

EVALUATION OF WATER HYACINTH STEM ASH AS POZZOLANIC MATERIAL FOR USE IN BLENDED CEMENT

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Abstract- In this paper, the potential use of water hyacinth stem ash (WHA) in the partial replacement of cement is studied. WHA was used as a replacement for ordinary Portland cement at 10, 15, 20 and 25 wt. %. To evaluate the pozzolanic activity of WHA, the properties investigated were chemical composition, particle size, soundness, setting time, specific gravity, presence of crystalline matter, compressive strength, water absorption and sorption. Mortar cubes were tested for compressive strength up to the age of 56 days, whereas water absorption and sorption tests are carried out at the age of 28 days. Test results reveal that mortar cubes with 10% WHA substitution for Portland cement produced comparative compressive strength values to control mortar. It was also observed that the use of WHA in Portland cement has reduced water absorption characteristics.

Keywords: Compressive strength, Mortar, Sorptivity, Water absorption, X-ray diffraction

1.0 INTRODUCTION

Over the last few decades, there has been an increasing trend on blending ordinary Portland cement with locally sourced raw materials such as industrial, agricultural or domestic waste [1-3]. Fly ash, blast furnace slag, silica fume, rice husk, oil palm shell, coconut shell, corn cob, tobacco waste, bamboo leaf, sugarcane baggage, groundnut shell, egg shell have already been tested as suitable and dependable alternative materials in cement production due their wide availability and successfully utilized, wherever applicable [4-10]. Amongst these, rice husk, fly ash, blast furnace slag, silica fume and egg shell have proven their effectiveness as partial cement replacement material both in laboratory and practice. The search for a new and viable alternative is important for conservation of natural resources and reduction in the manufacturing cost. It will also solve the disposal problem of these wastes, and hence, helps environmental protection.

Water hyacinth (*Eichhornia crassipes*), an entirely free source of biomass is found unutilized as supplementary cementitious material (SCM) until now. It grows vigorously and richly to produce a large biomass and doubles the population in two weeks (Figure 1). The plant consists of long and fibrous roots which may be up to three meters in length and has fibrous stem. The average length of the fiber is 1.604 mm and the average diameter 5.5 micron [11]. In this work, studies have been carried out to evaluate this bio-waste for the first time as SCM and this will be beneficial for future application of WHA in cement and concrete.



Figure 1: *Water hyacinth*

2.0 MATERIALS AND METHOD

A. *Materials used*

Ordinary Portland cement (OPC) of 43 grade conforming to IS: 8112-2013 [12] was used throughout the investigation. River sand was used as fine aggregate conforming to grading zone III of IS: 383-1970 [13]. The river sand was washed and screened through 1.18 mm sieve to eliminate over size particles.



Figure 2: *Preparation of water hyacinth stem ash (a) initial material, (b) after furnace and (c) after grinding and sieving*

Water hyacinth stems were collected from fresh water hyacinths in local ponds of Kokrajhar District of Assam, India. Stems of water hyacinth were cleaned and cut into small pieces (Figure 2). Then, they were dried in sun and incinerated in electric muffle furnace at a rate of 10°C per min up to 700°C for 6 hours to remove organic matter. After the burning process the ash was allowed to cool completely in the furnace so that it can't absorb atmospheric water. The burned WHA was grounded in a ball mill for 30 minutes and screened through 150μ sieve (as per IS: 1727-1967 [14]) to reach fineness similar to OPC. The particle size distribution of the ash is shown in Figure 4.

B. Physical and chemical analysis of WHA

The mineralogical composition was analyzed by XRD analysis using Rigaku Ultima IV X-ray diffractometer. The chemical composition of the ash were determined as per IS: 1350(Part III)-1969 [15], IS: 1355-1984 [16] and Vogel's text book of quantitative inorganic analysis [17]. Physical properties such as specific gravity, soundness, fineness by sieving were determined as per IS: 1727-1967 [14].

