Experimental Investigation of Water Hyacinth Ash as the Partial Replacement of Cement Using Alkaline Activators in Concrete

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Abstract: - Cement production is a major contributor to greenhouse gas emissions and global warming. The primary source of emissions is the chemical reaction that takes place during the production of clinker, the key ingredient in cement, which releases large amounts of carbon dioxide (CO2). In addition, the transportation and use of cement also results in emissions. To mitigate the environmental impact of cement, efforts are being made to reduce emissions in cement production, increase the use of alternative and lower-carbon materials, and promote the use of more efficient and sustainable building practices. Cement is a significant contributor to greenhouse gas emissions and global warming, so there is a growing interest in finding alternative materials that can reduce its environmental impact. Some of the most promising substitutes for cement include Fly ash, Ground granulated blast furnace slag (GGBS), Rice husk ash and Silica fume e.t.c. The study investigated the use of water hyacinth ash of 0%, 10%, 20% & 30% as a partial replacement for cement in concrete with the addition of alkaline activator of NAOH with different molarities in concrete such as 2, 4, 6 and 8. The aim was to determine the effect of the replacement on the mechanical properties of concrete. Expecting the results will show that the replacement of cement with water hyacinth ash improved the compressive strength and durability of concrete, with the addition of alkaline activators having a significant effect on the properties. This study highlights the potential of water hyacinth ash as a sustainable alternative in concrete production and the importance of alkaline activators in improving the performance of concrete.

Keywords: *Water hyacinth ash, Partial replacement, Cement, Alkaline activators, Concrete, Mechanical properties, Compressive strength, Durability, Sustainable alternative, Performance improvement.*

1. Introduction

Concrete is a crucial material in construction for several reasons: Durability: Concrete is a strong and durable material that can withstand harsh weather conditions and heavy loads, making it suitable for a wide range of structures, from buildings to bridges and roads. Versatility: Concrete can be molded into various shapes and sizes, making it a versatile material for construction. It can be used for flooring, walls, columns, beams, and many other structural elements. Cost-effectiveness: Concrete is a relatively inexpensive material compared to other construction materials, making it a cost-effective solution for many construction projects. Fire resistance: Concrete is naturally fire-resistant, making it a safe material for building structures in areas prone to fires. Sustainability: Concrete can be made using recycled materials, such as fly ash and slag, and can also be recycled at the end of its useful life, making it a sustainable material for construction. In conclusion, concrete is an essential material in construction due to its strength, versatility, cost-effectiveness, fire resistance, and sustainability.

Cement is a critical component of global construction and is used as a binding material in the production of concrete. Its importance lies in its ability to provide strength, durability, and stability to buildings, roads, bridges, and other structures. Cement is versatile, inexpensive, and readily available, making it a popular choice for construction projects around the world. Additionally, cement production has a significant impact on the global economy and provides employment opportunities in many countries. Overall, cement plays a crucial role in shaping the built environment and supporting the infrastructure that drives modern society.

1.1 Water Hyacinth

Water hyacinth is an aquatic plant species native to South America. It is an invasive species in many parts of the world and is considered one of the worst aquatic weeds. Water hyacinth can grow rapidly and form dense mats on the surface of waterways, hindering water flow, reducing light penetration and oxygen levels, and altering aquatic habitats. The plant also has negative impacts on fishing, recreation, and water-based industries. On the positive side, water hyacinth has been used for various purposes, including as a source of biofuel, animal feed, and bioremediation. Efforts to control water hyacinth populations and prevent further spread are ongoing in many areas.

