Journal of Harbin Engineering University
ISSN: 1006-7043
Vol 47 No. 10
Oct 2026

Evaluation of Water Hyacinth Ash as a Supplementary Cementitious Material in concrete mixes – A Comprehensive Characterization based on Physical, chemical and microstructural properties

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ABSTRACT
The giant advancements in the construction sector has led to the enormous consumption of cement in civil works. Manufacturing of cement creates higher carbondioxide emissions and increases global warming. This demands the research on Supplementary Cementitious Materials and sets the stage for sustainable development, which is the need of the hour in today's scenario. The ashes of Water Hyacinth plants is one such material. Water Hyacinth plants are found in abundance in freshwater bodies, creating environmental hazards. The study aims at harnessing the locally available Water Hyacinth plants and turning it into ashes for use as an SCM. This supports the SDG goal 11, sustainable cities and communities and also protects the life below water, SDG goal 14. Locally available Water Hyacinth plants were collected and processed into ashes and tested for its physical, chemical and microstructural properties. The outcomes of the physical properties and the chemical composition were compared with FESEM and EDS results of WHA to justify its usage as a replacement for cement. The results obtained were favourable for the employment of WHA as a SCM in concrete construction works.
KEYWORS: Water Hyacinth Ash, Supplementary Cementitious Material, Ordinary Portland Cement, Characterisation.

1.0 INTRODUCTION

Living in the modern world couldn't be imagined without cement[1]. Due to its widespread use in industrialized nations, cement is regarded as one of the materials most commonly employed in construction, decoration and medical purposes. Cement manufacture has numerous economic advantages that strengthen industrial areas and increase employment prospects. But still, the cement business faces several issues coming from sustainability and environmental concerns. Every year, one ton of cement is produced worldwide for every human [2]. The globe may use up to 5800 million metric tons of cement by 2050.[3]. Due to its extensive availability in the worldwide market, awareness on the detrimental effects of cement manufacturing on the environment is becoming increasingly important [4]. As a consequence, intense research is being carried out to find alternative replacements for cement. The Water Hyacinth Ashes is one such alternative to cement.

Water hyacinth (Pontederia crassipes; originally Eichhornia crassipes) is a free-floating, perennial aquatic plant belonging to the family Pontederiaceae. It typically occurs in still or slow-moving freshwater settings, including lakes, ponds, rivers, marshes and canals. It is distinguished by broad, glossy, oval to rounded leaves that are grouped in rosettes. The petioles of these leaves are inflated and spongy, with air-filled tissues that give them buoyancy. The plant is able to absorb nutrients straight from the surrounding water because of its extensive network of feathery, freely floating roots, which are often dark purple to black in color. Under favourable circumstances, the plant can reach a height of around one meter above the water's surface. Horizontal stolons facilitate its quick vegetative proliferation, allowing dense, interconnected floating mats to spread

across the water's surface. The plant generates a large number of seeds in addition to vegetative reproduction, which enables it to quickly establish and spread in favourable environmental circumstances. Water hyacinth is one of the most invasive aquatic plants in many tropical and subtropical locations because of its rapid reproductive capability, which allows populations to grow significantly in a short amount of time. By limiting light penetration, decreasing gas exchange, and competing with native aquatic vegetation for nutrients and space, the development of large floating mats can block the water bodies and also,modify the physical and ecological properties of water bodies.[5]. Additionally, in some countries where tourists visit reservoirs and dams for leisure and recreation, the presence of Water Hyacinth plants has a negative effect on the tourism sector [6]. So, these plants are to be removed from the water bodies. In contrast to herbicide control, bringing secondary water pollution into rivers via chemical contamination induced by herbicides [7], mechanical removal of these plants is commonly followed. Because of these features, water hyacinth's qualities are especially crucial when evaluating its effects on the environment and investigating its possible uses, such as turning it into valuable materials like ash for additional cementitious applications. Also, it finds enormous applications in divergent fields, such as formulation of medicines [8], biosorbent for the removal of toxic metals[9], phytoremediation agents [10], as a construction material- admixture[11], bricks[12], high performance composite [13], biomaterial fillers[14], superplasticizer [15], replacement for sand[16], acoustic insulation boards [17].

