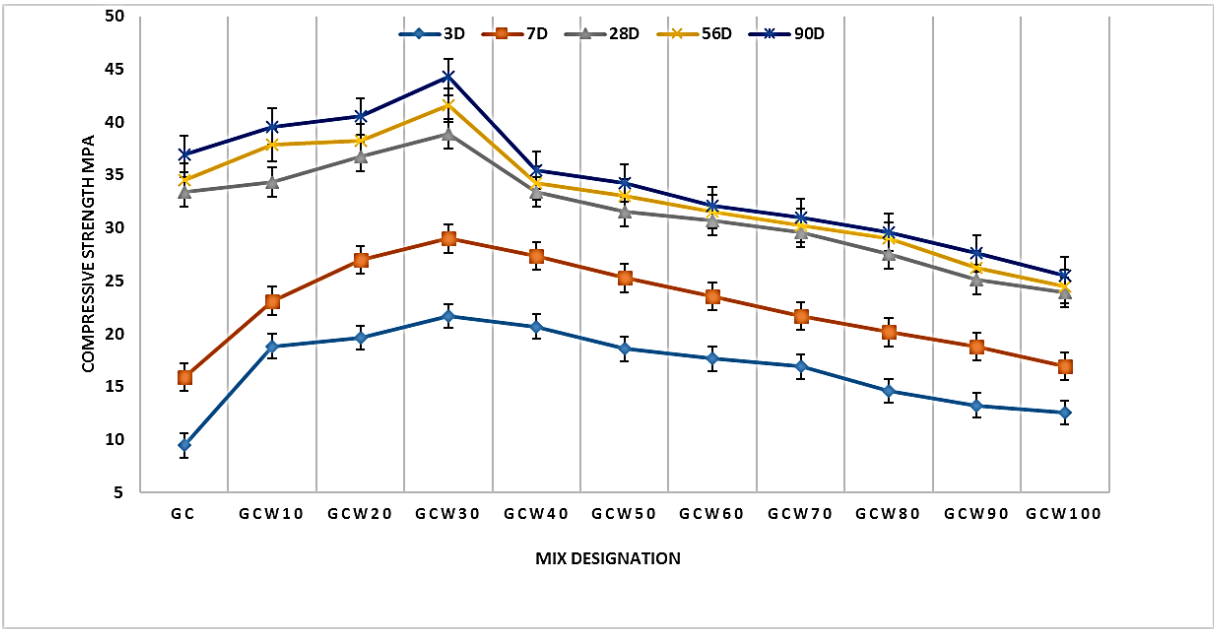

Figure 3. Influence of LCWWA on compressive strength

There was a 19 percent increment in the strength of the optimum mix after 90 days of curing compared to the control mix.

Flexural Strength: The results of the influence of LCWWA replacement on the flexural strength of the eco-friendly geopolymer concrete has been presented in figure 4. Similarly to the increment in compression strength, replacing LCWWA up to a percentage replacement of 30% had a substantial effect on the enhancement in flexural strength of all ages (Cheah and Ramli, 2013). Moreover, the inclusion of LCWWA of 30% or more reduced strength accomplishment (Arunkumar. et al., 2021). In all measured curing ages, the mix exhibited the greatest flexural strength when it contained 30% of the LCWWA (Zhang et al., 2020b). An LCWWA content above 30% offers reduced flexural strength compared to controls at any age of concrete (Ban et al., 2017). The lack of CaO molecules caused the formation of CASH gel and CA polysialate frames (Winnefeld et al., 2010). The mix with 30 percent of LCWWA has enhanced flexural strength of 4.89MPa, after 90 days of curing, Whereas the control mix has 4.59MPa of flexural strength at the same age of curing. Hence, the LCWWA replacement up to 30 percent adversely helped in enhancing the flexural strength. The bond strength can be increased by increasing the interfacial zone to resist the flexural load (Hajimohammadi et al., 2019). At the same time, the geopolymerization reaction created a C-S-H gel that improved the pore filling capacity of the geopolymeric gel matrix, thus leading to improved flexural strength as the material cures (Cheah and Ramli, 2011).