C. Blended cement

WHA blended cement were prepared by replacing OPC with 0, 10, 15, 20, 25 wt. % of WHA (Table 1). Mix proportion used for preparation of mortar cubes was composed of one part of cement plus WHA, three parts of standard sand by mass and (P/4 + 3.0) percent water of combined mass of WHA, cement and sand, where P is the percentage of water required to produce a paste of standard consistency.

Table 1: Adopted blended ratios of mortars

Specimen ID	Blending ratio (By weight %)
W0	100% OPC + 0% WHA
W10	90% OPC + 10% WHA
W15	85% OPC + 15% WHA
W20	80% OPC + 20% WHA
W25	75% OPC + 25% WHA

D. Consistency and setting time of blended cement

Vicat apparatus method conforming to IS: 4031(Part-4)-1995 [18] was used to determine the water consistency of WHA pastes and the pastes having normal consistency were used to determine initial and final setting time as per IS: 4031 (Part 5)-1995 [19].

E. Compressive strength of blended cement

Mortar cubes of dimensions 50x50x50 cm³ were cast and cured as per IS: 4031(Part 6)-1988 [20] for the compressive strength test. After 24 hours, mortar cubes were striped from moulds and cured by complete immersion in clean water for 7, 14, 28 and 56 days. For each specimen ID, 18 mortar cubes were prepared and the compressive loading tests were conducted on a compression testing machine (capacity: 500kN, least count: 2kN) with a loading rate of 140 kg/cm²/min as per IS: 1727-1967 [14].

F. Water absorption

Three mortar cubes from each specimen ID after 28 days of curing were dried in an oven at 105⁰C for 24 hours to obtain the dry weight. The mortars were weighted using an electronic balance that can be readable up to 0.001g and their weights are taken as dry weight (A) of specimen. Then they were again submerged in water for a period of 24 hours and this weight was taken as wet weight (B). The water absorption [21] was calculated as a percentage of initial mass as:

$$\text{Water absorption (\%)} = \frac{B - A}{A} \times 100$$

G. Sorptivity

Sorptivity test was conducted on three oven dried cubes of each specimen ID after 28 days of curing to measure the capillary suction of the mortar cubes when it comes in contact with water. The mortar cubes were coated with waterproof paint on all four lateral sides such that only water absorption from its base is possible. Water level was kept at 5 mm above the base of the cubes. The masses of the cubes were measured by weighing at regular intervals up to 120 minutes on an electronic balance that can be readable up to 0.001g. The following equation was used to calculate the sorptivity coefficient [22]:

$$\frac{Q}{A \cdot \rho} = S \cdot \sqrt{t}$$

Where Q is the amount of water absorbed, A is the surface area of the specimen through which water penetrated, t is the elapsed time, ρ is the density of water and S is the sorptivity coefficient of the specimen ($\text{mm}/\text{min}^{0.5}$).

3.0 RESULTS AND DISCUSSION

A. Chemical and mineralogical composition of material

Based on the chemical composition data of OPC and WHA listed in Table 2, it is seen that WHA has very high LOI, high alkali content (K_2O and Na_2O) and very low SiO_2 values. High value of LOI indicates presence of appreciable amount of un-burnt carbon. The sum of SiO_2 , Al_2O_3 and Fe_2O_3 is not more than 13% of the overall material composition, but CaO content is found high. SO_3 content is not more than 3%.

The mineralogical composition of WHA determined by X-ray diffraction is presented in Figure 3. Calcite, potassium oxide are present as major constituent with silica in the form of quartz as minor constituent and have been attributed to the original inorganic elements present in water hyacinth stem ash. The most distinguished crystalline materials were potassium oxide, calcite and quartz. Diffraction peaks of potassium oxide appeared at 23.180° , 28.480° and 40.640° , peaks of calcite were 23.180° , 29.540° , 36.080° , 47.620° , 48.600° , 57.500° and 95.060° , whereas that of quartz (silica) were 39.540° , 40.640° , 58.840° and 73.020° .