The physical and chemical water quality as well as the trophic status of Lake Tana were examined in a study on the invasion of water hyacinth. [18]. Twenty-seven water samples in all were gathered and examined. The amounts of total phosphorus (TP) and chlorophyll-a (Chl-a) were used to determine the trophic status. The findings demonstrated that the invasion of water hyacinth considerably changed the lake's chemical and physical water quality. Both invaded and non-invaded areas were typically categorized as oligotrophic based on phosphorus content, while mesotrophic to eutrophic conditions were indicated by chlorophyll-a, especially in invaded areas. The study found that the invasion of water hyacinth significantly affects Lake Tana's trophic state and water quality, illustrating the ecological effects of invasive aquatic plants. These results further emphasize the necessity of managing water hyacinth effectively in order to preserve the ecosystems and the services they provide.

Iswariya et al.[19] made a study on the South American plant known as water hyacinth (Eichhornia crassipes). It has spread throughout tropical and subtropical aquatic environments as an invasive species destroying aquatic biodiversity, impeding rivers, limiting fishing, agriculture, and transportation, and establishing habitats for organisms that spread illness. Many control techniques, including chemical treatment, biological control, and mechanical removal, have been used; however, the plant's constant growth and quick regeneration frequently restrict their efficacy. The research highlights the necessity of sustainable and integrated management strategies that involve coordinated activity and community involvement. Notwithstanding its negative effects, water hyacinth may be useful for building homes, controlling soil erosion, purifying water, and creating economic value. Therefore, utilizing it effectively and managing it properly may help minimize its negative effects on the environment while maximizing its potential advantages.

The literature by Rezaenia[20] also details a number of potential value-added uses for the biomass, such as the manufacturing of fiberboard, ethanol, biogas, animal and fish feed, briquettes for energy generation, and compost. Therefore, combining water hyacinth-based phytoremediation with suitable biomass management, biological control, and watershed management techniques could offer a sustainable method for managing invasive water hyacinth biomass.

2.0 LITERATURE REVIEW

Gaurav Goel.et.al [12] studied the feasibility of using Water Hyacinth as an additive in producing fire bricks. The results depicted that the maximum amount of Water Hyacinth that could be added to produce a successful firebrick was found to be 10% by weight. This addition yielded good compressive strength, reduced bulk density, increased porosity

and also provided less water absorption values. Studies made by Juby Mariam Boban. et.al(2017) suggest the successful replacement of Water Hyacinth fibres as a partial replacement of fine aggregates in the proportion of 0.5% by weight. The work revealed the fact that WHF in concrete produces reduced water absorption characteristics, enhanced durability and improved compressive strengths at higher temperatures. Okwadha.et.al [15] tested the replacement of Water Hyacinth extract in various proportions by volume of superplasticizer, Auramix 400 for class 25 concrete. Consistency, setting time, workability, compressive strength and water absorption tests were done. The results revealed that the optimum superplasticizer replacement was 20%. The results indicated that water hyacinth extract retards the hydration rate and hardening process, thereby making the concrete to have high flowability and filling ability. As a result, the shrinkage potential of concrete created by high heat of hydration during the hydration process will be reduced.

As per Murugesh et al.[21], the chemical properties of water hyancinth plant ash.had better pozzolanic materials than cement at a certain proportion, according to visual observation of the hydration interaction between cement and WHA; Calcium Oxide above 20% gives it strength and hardens, according to the EDAX study. García et al. [11] reviewed the utilization of water hyacinth as a supplementary cementitious material, admixture and natural fibre in mortar and concrete. The study reported that the chemical composition and performance of water-hyacinth-based materials are strongly influenced by processing conditions such as washing and burning. WHA containing higher SiO_2 and lower LOI was considered more suitable for SCM applications. The review indicated that moderate WHA replacement levels, particularly around 5–10%, can improve mechanical properties, whereas higher replacement levels may reduce strength. The authors further highlighted that the manufacturing method of WHA can significantly influence concrete performance and identified durability, microstructure and long-term behaviour as important areas requiring further investigation.