Fig 1: Water Hyacinth plants

Fig 2: Water Hyacinth Ash

1.2 Water Hyacinth Ash

Water hyacinth ash is a byproduct produced when water hyacinth is burned as a source of fuel. The ash contains a high amount of silica and other minerals, making it useful for various industrial and agricultural applications. Some of the uses of water hyacinth ash include:

- Fertilizer: The ash can be used as a source of nutrients for crops and can improve soil fertility.
- Construction material: Water hyacinth ash can be used as a substitute for cement in the production of concrete and other construction materials.
- Raw material for ceramics: The high silica content of water hyacinth ash makes it a suitable raw material for the production of ceramics and other refractory materials.
- Filtering material: Water hyacinth ash can be used as a filtering material to remove impurities from water and other liquids.
- Pest control: The ash can be used as a natural pesticide to control pests in agriculture

Water hyacinth ash can be used as a partial replacement for cement in concrete production. The ash contains silica, which can react with calcium hydroxide to form compounds that enhance the strength and durability of concrete. Additionally, the use of water hyacinth ash in concrete can reduce the amount of cement required, potentially reducing the carbon footprint of concrete production and the overall cost of construction.

However, it is important to note that the quality and properties of water hyacinth ash can vary depending on the source and the burning conditions. Therefore, careful testing and evaluation of the ash should be performed before it is used in concrete production. Additionally, the ash should be processed to remove impurities and ensure that it meets the relevant standards and specifications for use in construction.

Cement is an essential component in concrete, but its production is a major contributor to greenhouse gas emissions and environmental degradation. To address these concerns, researchers have been exploring alternative materials that can replace cement while maintaining the performance and durability of concrete.

One such alternative is water hyacinth ash, which is a byproduct of the burning of water hyacinth, a common aquatic plant. The ash can be used as a partial replacement for cement in concrete, and its addition has been shown to improve the strength and durability of the material.

However, simply adding water hyacinth ash to concrete is not enough to realize its full potential. To further improve the performance of concrete made with water hyacinth ash, researchers have been experimenting with the addition of alkaline activators. Alkaline activators can enhance the reaction between the water hyacinth ash and the other components of concrete, leading to improved strength and durability.

In this study, an experimental investigation was carried out to determine the effect of using water hyacinth ash as a partial replacement for cement in concrete with the addition of alkaline activators. The results of this investigation will provide valuable insights into the potential of water hyacinth ash as a sustainable alternative to cement in concrete production

1.3 Alkaline Activators

Alkaline activators are substances used to enhance the reaction between cement and water in the production of concrete. The activators increase the alkalinity of the mixture, which accelerates the hydration of the cement and results in improved strength and durability of the concrete. Alkaline activators are typically added in small amounts to the concrete mixture, and the most commonly used activators are sodium hydroxide, potassium hydroxide, and sodium silicate.
Alkaline activators can also improve the workability and plasticity of concrete, making it easier to place and finish. They can also increase the resistance of concrete to chemical attack and weathering, and improve the durability of concrete in harsh environments.
However, the use of alkaline activators can also have some disadvantages, such as increased shrinkage and cracking, and the potential for corrosion of reinforcing steel in the concrete. It is important to use the correct type and amount of activator to ensure the optimal performance of the concrete.
The different types of alkaline activators used in concrete production include:

- Sodium Hydroxide (NaOH): A strong base commonly used as an alkaline activator in concrete.
- Potassium Hydroxide (KOH): A strong base similar to sodium hydroxide, but with a different effect on the properties of concrete.
- Sodium Silicate (Na_2SiO_3): A sodium-based compound commonly used as an alkaline activator in concrete, often in combination with other activators.
- Sodium Carbonate (Na_2CO_3): A sodium-based compound used as an alkaline activator in concrete, with a lower pH than sodium hydroxide or potassium hydroxide.
- Sodium Gluconate: A naturally occurring compound that is used as an alkaline activator in concrete, and is often used in eco-friendly or sustainable concrete production.
- Potassium Carbonate (K_2CO_3): A potassium-based compound used as an alkaline activator in concrete, with a lower pH than potassium hydroxide.