Table 2: Physical and Chemical properties of cement and WHA

Properties	Cement	WHA
A) Physical Properties		
Specific Gravity	3.15	2.168
Fineness (Residue on 75 μm sieve)	92%	87%
Le Chatelier Expansion	0.5mm	0.5mm
B) Chemical Composition		
SiO_2 (Silica)	19.62%	4.40%
Al_2O_3 (Alumina)	5.62%	2.20%
Fe_2O_3 (Iron Oxide)	5.33%	1.27%
CaO(Calcium Oxide)	61.24%	22.61%
MgO (Magnesia)	0.88%	14.01%
SO_3 (Sulphur Trioxide)	2.60%	3.09%
Na_2O (Sodium Oxide)	--	0.35%
K_2O (Potassium Oxide)	--	14.82%

Lime saturation factor (CaO- 0.7SO ₃)/ (2.8SiO ₂ +1.2Al ₂ O ₃ +0.65Fe ₂ O ₃)	0.91	1.29
Ratio of Alumina/Iron Oxide	1.05	1.73
Total Loss on Ignition	2.06%	31.45%

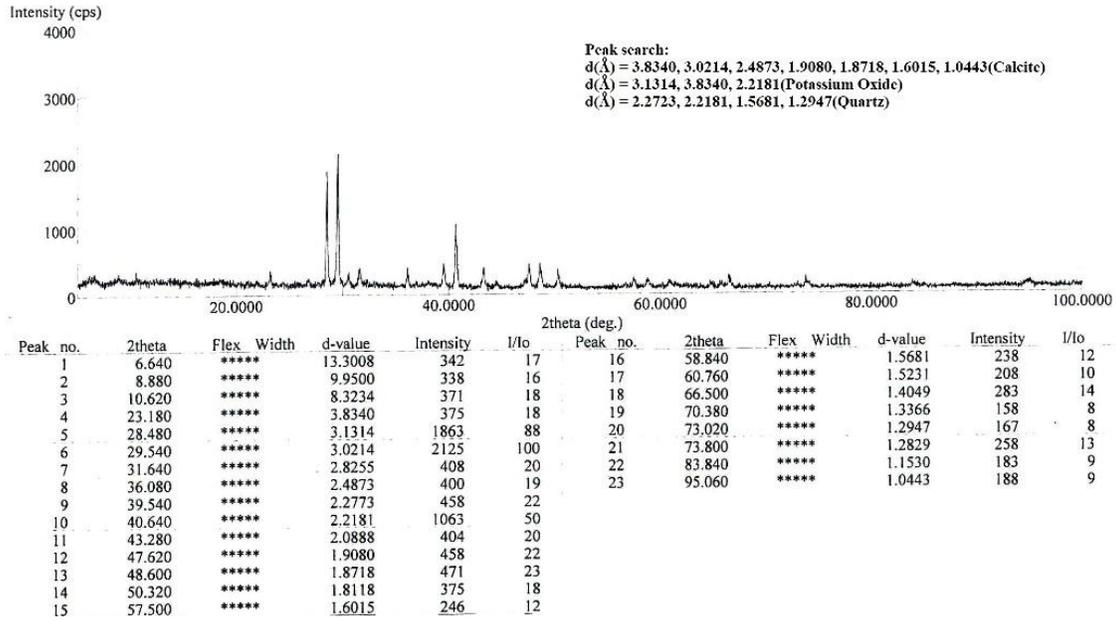


Figure 3: X-ray diffractogram of WHA

B. Consistency and setting time of blended cement

The graph of water consistency in Figure 5 indicates that the water required for normal consistency increased with the increase of cement replacement level and it is because of the high hygroscopicity nature of water hyacinth stem ash. The various oxides of WHA including Ca, K and Si are basic or amphoteric and produce hydroxides upon their reaction with water. Among these, KOH is known to be highly hygroscopic compound.