The use of water hyacinth fibers in concrete as a partial substitute for fine aggregate was studied by Boban et al.[16]. By weight of fine aggregate, water hyacinth fibers were added at replacement levels of 0.5%, 1%, 1.5%, and 2%. The experimental study assessed the concrete's heat resistance, sorptivity, water absorption, splitting tensile strength, and compressive strength. The findings showed that the concrete with 0.5% water hyacinth fibers had tensile and compressive strengths that were much higher than those of regular concrete. Reduced water absorption and improved performance upon exposure to high temperatures were also noted in the study. The ideal percentage of water hyacinth fiber integration among the mixes under investigation was determined to be 0.5%.

The Cooum River in Maduravoyal, Chennai, is notable for the water hyacinth (Eichhornia crassipes) plants that grows and accumulates along a number of river segments. This aquatic weed's dense growth is frequently linked to slow-moving or stagnant water and the presence of excess nutrients, especially phosphorus and nitrogen, which come from urban runoff, household wastewater, and other human activities. The great availability of water hyacinth in the Cooum River therefore gives an opportunity for its systematic collection and exploitation in value-added applications, including the generation of ash for prospective use as a supplementary cementitious ingredient in concrete. Based on the review of literatures, the study aims to collect the locally available water hyacinth plants at Maduravoyal stretch of Coovum river at Chennai, Tamilnadu, India and process it into ashes for investigating its utility as a SCM.

3.0 OBJECTIVE OF THE STUDY

- To study the physical properties and chemical composition of WHA and compare the results with that of OPC.
- To characterise WHA using FESEM and EDS tests and compare it with OPC to understand its potential feasibility for use in concrete production as SCM.

4.0 MATERIALS AND METHODS

Water Hyacinth plants were collected from Coovum river at Maduravoyal, Chennai. The plants were washed to get rid of the mud and other impurities sticking on to it. They were sun-dried for 3 to 5 days and then incinerated at a temperature of 650 degree Celsius. The ash obtained was sieved through 90 micron sieve to obtain the final product, WHA. Ordinary Portland Cement (OPC 53) was taken up for comparison. The cement satisfies IS 12269:2013[22] criteria for 53 Grade OPC.

5.0 RESULTS AND DISCUSSION

PHYSICAL PROPERTIES

The physical characteristics of OPC and WHA—such as standard consistency, setting time, fineness, soundness, specific gravity were assessed. The physical properties were tested as per IS 4031:1988[23] and checked with the requirements as per IS 269:2015[24].

Table 1. Physical properties of Ordinary Portland Cement and Water Hyacinth Ash

Property	Cement	WHA
Color	Grey	Grey
Specific Gravity	3.137	1.97
Consistency(%)	30	30
Setting Time - Initial	30 min	65
Setting Time - Final	267	315
Bulk Density(kg/m3)	1438	1352
Fineness(m2/kg)	339	368
Particle Size	<90 µm	<90 µm

The physical properties of cement and water hyacinth ash (WHA) are compared in the above table 1. WHA has a specific gravity of 1.97, which is significantly lower than that of cement (3.137), suggesting that it is a lighter material and can help lower the binder's unit weight. The standard consistency values for both cement and WHA are reported as 30%, indicating comparable water requirements under the test conditions. However, WHA shows a longer setting time: its initial setting time is 65 min, versus 30 min for cement, and its final setting time rises from 267 min for cement to 315 min for WHA. This delayed setting behaviour may be explained by the lower cementitious reactivity of WHA relative to ordinary cement and by the presence of unburnt or less-reactive constituents within the ash.