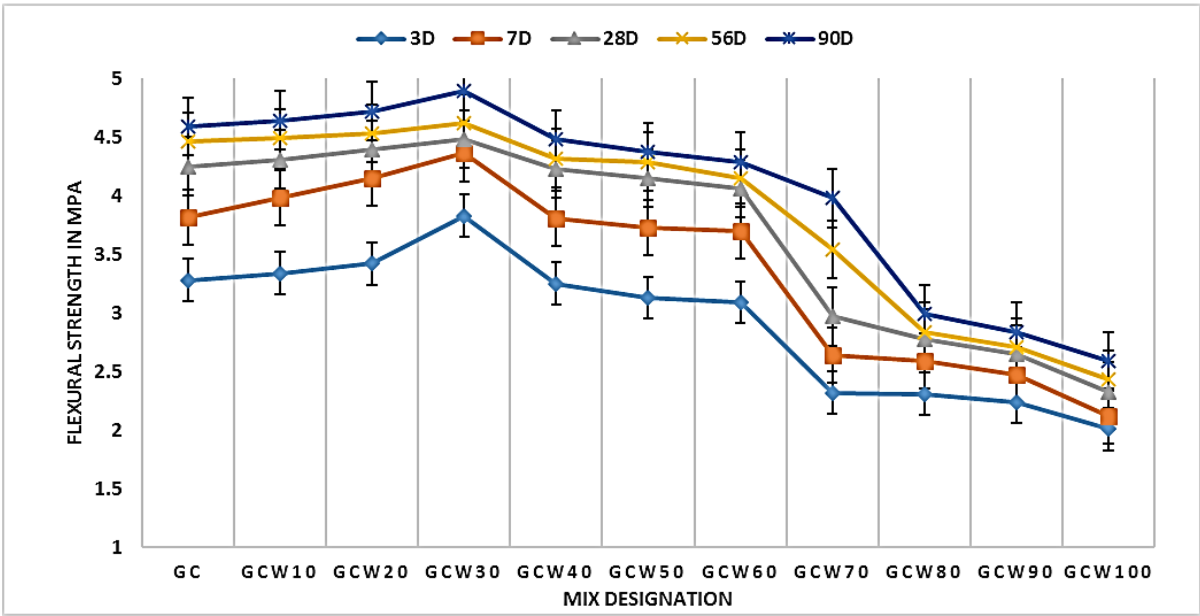

Figure 4. Influence of LCWWA on flexural strength

Dynamic modulus of elasticity: The average results of the modulus of elasticity for all LCGPC specimens at all age of concrete has been illustrated in figure 5. The result showed a growing trend in the elastic modulus as the amount of LCWWA gradually increased to 30 percent (Zhang et al., 2020a). In the meantime, 23.69-72.50 percent declined significantly in the elastic modulus compared with the control mixture in all ages, when the replacement of LCWWA was over 30 percent (Arunkumar. et al., 2021). The earlier age elastic modulus was higher than other curing ages. The 3 days elastic modulus has increased by 24.6-58 percent than the control mixture (Arunkumar. et al., 2021). Whereas the 7 days elastic modulus has enhanced by nearly 42 percent than the control mix. This is because the binder materials dissolve quickly with the alkaline activators at earlier ages (Malkawi et al., 2016). In addition, the dynamic modulus of elasticity increment rate slowed down significantly in later ages as opposed to earlier ages (Amran et al., 2020). The highest modulus of elasticity was observed, with the mix having 30 percent LCWWA. The same mix achieved the elastic modulus of 22.54, 28.82, 35.98, 37.13 and 38.94 MPa, after 3, 7, 28, 56, and 90 days of curing. Ca levels were low, resulting in decreased overall pore volume and decreased pore connections. At the interface, geopolymeric reactions increased pore filling (Shadnia and Zhang, 2017). The presence of amorphous monomers has been thought to lead to a rise in polysial networks being produced at ambient curing (Chithambar Ganesh et al., 2020).