Fig 3: Alkaline Activators of NAOH and NA_2SIO_3

1.4 Scope of work:

The scope of research into water hyacinth ash as a partial replacement of cement using alkaline activators in concrete is as follows:

- Material selection: The focus of this research is to evaluate the suitability of water hyacinth ash as a partial replacement for cement in concrete.
- Alkaline activators: The study will investigate the role of alkaline activators in enhancing the performance of concrete made with water hyacinth ash as a partial replacement for cement.
- Performance evaluation: The research will focus on evaluating the physical and mechanical properties of concrete made with water hyacinth ash and alkaline activators, including compressive strength, tensile strength, and durability.
- Comparative analysis: The study will compare the performance of concrete made with water hyacinth ash and alkaline activators to that of conventional concrete made with cement only.
- Applications: The research will investigate the potential applications of concrete made with water hyacinth ash and alkaline activators, including the suitability of this material for various construction projects.

In conclusion, the scope of research into water hyacinth ash as a partial replacement of cement using alkaline activators in concrete covers the selection of materials, the role of alkaline activators, performance evaluation, comparative analysis, and potential applications of the resulting concrete

2. Literature review

Water Hyacinth as Renewable Energy Source

Jafari, N.(2010) reported that through water hyacinth‟s engulfing presence, large amounts of sunlight are blocked, thorough oxygen exchange is prevented and dissolved oxygen levels drop, the food web is altered, habitat for water fowl and other organisms is either destroyed or changed, and the biological diversity of the invaded area is greatly reduced. Water hyacinth can be a problem economically as it negatively affects fisheries, slows or even prevents water traffic, impedes irrigation, reduces the water supply, obstructs water ways, and slows hydropower generation.

Mahamadi C (2020), investigated the potential of water hyacinth in producing biogas. It also focused on comparing the biogas output from dry and fresh water hyacinth. The wet mass of WH in Lake Chivero was found to be 197 400 tons/yr. and the dry mass was 23 688 tons/yr. Experimental analysis gave a Water Hyacinth Total Solids of 10% and a Volatile Solids of 89.13%. Laboratory experiments showed that 1kg of WH yields 12.1 liters of biogas and a potential yield of 1681.08m3 /day which in turn yields 573 248.28 m3 /yr. The potential biogas obtainable would benefit 934 households and has an electrical generation potential of 87.56kW.The digester volume required was computed to be 10 419.90 m3.

Mbugua, M, et al. (2014) said that an anaerobic process can be used to produce biogas from the water hyacinth, although in small scale the weed needs to be mixed with other substrates. On a larger scale water hyacinth can be used alone. reported that some problems with digestion of water hyacinths are primarily low efficiency due to the plants very large water content and costly pre-treatment processes of plant tissue in order to reduce entrapped air.

Murugesh, V, and N Balasundaram (2023) On paper, water hyacinths can be considered as feasible substrate to produce ethanol fuel due to their amount of crude protein and hemicellulose unfortunately the process of fermenting the sugars to alcohol is not as effective as initially hoped when using water hyacinths and this utilization area is only recommended when there is high demand for ethanol as liquid fuel.

Composting water hyacinths is a good and feasible way of using harvested plants, especially in developing countries. Composting is a well-known low budget option for improving crop yields and can be carried out by mixing dried water hyacinths with soil, ash and organic municipal waste (PACE, 2013). This is also an advantageous way of disposing water hyacinths because the ability to reproduce is lost as it passes the stomach of earthworms.

Renewable Materials as Partial Cement Replacement

Water hyacinth is one of the most aggressive enemies of water courses and water life. The governmental authorities used to collect the plant mechanically and burn it in the open air. This method is considered the less harmful one to the adjacent life; however, it participates significantly to air pollution. A research conducted by Ahmed, Makhlou, Hodhod, and El-Sayed (n.d.), (2011) includes a study of the pozzolanic and chemical properties of WHA, and an experimental comparative study of the mechanical properties of mortar and concrete containing WHA with different replacement ratios as well as a reference ratio of silica fume. Scanning electron microscope and x-ray spectrum analysis were used to identify the structure of concrete. Also, the dissertation includes an experimental study of durability of WHA concrete. The dissertation concludes that water hyacinth ash improves the mechanical properties and durability of concrete.