WHA is comparatively light, as seen by its bulk density of 1352 kg/m³, which is less than the cement value of 1438 kg/m³. WHA has a fineness of 368 m²/kg, which is greater than the cement's 339 m²/kg measurement. The study made by Sukarni[27] depict identitical properties of WHA. The WHA has been processed to a relatively fine size appropriate for use as an additional cementitious material because both materials have identical characteristics. Although WHA's overall contribution to strength will also rely on its chemical composition, silica concentration, loss on ignition, and level of pozzolanic activity, its finer fineness may offer more surface area for pozzolanic processes. Overall, the findings indicate that WHA has higher fineness, longer setting periods, and lower specific gravity and bulk density than cement—qualities that should be taken into account when figuring out the ideal WHA replacement level in concrete.

CHEMICAL COMPOSITION

Table 2. Chemical composition of cement and water hyacinth ash

Chemical Compound	CaO	SiO_2	Al_2O_3	MgO	SO_3	Fe_2O_3	K_2O	LOI (Loss of Ignition.)

Chemical Compound	**CaO**	**SiO_2**	**Al_2O_3**	**MgO**	**SO_3**	**Fe_2O_3**	**K_2O**	**LOI (Loss of Ignition.)**
WHA	30.7	36.4	15.8	1.61	0.82	10.7	2.1	1.2
OPC	62.5	20.2	4.5	3.2	2.7	4.2	0.8	1.9

The chemical composition of water hyacinth ash (WHA) and ordinary Portland cement (OPC) tested as per IS 4032:1985[25] and reported in terms of their principal oxide constituents, are provided in Table 2. WHA is mainly made up of SiO_2 (36.4%), CaO (30.7%), and Al_2O_3 (15.8%), with Fe_2O_3 (10.7%). By contrast, OPC is primarily composed of CaO (62.5%), followed by SiO_2 (20.2%), Al_2O_3 (4.5%), Fe_2O_3 (4.2%), and MgO (3.2%). The comparatively high SiO_2 and Al_2O_3 levels in WHA suggest the existence of substantial silica- and alumina-containing phases, which may support its potential pozzolanic activity. The combined proportion of SiO_2 + Al_2O_3 + Fe_2O_3 in WHA is about 62.9%, whereas the corresponding figure for OPC is about 28.9%. Nevertheless, chemical composition by itself is not adequate to confirm pozzolanicity, because the reactivity of these oxides is highly dependent on their amorphous fraction, mineralogical properties, fineness, and processing conditions. The CaO content of WHA (30.7%) is markedly higher than that typically reported for purely siliceous pozzolanic materials. This comparatively elevated calcium level may promote the generation of additional cementitious hydration products when WHA is used within cementitious systems. Even so, the lower CaO content of WHA relative to OPC suggests that substituting part of the OPC with WHA will alter the binder's overall chemical composition and hydration behaviour. The LOI of WHA is 1.2%, a value that is relatively low and indicates that the ash contains only a small amount of residual organic matter, unburnt carbon, or other volatile components following the selected ash-production process. The LOI of OPC is 1.9%. WHA's low LOI is advantageous for its possible application as a supplementary cementitious material; however, its suitability should be judged in light of physical properties, mineralogical composition, and strength activity. The chemical composition of WHA reported by several authors has been compared by García et al. [11]. All the results show that the oxide composition of WHA contains substantial quantities of silica, alumina, and iron oxides, along with a significant proportion of calcium oxide. These features justify the further study of WHA as a supplementary cementitious material for concrete.

MICROSTRUCTURAL STUDY

Characterizing SCMs by microstructural studies is crucial for elucidating their surface morphology, microstructure & grain analysis and elemental composition. WHA was subjected to FESEM and EDS tests. Collectively, these methods yield complementary insights that support evaluating the potential reactivity and overall suitability of WHA as a supplementary cementitious material.