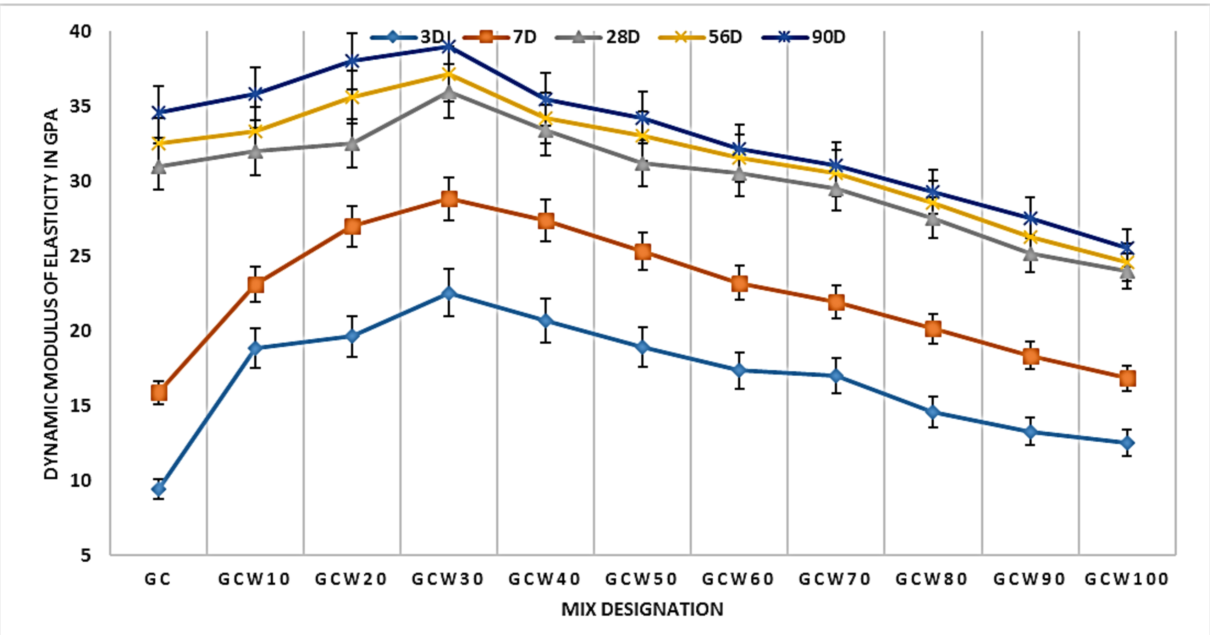

Figure 5. Influence of LCWWA on the modulus of elasticity

SEM: The SEM image of selected mixtures chosen for microstructural analysis has been presented in fig 6 (a-d). GCW30, a heterogeneous and cracked matrix with the existence of inert solvent as a result of curing and ageing, is pictured in the micrograph. A stronger connection has been formed by combining reacted and unreacted microspheres (Jiang et al., 2020). However, the particle pore bridging results are just as important. While the GCW10 and GCW30 mixtures show similar properties compared to the mixture with full fly ash, the GCW30 mixture has higher homogeneity and volume of gel matrices, especially when compared to the GCW10 mixture. In addition, the study found that the presence of unreacted particles has lowered in the mix, having 30 percent LCWWA and 100 percent LCWWA, than the control mixture (Sivasakthi et al., 2021). Thus, the greater FA dissolution rates in mineral mixtures have been due to the addition of LCWWA.