Based from the study conducted by Raheem and Sulaiman (2013), the results showed that the density of sandcrete blocks decreases as the Saw Dust Ash increases but increases as the curing days increase. Also, the compressive strength of sandcrete blocks increases as the curing age increases but decreases as the SDA content increases. Only up to 10% SDA replacement is adequate for use in sandcrete hollow blocks for non-load bearing walls in buildings.

It was reported in the study conducted by Utsev (2012) that the compressive strength decreases with increase in percentage replacement of OPC with Coconut Shell Ash. In conclusion, the study reveals that 10% to 15% partial replacement of OPC with CSA using W/C ratio of 0.5 are suitable for production of both heavy weight and light weight concrete.

From the investigations carried out in the study by Obilade and Taku (2014), the following conclusions showed that the optimum addition of saw dust ash (SDA) as partial replacement for cement is in the range 0-15%. It also showed that the compacting factor values of the concrete reduced as the percentage of SDA increased. The bulk densities of concrete reduced as the percentage SDA replacement increased and the compressive strengths of concrete reduced as the percentage SDA replacement increased. This investigation reveals that there is a promising potential for the use of palm oil fuel ash as partial cement replacement in oil palm shell lightweight aggregate concrete production. Replacement of palm oil fuel ash which is around 20% would be able to produce lightweight concrete suitable for structural application (Muthusamy and Nur Azzimah, 2014).

According to Pitroda et al. (2012), the compressive strength reduces when cement is replaced with fly ash. As fly ash percentage increases compressive strength and split strength decreases. The use of fly ash in concrete can save the coal & thermal industry disposal costs and produce a „greener" concrete for construction. The cost analysis indicates that percent cement reduction decreases cost of concrete, but at the same time strength also decreases. This research concludes that fly ash can be innovative supplementary cementitious construction material but judicious decisions are to be taken by engineers.

Chemical Composition of WHA and Its Effect in Cement

In a study conducted by Mbugua et al. (2014), Rice Husk Ash Derived Zeolite Blended with Water Hyacinth Ash for Enhanced Adsorption of Cadmium Ions, the capacity and efficacy of water hyacinth ash (WHA) insoluble residue (WHAR) and rice husk ash (RHA) were used to remove cadmium ions and methylene blue from contaminated water. From the table shown below, WHA had 35.8% of K2O followed by 27% of CaO and Cl at 21% hence serving as a good source of KOH base. Based from the XRF analysis of WHA, it contains more than 20% CaO which meets the required lime content of Class C fly ash.

COMPOUND	Al_2O_3	P_2O_5	Cl	K_2O	CaO	MnO	Fe_2O_3	ZnO
% OXIDE	1%	6.0%	21%	35.8%	27%	7.1%	1.8%	0.2%

High-calcium fly ashes (> 20% CaO) may be produced from lignite or sub- bituminous coals and are comprised of calcium-alumino-silicate glass and a wide variety of crystalline phases in addition to those found in low-calcium fly ash. Some of these crystalline phases will react with water and this, coupled with the more reactive nature of the calcium-bearing glass, makes these fly ashes react more rapidly than low-calcium fly ashes and renders the fly ash both pozzolanic and hydraulic in nature. These fly ashes will react and harden when mixed with water due to the formation of cementitious hydration products. Class C fly ash is produced from lignite or sub-bituminous coal as required in ASTM C311 (Thomas, n.d.).

The study of Minocha Ak et. al., (n.d.), concurs with the findings of this study, showing that Cadmium increased the compressive strength at different intervals of time to an appreciable extent as the concentration increased. Different concentration of added Cadmium ions increased the bulk density values and it is found directly proportional to the added Cadmium ions.

According to Gunnarson and Peterson (2007) as cited by the Food and Agriculture Organization of the United Nations, in a review that covered water hyacinth collected from various sources, also reported levels of some other components: hemicellulose 22-43.3%; cellulose 17.8-31%; lignin 7-26.36%; and magnesium 0.17%.