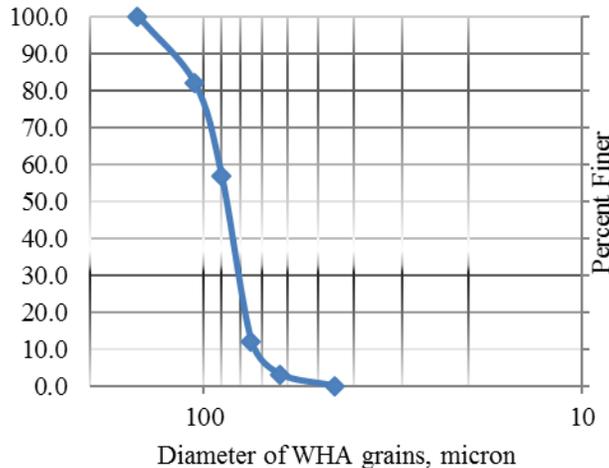


Figure 4: Particle size distribution of WHA

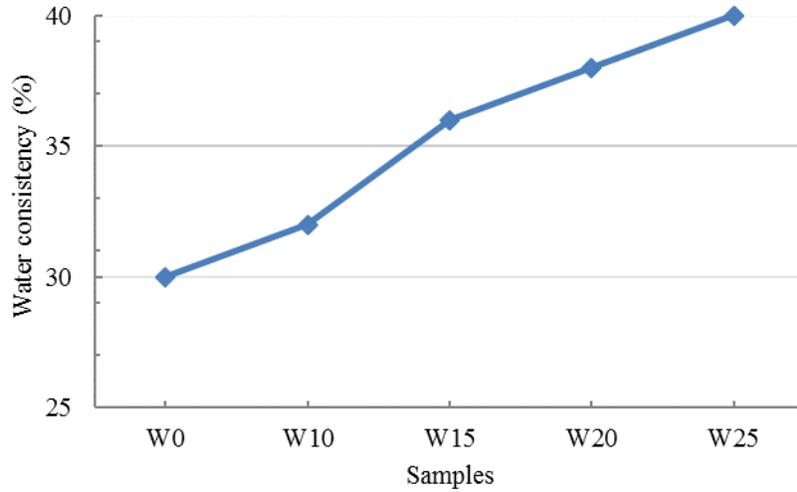


Figure 5: Water consistency of WHA blended cement

From the chart of setting time in Figure 6, it is observed that with the addition of WHA, the setting time is retarded and this is due to the absorption of water at the surface of WHA. With the increase in the proportion of WHA, the absorption of water is also increased and hence the higher amount of water has delayed the setting time. However, the setting time values are found to be well within the permissible limits as per IS: 8112-1989 [13].