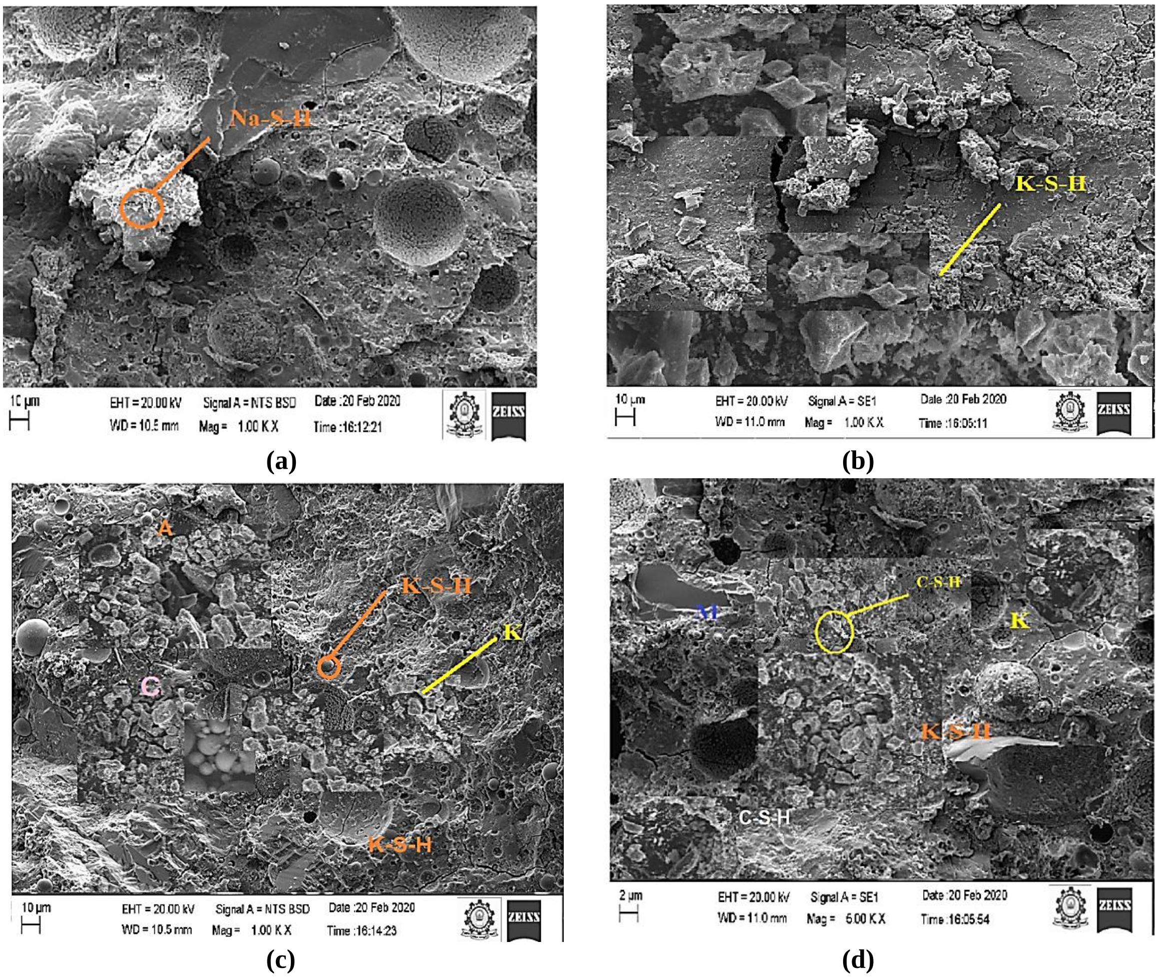

Figure 6. SEM image of Mixes (a) GCW0 (b) GCW100 (c) GCW10 (d) GCW30

XRD: The XRD patterns of selected mixtures observed using the X-Ray Diffraction Analysis have been presented in Fig. 7. This XRD analysis showed a range of 2θ degrees with an amplitude of around 28-30 degrees. This property usually shows the development of a geopolymer if there has been a geopolymerization. (Xiao et al., 2020). The system initially generated a collection of amorphous zones (originally created by FA), which then reacted with the geopolymerization process to form a new phase of albite with the mix having 100 percent FA (Huseien et al., 2018). Albite has a partially-crystallized structure analogous to the sodium-polysialate gel film (Abdulkareem et al., 2019). XRD diffractograms from mixtures with different percentages of wood ash showed a large variety of crystalline structures (Zakka et al., 2021). As a result of the dilution of LCWWA, the peak of crystal quartz concentration was obtained, which causes decreases in the intensity (Xiao et al., 2020). This is because the concentration of calcium in the LCWWA has increased. Coexistence of different phases has been assumed to exist during the advancement of this new phase of Altobermorite (Cheah et al., 2017). The ultimate intensity has reached when FA is used 100% in the mixture. In relation to the formation of Na phases, the rate of Na precipitation increases as the replacement percentage of LCWWA increases. In the presence of wood ash, a K-S-H phase (Kaewmee et al., 2020) has been observed. In contrast, the percentage of LCWWA has increased the percentage of potassium silicate formed due to the presence of potassium in LCWWA (Kaewmee et al., 2020). All the phase formations like potassium silicate, calcite, mulite, Quartz, Silicate gel, and Albite all reached their peak values in the mixture GCW30 found an optimum (Hwang et al., 2015). In order to achieve greater overall efficiency, the improved characteristics of the 30% wood ash blend have been used.