FESEM AND EDS

The surface morphology and microstructural features of WHA were investigated at different magnifications using FESEM. An SCM's specific surface area, water requirement, dispersion, and interaction with the cementitious matrix can all be influenced by its shape and surface properties. FESEM analysis gives useful information to assess these features and also, their possible influence on hydration products, pore structure, CSH formation in WHA concrete. Energy-dispersive X-ray spectroscopy (EDS) is often linked with FESEM and is used to identify the elemental composition of the sample. The constituent elements release distinctive X-rays when the electron beam interacts with the specimen, enabling their qualitative and quantitative identification.

Table 3. EDS results of WHA

Element	% by weight
Oxygen	35.5
Carbon	26.2
Chlorine	6.8
Silica	6.4
Potassium	6.2
Calcium	4.9
Sodium	2.9
Aluminium	2.8
Iron	2.6
Sulphur	2.3
Magnesium	1.9
Phosphorus	1.5

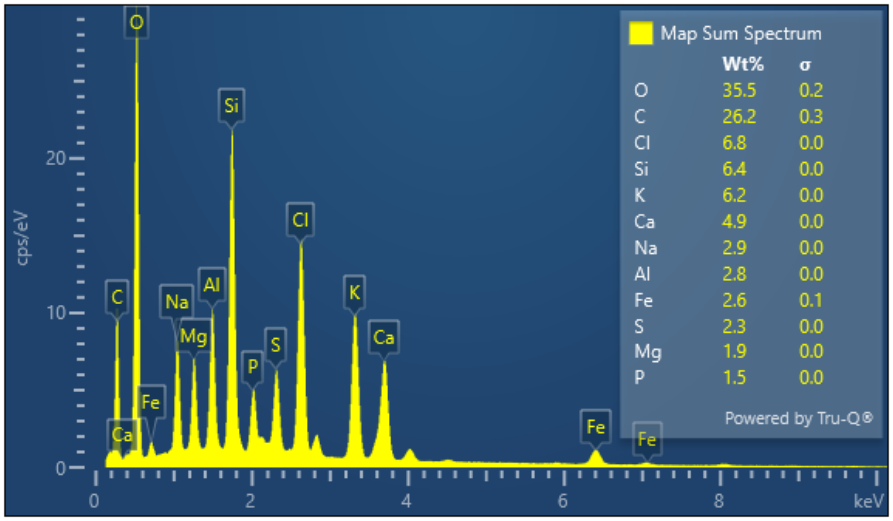


Fig. 1 EDS results of WHA

EDS results of WHA is presented in table 3 and fig.1. The chemical constituents in WH are dominated by carbon (C) and oxygen (O)[26]. The residual carbonaceous materials from the combustion process may be responsible for the carbon content, the relatively high oxygen content is linked to the oxide phases found in the ash. Silicon (6.4%), calcium (4.9%), potassium (6.2%), and aluminum (2.8 %) are among the elements found in WHA that are frequently linked to cementitious and pozzolanic products. Silica is especially important because silica-containing phases can take part in pozzolanic processes when calcium hydroxide and water are present, which helps create more calcium silicate hydrate (C–S–H) gel. Calcium (4.9%) may contribute to the production of calcium-bearing hydration products, while aluminum (2.8.%) can participate in the formation of calcium aluminosilicate hydrate and other alumina-containing reaction products. WHA's potassium level suggests that it contains alkali-bearing mineral phases, which are typical of ashes formed from plants. There were also trace amounts of magnesium , phosphorus, iron, sulfur and sodium. These elements are often connected with the mineral nutrients received by the water hyacinth plants during its growth and subsequently concentrated during the ash-forming process. The detection of chlorine is connected to the absorption of compounds containing chloride from the original biomass or the aquatic environment. The results are in line with the elemental composition of WHA done by Murugesh et, al.[27].