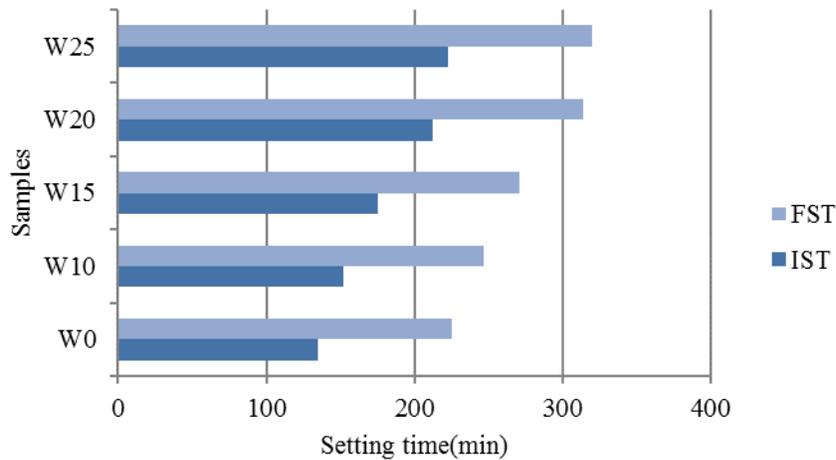


Figure 6: Initial and final setting time of WHA blended cement

C. Compressive strength of blended cement

Figure 7 shows variation in compression strengths for control and WHA blended mortar cubes with different ages. It can be seen that strength increased with the curing age for all the samples. Control mortar gained 49% at day 7 and 71% after 14 days, 91% after 28 days of curing over its 56 days compressive strength. The WHA blended mortars gained 49-54% at day7, 62-71% after 14 days, and 81-89% after 28 days of curing than their corresponding 56 days strength. It is clear from the observation that strength enhancement is lower than the cement mortar between 7 and 56 days. However the 10% replacement of WHA to OPC can be considered as optimal limit.

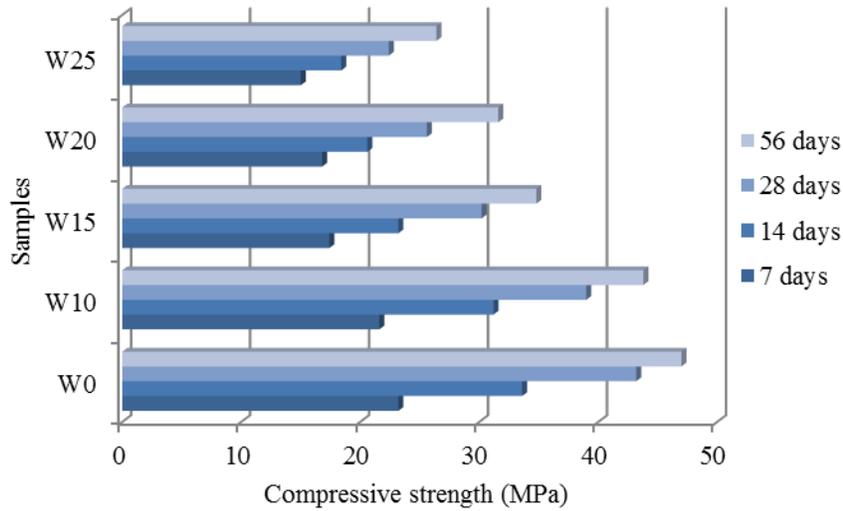


Figure 7: Development of compressive strength of mortar samples

D. Water absorption and sorptivity

The results of water absorption and sorptivity tests are presented in Table 3. It can be seen that mortar mixes containing WHA produces lower absorption and sorptivity compared to the mixture containing no WHA (control). This may be due to the gradual closing of pores in the mortar as WHA is finer than OPC.

Table 3: Water absorption and sorptivity test results of specimen

Specimen ID	Water absorption (%)	Water sorptivity (mm/min ^{0.5})
W0	7.31	0.146
W10	6.76	0.135
W15	6.41	0.127
W20	6.24	0.124
W25	5.93	0.116

4.0 CONCLUSIONS

Based on the results of this study, the following key conclusions can be drawn:

- Chemical composition analyses of the WHA reveals silica as the minor constituent and also have other compounds of Ca, Mg, K and S.
- The WHA blended cement paste specimen presented a long initial and final setting time when the replacement amount increased. This can be helpful while concreting in hot weather.
- Mortar specimens containing 10% of WHA had a compressive strength comparable to that without WHA.
- Mortar specimens prepared with WHA resulted in lower water absorption and sorptivity at ages of 28 days than that containing no WHA (control), which are important features of mortar resistance to exposure in aggressive environment.