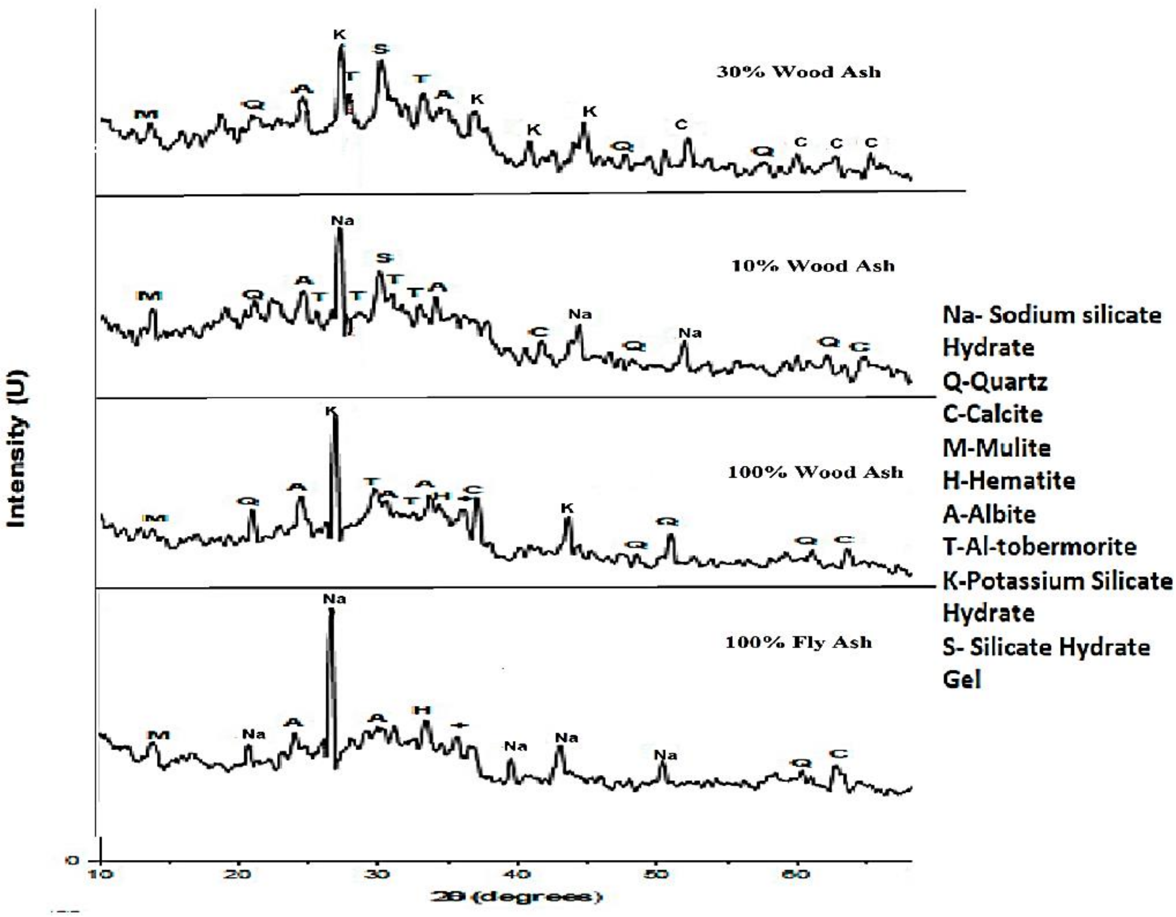

Figure 7. XRD Analysis of selected Mixes

CONCLUSION

Efficient and sustainable production of low calcium green geopolymer concrete has been researched in this study. The setting and mechanical properties of LCGPC were further studied as a result of low calcium waste wood ash. The substitution of LCWWA for LCGPC has a significant effect on its properties. LCWWA addition to the GPC mix has a substantial influence on the need for water for standard consistency because of its surface area ($558m^2/kg$). The lower water requirement was due to the specific surface area of fly ash ($324m^2/kg$), which was highly present in the mixes up to 30 percent replacement. The mix filled with fly ash required more time to initial and final setting because the amount of calcium in fly ash is less than in wood ash. However, replacing LCWWA with fly ash improves calcium content and speeds up setting time. An increase in the compressive strength, flexural strength, and dynamic modulus of elasticity have been induced by a 30% LCWWA replacement level. Increased substitution of LCWWA above 30% caused a reduction in all concrete strength. Thus, to address the issue of waste disposal effectively and address the issues associated with fly ash-based GPC, replacing LCWWA up to 30 percent could be used as a suitable binding material in geopolymer concrete. This study showed the alternative binding material for the GPC had been offered through the research hypothesis.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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