CaO also known as lime and known as one of the four major oxide composition (60-67%) which secure the sand and water together. When CaO is mixed with water, it forms calcium hydroxide that reacts faster with carbon dioxide, producing a mortar that hardens more quickly. It is the major constituent of cement that controls the strength and soundness where exact proportion is important. The right proportion makes cement sound and strong otherwise making the cement unsound and causing the cement to expand and disintegrate. In case of deficiency, the strength of cement is decreased and cement sets quickly. The other two are K2O and chlorine where chlorine dissolves when mixed with water while alkali oxides where K2O belong, amount should not exceed 1% because it leads to the failure of concrete made from that cement.

3. Research significance

The significance of research into water hyacinth ash as a partial replacement for cement in concrete with the addition of alkaline activators lies in the following:

- Environmental impact: Cement production is a major contributor to greenhouse gas emissions and environmental degradation. By exploring alternative materials, such as water hyacinth ash, to replace cement in concrete, researchers are working to reduce the environmental impact of construction.
- Waste utilization: Water hyacinth ash is a byproduct of burning water hyacinth, a common aquatic plant. By using this waste material in construction, researchers are working to find sustainable solutions for waste utilization.
- Improved performance: The addition of water hyacinth ash to concrete has been shown to improve the

strength and durability of the material. By combining water hyacinth ash with alkaline activators, researchers aim to further enhance the performance of concrete made with this material.

- Economic benefits: By reducing the amount of cement required in concrete, the use of water hyacinth ash as a partial replacement has the potential to lower the cost of construction, making it a more affordable option for many projects.

In conclusion, research into water hyacinth ash as a partial replacement for cement in concrete with the addition of alkaline activators is important because it has the potential to reduce the environmental impact of construction, utilize waste materials, improve the performance of concrete, and provide economic benefits.

4. The objective of current study

The objectives of the experimental investigation of water hyacinth ash as a partial replacement of cement using alkaline activators in concrete are as follows:

1. To evaluate the suitability of water hyacinth ash as a partial replacement for cement in concrete.
2. To determine the optimal combination of water hyacinth ash and alkaline activators that enhances the performance of concrete of 0%, 10%, 20% & 30% as a partial replacement for cement in concrete with the addition of alkaline activator of NAOH with different molarities in concrete such as 2, 4, 6 and 8.
3. To assess the physical and mechanical properties of concrete of grade M-25 made with water hyacinth ash and alkaline activators, including compressive strength, tensile strength, and durability.
4. To compare the performance of concrete made with water hyacinth ash and alkaline activators to that of conventional concrete made with cement only.
5. To investigate the potential applications of concrete made with water hyacinth ash and alkaline activators, including the suitability of this material for various construction projects.
6. To reduce the environmental impact of construction by reducing the use of cement and finding a sustainable solution for waste utilization through the use of water hyacinth ash.

5. Methodology

The methodology for investigating water hyacinth ash as a partial replacement of cement using alkaline activators in concrete can be broken down into several steps:

- Material preparation: Water hyacinth ash will be collected, dried, and ground to a fine powder to prepare the material for use in concrete. Alkaline activator NAOH will also be prepared according to specified ratios with different molarities in concrete such as 2, 4, 6 and 8.
- Mix design: M-25 Concrete mixtures will be designed with varying ratios of water hyacinth ash and alkaline activators, and with a constant water-cement ratio. The mixtures will be thoroughly mixed to ensure homogeneity.
- Casting and curing: Concrete specimens will be cast and allowed to cure for specified periods, according to standard curing procedures.
- Testing: Physical and mechanical properties of the concrete specimens will be tested using standard tests, including compressive strength, tensile strength, and durability tests.
- Result analysis: The data obtained from the testing will be analyzed to determine the optimal combination of water hyacinth ash and alkaline activators that enhances the performance of concrete.
- Comparison with conventional concrete: The results of the study will be compared to those of conventional concrete made with cement only to determine the effectiveness of water hyacinth ash and alkaline activators as a partial replacement for cement.