REFERENCES

- [1] Mohammed S Imbabi, Collette C, Sean M. Trends and developments in green cement and concrete technology. *International Journal of Sustainable Built Environment* 2012; 1:194-216.
- [2] Payam Shafigh , Hilmi Bin Mahmud, Mohd Zamin Jumaat, Majid Zargar. Agricultural wastes as aggregate in concrete mixtures – A review, *Construction and Building Materials* 2014; 53:110–117.
- [3] Sata V, Jaturapitakkul C, Kiattikomol K. Influence of pozzolan from various by-product materials on mechanical properties of high-strength concrete. *Construction and Building Materials* 2007; 21(7):1589–98.
- [4] B A Alababan, M A Olutoye, M S Abolarin and M Zakariya , Partial Replacement of Ordinary Portland Cement (OPC) with Bambara Groundnut Shell Ash (BGSA) in Concrete, *Leonardo Electronic Journal of Practices and Technologies* 2005; 6:43-48.
- [5] D Gowsika, S Sarankokila, K Sargunan. Experimental Investigation of Egg Shell Powder as Partial Replacement with Cement in Concrete, *International Journal of Engineering Trends and Technology* 2014; 14(2):64-68.
- [6] D A Adesanya. Evaluation of blended cement mortar, concrete and stabilized earth made from ordinary Portland cement and corn cob ash, *Construction and Building Materials* 1996; 10(6):451–456.
- [7] Ernesto V C , Eduardo V M, Sergio F S, Holmer S Jr., Moisés F. Pozzolanic behavior of bamboo leaf ash: Characterization and determination of the kinetic parameters, *Cement and Concrete Composites* 2011; 33(1):68-73.
- [8] G C Cordeiro , R D Toledo Filho, L M Tavares, E M R Fairbairn. Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars, *Cement and Concrete Composites* 2008; 30(5):410-418.
- [9] K. Gunasekaran , P.S. Kumar, M. Lakshmipathy. Mechanical and bond properties of coconut shell concrete. *Construction and Building Materials* 2011; 25(1):92–98.
- [10] T Ozturk, M Bayrakl. The possibilities of using tobacco wastes in producing lightweight concrete, *Agricultural Engineering International: the CIGR Ejournal* 2005; 5.
- [11] Keith Lindsey, Hans-Martin Hirt. *Use Water Hyacinth! A Practical Handbook of Uses for Water Hyacinth from Across the World*, Anamed International, Schafweide 77, 71364 Winnenden, Germany, 2000.
- [12] IS:8112-2013, Ordinary Portland Cement, 43 Grade – Specification, Bureau of Indian standards, New Delhi, India
- [13] IS:383-1970, Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian standards, New Delhi, India.
- [14] IS:1727-1967, Methods of Test for Pozzolanic Materials, Bureau of Indian standards, New Delhi, India.
- [15] IS:1350 (Part III)-1969, Methods for Test of Coal and Coke - Determination of Sulphur, Bureau of Indian standards, New Delhi, India.
- [16] IS:1355-1984, Methods of Determination of the Chemical Composition of Ash of Coal and Coke, Bureau of Indian standards, New Delhi, India.
- [17] J Basett, RC Denney, GH Jerrery, J Mendham. *Vogel's text book of quantitative inorganic analysis*, Longman Group, England, 1986.
- [18] IS:4031(Part-4)-1995, Methods of Physical Tests for Hydraulic Cement - Determination of Consistency of Standard Cement Paste, Bureau of Indian standards, New Delhi, India.
- [19] IS:4031(Part-5)-1988, Methods of Physical Tests for Hydraulic Cement - Determination of Initial and Final Setting Times, Bureau of Indian standards, New Delhi, India.
- [20] IS:4031(Part-6)-1988, Methods of Physical Tests for Hydraulic Cement - Determination of Compressive Strength of Hydraulic Cement other than Masonry Cement, Bureau of Indian standards, New Delhi, India.
- [21] ASTM C 1403-2005. Standard Test Method for Rate of Water Absorption of Masonry Mortars, ASTM International, PA, USA.
- [22] Hall, C. Water movement in porous building materials--IV. The initial surface absorption and the sorptivity, *Building and Environment* 1981, 16(3): 201-207.