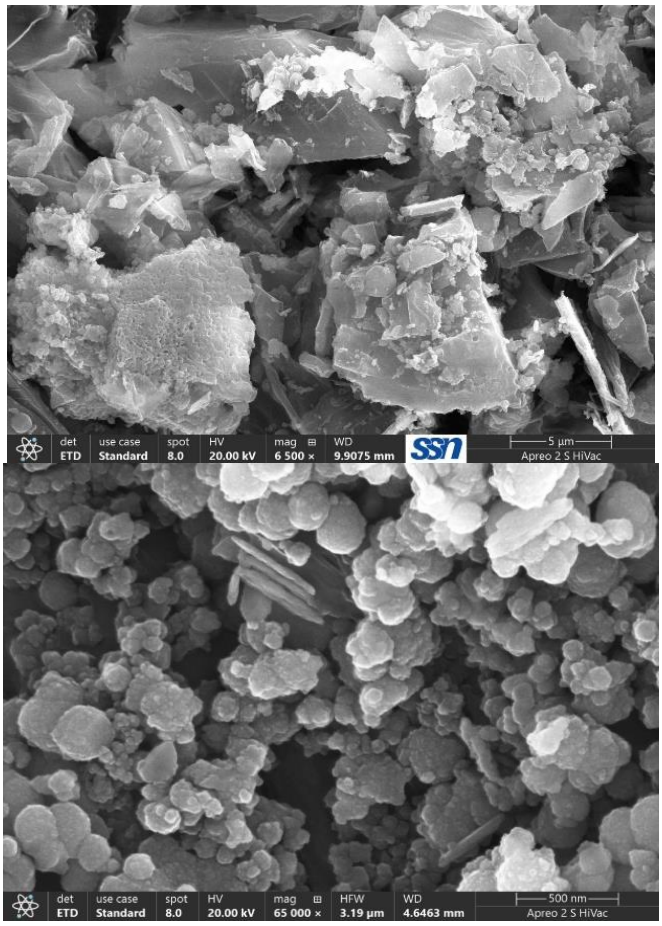


Fig. 2. FESEM images of Water Hyacinth Ash

The figure 2 above displays a heterogeneous surface made up of broken micro-scale particles and enormous, asymmetrical, piled structures that resemble sheets or flakes. A high surface area and porous matrix appropriate for active surface sites are indicated by the sheet-like structures' and noticeable interstitial voids. The images at different magnifications show that WHA is porous and mainly contains angular particles of irregular shape and rough texture, with a few spherical particles having smooth surfaces similar to the OPC[29 Makhlouf]. The figure reveals precise nanoscale surface details where spherical/quasi-spherical nanoparticles and clusters are attached across the base matrix. A highly rough nanoscale architecture and composite production are confirmed by strong aggregation into nodular cluster networks with visible rod-like or elongated nanostructures scattered throughout the matrix. Compared to the densely packed, angular clinker remnants of unhydrated or partially hydrated OPC, this layered architecture allows for improved porosity and accessibility. Quasi-spherical nano-agglomerates provide plenty of surface sites for the precipitation of calcium silicate hydrate gel, which speeds up early-age nucleation. Because of its exposed step-edges and high surface energy, the exfoliated, flake-like/sheet-like base matrix can react with free calcium hydroxide produced during OPC hydration to form secondary binder gel C-S-H.

6.0 CONCLUSION

The physical properties and chemical composition of WHA prove its similarity with OPC. The results obtained are further supported by output of FESEM and EDS tests . EDS analysis confirms the presence of compounds of silica, calcium and aluminium – the major elements responsible for setting, hydration, binding, hardening and strength development in concrete. In cementitious composite systems, SCM performance depends greatly on particle size distribution, morphological characteristics, and surface area. A hierarchical structure made up of exfoliated micro-sheets adorned with evenly distributed quasi-spherical

nanoparticles is confirmed by the high-magnification images of FESEM analysis. The morphological characteristics imply that WHA has advantageous microstructural characteristics for use as a nano-pozzolanic additive or high-reactivity Supplementary Cementitious Material (SCM).