In conclusion, the methodology for investigating water hyacinth ash as a partial replacement of cement using alkaline activators in concrete involves material preparation, mix design, casting and curing, testing, data analysis, and comparison with conventional concrete.

6. RESULTS AND DISCUSSIONS

Table 1 Properties of materials used

Description	Cement	Fine Aggregate	Coarse Aggregate	Water Hyacinth
Specific gravity	3.2	2.58	2.59	2.13
Fineness	4.02	4.6	12 & 20 mm	9
Water absorption	-	4.2%	6%	-

The data depicted in Figure 4 illustrates the relationship between water consistency and the incorporation or substitution of water hyacinth ash (WHA) in cement. The findings suggest that as WHA is introduced, the consistency of the water increases. This observation leads to the conclusion that water hyacinth ash possesses a notable hygroscopic nature.

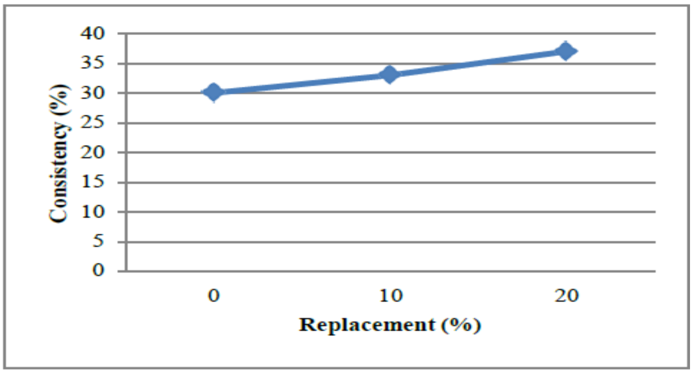

Fig 4: Setting time of cement with various proportions of WHA

Figure 5 delves into the evaluation of setting time across different ratios of water hyacinth ash (WHA) used to replace cement. As the proportion of WHA in the cement mix varies, there is a corresponding increase in the setting time of the cement. This elongation in setting time can be attributed to the absorption capabilities of water hyacinth ash. Notably, a higher mix ratio of WHA leads to a further prolongation of the setting time. The setting time of cement under various WHA proportions is documented in accordance with IS: 8112-1989 standards [13].

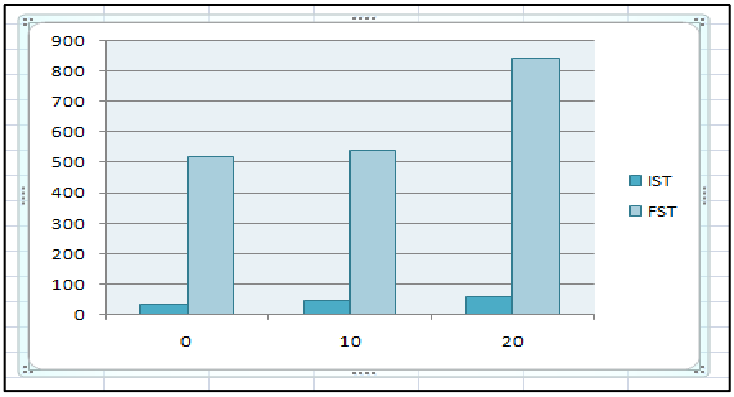

Fig 5: Setting time of cement with various proportions of WHA

Table 2 outlines the workability of concrete across various percentages of water hyacinth ash (WHA) in cement. In the absence of WHA replacement, the concrete exhibits a slump range of 40-45 mm. However, by substituting 10% of the cement weight with WHA, the slump range increases to 90-100 mm. Further, replacing 20% of the cement weight with WHA results in a slump value of approximately 135-140 mm. These slump values indicate that the replaced concrete demonstrates moderate characteristics and offers a high degree of workability.