Despite the benefits, WHA also has some limitations. When WHA substitutes cement by mass, the volumetric proportions of concrete may change due to the decreased specific gravity and bulk density. For concrete to maintain the essential workability, density, and strength, appropriate mix-design modifications are therefore required. WHA's fineness is lower than that of OPC's. If the ash is sufficiently reactive, its enhanced fineness can enhance particle packing and possibly stimulate reactions. However, pozzolanic activity cannot be established by fineness alone. Slower setting characteristics compared to OPC are indicated by the longer setting time results. As a result, adding WHA may postpone concrete's early strength development and setting, which could have an impact on construction timelines and formwork removal. However, because it depends on the replacement proportion and interactions between WHA and cement, the setting behaviour of the blended cement needs to be confirmed experimentally. The presence of carbon, oxygen, chlorine and potassium elements in EDS analysis proves to be a limiting factor, but silica, calcium and aluminium is the major supporting factor.

Overall, WHA can be regarded as a viable option for partially substituting cement as an SCM based on the physical, chemical, mineralogical and microstructural characterisation. By lowering reliance on traditional cement and transforming an invasive aquatic biomass into a valuable building material, its application provides an additional environmental benefit and aligns with the concept of sustainable construction.

The further scope of the study will be to replace cement in concrete with WHA and carry out the experimental investigations related to workability, mechanical strength properties such as compressive strength, tensile strength and serviceability aspects like durability. This will reveal the potential of WHA as an SCM in commercial concrete production and also could contribute to reduced CO_2 emission.

7.0 REFERENCES

1. S. Mishra, N.A. Siddiqui, A Review On Environmental and Health Impacts Of Cement Manufacturing Emissions, 2(3), 26-31, 2014.
2. Alobaydy, O. (2024). Impacts of Cement Production on the Environment with Practical Solutions: A critical review. *J. Res. Technol. Eng*, *2*, 12-27.
3. M.S. A. Doaa, An assessment to the oligopoly cement industry in Egypt: is it a curse or a blessing? Int. J. Green Econ, 11(1), 41–61, 2017.
4. EM. Nigri, S. Denise, F. Rocha, ER. Filho, Portland cement : an application of life cycle assessment, Prod Management Development, 8, 167–172, 2010.
5. Amalina, F., Abd Razak, A. S., Krishnan, S., Zularisam, A. W., & Nasrullah, M. (2022). Water hyacinth (Eichhornia crassipes) for organic contaminants removal in water–A review. *Journal of Hazardous Materials Advances*, *7*, 100092.
6. Ayanda, O. I., Ajayi, T., & Asuwaju, F. P. (2020). Eichhornia crassipes (Mart.) Solms: Uses, challenges, threats, and prospects. *The Scientific World Journal*, *2020*(1), 3452172.
7. Lai, K. C., Lee, L. Y., Hiew, B. Y. Z., Yang, T. C. K., Pan, G. T., Thangalazhy-Gopakumar, S., & Gan, S. (2020). Utilisation of eco-friendly and low cost 3D graphene-based composite for treatment of aqueous Reactive Black 5 dye: Characterisation, adsorption mechanism and recyclability studies. *Journal of the Taiwan Institute of Chemical Engineers*, *114*, 57-66.
8. Ratnani, R. D., Arianti, F. D., & Sasongko, N. A. (2024). Exploring the potential of water hyacinth weed (Pontederia crassipes) as an environmentally friendly antifungal to realize sustainable development in lakes: A review. Case Studies in Chemical and Environmental Engineering, 9, 100702.
9. Ahmad, M. M., Alam, M. T., & Naaz, S. (2025). Water Hyacinth is A Potential Aquatic Plant Used in Water Treatment: A Short Review. Sch Acad J Biosci, 7, 898-907. DOI:

10. Nandiyanto, A. B. D., Ragadhita, R., Hofifah, S. N., Al Husaeni, D. F., Al Husaeni, D. N., Fiandini, M., ... & Aziz, M. (2024). Progress in the utilization of water hyacinth as effective biomass material. Environment, Development and Sustainability, 26(10), 24521-24568.
11. García, G., Cabrera, R., Rolón, J., & Pichardo, R. (2025). Recycling water hyacinth as supplementary cementitious material, admixture, and fiber in mortar and concrete: current trends and research gaps. *Recycling*, 10(1), 18.
12. Goel, G., & Kalamdhad, A. S. (2018). A practical proposal for utilisation of water hyacinth: Recycling in fired bricks. *Journal of Cleaner Production*, 190, 261-271. Doi:
13. Mondal, M. S., Hussain, S. Z., Roy, P., & Halder, C. (2023). Development of high-performance composite via innovative route using water hyacinth extracted nanocellulose and analysis of its physical properties. *Heliyon*, 9(12).
14. Niyasom, S., & Tangboriboon, N. (2021). Development of biomaterial fillers using eggshells, water hyacinth fibers, and banana fibers for green concrete construction. *Construction and Building Materials*, 283, 122627. https://doi.org/10.1016/j.conbuildmat.2021.122627.
15. Okwadha, G. D. O., & Makomele, D. M. (2018). Evaluation of water hyacinth extract as an admixture in concrete production. *JDOI: Journal of Building Engineering*, 16, 129-133.
16. Boban, J. M., Nair, P. V., Shiji, S. T., & Cherian, S. E. (2017). Incorporation of water hyacinth in concrete. *Int J Eng Res Technol*, 6.
17. Srisawas, M., Kerdkaew, T., & Chanlert, P. (2024). From invasive species to bio-based composites: utilizing water hyacinth for sound absorption and insulation. *Industrial Crops and Products*, 220, 119242.
18. Bayu Zeleke, T., Soeprobowati, T. R., Adissu, S., & Warsito, B. (2025). Analysing the effect of water hyacinth (*Eichhornia crassipes*) invasion on water quality and trophic state of Lake Tana. *Chemistry and Ecology*, *41*(3), 297–313.
19. Iswariya et al. 2024. "Water Hyacinth: an Overview", Asian Journal of Science and Technology, 15, (08), 13083-13087.
20. Rezania, S., Ponraj, M., Talaiekhozani, A., Mohamad, S. E., Din, M. F. M., Taib, S. M., ... & Sairan, F. M. (2015). Perspectives of phytoremediation using water hyacinth for removal of heavy metals, organic and inorganic pollutants in wastewater. *Journal of environmental management*, *163*, 125-133.
21. Murugesh, V., Devi, S. K., Unni, P. M., Hemalatha, S., & Venugopalan, V. (2023). Chemical properties of water hyancinth plant ash. Journal of Advanced Zoology , ISSN: 0253-7214, Volume 44 Issue 03 Year 2023 Page 539:545
22. Bureau of Indian Standards. (2015). *Ordinary Portland cement, 53 grade—Specification (IS 12269:2015).* Bureau of Indian Standards.
23. Bureau of Indian Standards. (1988). *Methods of physical tests for hydraulic cement (IS 4031:1988).* Bureau of Indian Standards.
24. Bureau of Indian Standards. (2015). *Ordinary Portland cement—Specification (IS 269:2015).* Bureau of Indian Standards.
25. Bureau of Indian Standards. (1985). *Methods of chemical analysis of hydraulic cement (IS 4031:1985).* Bureau of Indian Standards.
26. Sukarni, S., Zakaria, Y., Sumarli, S., Wulandari, R., Ayu Permanasari, A., & Suhermanto, M. (2019, April). Physical and chemical properties of water hyacinth (Eichhornia crassipes) as a sustainable biofuel feedstock. In *IOP Conference Series: Materials Science and Engineering* (Vol. 515, No. 1, p. 012070). IOP Publishing.
27. Murugesh, V. (2021). Chemical Analysis of Water Hyacinth Ash by XRD and SEM. *Indian Journal of Advanced Botany (IJAB)*, *1*(1), 8-10.
28. Makhlouf, A. A. A. H. (2002). Application of water hyacinth ash as a partial replacement for cement [Doctoral dissertation, Cairo University].