Table 2 Slump Characteristics of Water Hyacinth Ash

% of Water Hyacinth Ash	Slump (mm)
0	50
10	100
20	150
30	180

Figure 6 illustrates the strength development of concrete cubes over 7, 14, and 28 days, comparing conventional concrete with varying ratios of water hyacinth ash (WHA) replacement in cement. It is noted that as the curing duration increases, so does the strength of the concrete.

In conventional concrete, by the 7th day, it achieves approximately 70-75% of its ultimate strength, reaching around 80-85% by the 14th day, and finally reaching its full strength of 90-100% after 28 days of curing. Conversely, concrete containing water hyacinth ash replacement exhibits slightly lower strength percentages during the same curing periods: around 50-65% strength at 7 days, 65-70% at 14 days, and 72-82% at 28 days.

Comparatively, the strength of concrete with a 10% replacement of WHA surpasses that of conventional concrete, especially noticeable during the 7th and 28th days of curing.

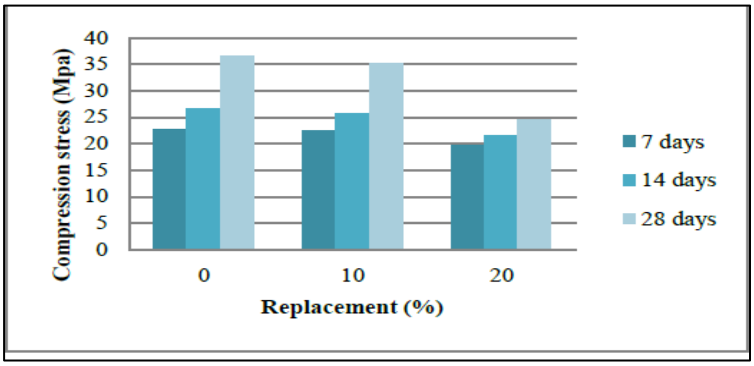

Fig 6: Compression Stress for different replacement of water hyacinth

Figure 7 depicts the fluctuation in split tensile strengths between conventional concrete and concrete cylinders where water hyacinth ash (WHA) replaces cement at various proportions. The findings reveal that the peak strength is achieved when 10% of the cement is replaced by WHA.

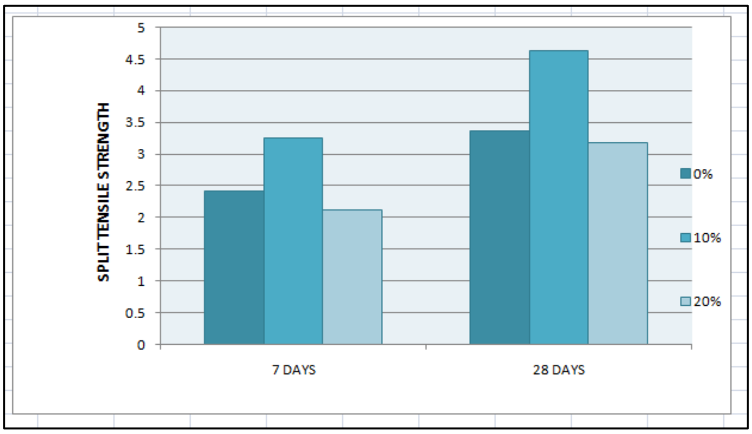

Fig 7: Split tensile Stress for different replacement of water hyacinth

Conclusions

This study aimed to investigate the impact of incorporating water hyacinth ash into cement concrete mixes on the characteristic strength of the concrete. The key findings are as follows:

- The most effective dosage for partially replacing cement with water hyacinth ash is determined to be 10%.
- Beyond this optimal dosage, the compressive strength of the concrete decreases. Specifically, replacing more than 10% of the cement with water hyacinth ash adversely affects the concrete's strength.
- The high absorptive nature of water hyacinth ash leads to an increase in the setting time of the cement.
- Workability of the concrete improves proportionally with the percentage of water hyacinth ash replacement.

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