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Influence of Bio Admixture on Mechanical Properties of Cement and Concrete

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ABSTRACT

There are several additives or admixtures used to change the composition of concrete or to accelerate or retard its hardening, curing, workability etc. Admixtures of bio origin have been used as reinforcement since ancient times. This study aims to use extract of Water Hyacinth, as bio-admixtures in cement and concrete. Consistency and setting time of cement is noted for 0, 10, 15 and 20% replacement of water with hydro extract of water hyacinth and the mechanical properties of concrete have been carried out. Workability increased with increase in replacement percentage (0-20%).Work is repeated with bio fine powder. The results showed a progressive increase in compressive strength with increase in percentage of replacement with bio admixture but delayed the setting time. The phyto-chemical analysis using GCMS revealed concentration of ligno cellulose, saturated and unsaturated fatty acids which make this admixture as a retardant. The present study has paved way for identifying water plant's feasibility in structural strengthening of concrete.

Key words: Bio admixtures, cement, concrete, water hyacinth, setting time, compressive strength

INTRODUCTION

Plant extracts contain a wide range of organic components. Extracts of plant based materials have been used as admixtures in altering the various properties of cement and many researches in this focal point have been constantly undertaken. Many research activities are undertaken elsewhere on possible ways of improving the quality of concrete. It deserves to mention here about two of such research efforts. On one hand, bio-based concrete accelerating admixture is developed as an alternative to calcium chloride component in cement. On the other hand, research on bio-based retarding admixture of concrete for tropical environments is underway (Arum and Olotuah, 2006).

Plants have always been recognized as source of naturally occurring compounds; some are with rather complex molecular structures and also have varying physical, chemical and biological properties (Farooqi *et al.*, 1997; Philip *et al.*, 2002; Magufuli, 2009). According to Nkunya (2002), majority of the compounds extracted from plants find their use in traditional applications such as phyto-therapy and bioenergy. Still, the uses of naturally available compounds are of primary interest, owing to their cheap and abundant availability and more over, as they are eco-friendly. On account of these advantages, extracts and phyto-chemical residues of some commonly available plants and plant products have been tried as concrete and cement admixtures for imparting and maintaining the strength of the structures. It is not precisely known about the exact period from when the use of admixtures in cement and concrete began but it could be ascertained that some of the ancient civilizations used admixtures. For example, the Roman civilization used milk, lard and blood; eggs were used as admixtures by Europeans in the middle ages; the Chinese employed rice paste, Lacquer, tung oil, molasses and boiled bananas as admixtures; Cactus juice, latex were utilized by the people of Meso America and Peru; extracts of barks were in use for Mayans as admixtures.

According to Uchikawa *et al.* (1997) and Ayoub *et al.* (2006), some phyto based organic admixtures could induce physical effects which modifies the bonds connecting particles and could act on the chemical processes such as hydration, principally on the crystal growth and nucleation. Luu and Getsinger (1990) quantified the amount of carbohydrates in the Water Hyacinth plant sample extract. In this context, the phyto extracts of water hyacinth could be chosen as a new and promising candidate for admixture. Water Hyacinth is an aquatic invasive plant species. If not controlled, this aquatic species will sprawl and cover lakes and ponds entirely; this critically impacts water flow, blocking the sunlight from reaching native aquatic plants and thereby depleting oxygen, leading to death of fish (or turtles). Inspite of its negative qualities, it has a beautiful flower and can grow vigorously and abundantly producing larger biomass. The stems are fibrous in nature absorbing toxic chemicals and pollutants including heavy metals.

However, utterly impossible its removal seems to be, in spite of this negative feature, it does, remarkably have some positive attributes such as large abundancy, no extra care of seeding, weeding or fertilizer application is needed and no land area or space in land is occupied/needed; zero cost and to harvest this plant is to do an environmental favour.

Extracts of Water Hyacinth in the form of liquid and powder could be added to cement as an admixture. Alteration in the consistency and setting time of cement sample is to be tested to confirm whether the admixture is an accelerator or retarder. Strength characteristics of cement concrete added with the extract is to be studied.

MATERIALS AND METHODS

Collection and extraction of plant sample: Whole plant samples of Water Hyacinth were collected from waste water stagnant pool located at Thiruvaiyaru Taluk of Thanjavur District. The plant was authenticated by authorized botanist. The plants collected were thoroughly washed in clean running water to get rid of muddy debris and impurities. Then the excess water was allowed to drain by spreading the samples over a blotting sheet in a well ventilated room for about 30 min to 1 h. Then the samples were uniformly cut into 2 inch pieces using a table knife and about ½ to 1 kg of the sample was set aside for blending and maceration after complete drying under shade. Then one part (500 g) of sample was macerated using a blender-mixer. Then the macerated paste was taken and was filtered using a coarse filter and a clear filtrate of the plant extract was collected. Similarly, the thoroughly dried whole plant was cut into small pieces and was macerated into fine powder with the fineness equal to that of Ordinary Portland cement of 33 grade Ultra Tech Cement. Clean, sharp river sand passing through the 4.75 mm sieve that was free from loam, clay, dirt and chemical or organic matter was used. The specific gravity of the sand was 2.57 colourless, odourless and tasteless fresh potable water, free from any type of organic matter was used.

Estimation of consistency and setting time for cement: Consistency for the cement sample without bio admixture was found out using Vicat apparatus and the value was found to be 33%. Again, the setting time for various replacement percentages of admixtures viz., 0, 10, 15 and 20% was checked and the results are presented in Fig. 1.

Cement mortar bio-admixture cubes: The cubes were developed using steel moulds of size 70.5×70.5×70.5 mm. The cement and sand were mixed in 1:3 ratio proportions. Hand mixing was done and the mix was turned over a number of times until an even colour, consistency and blend was attained. Water and cement were replaced separately in the proportions namely 10, 15 and 20%, respectively. Water replacement was done with clear filtrate of Water Hyacinth and cement replacement was done with macerated fine powder of Water Hyacinth. The ratios were constituted based on the consistency test result of the cement cubes with 0% replacement of water. After removing from the metal moulds, the cubes were kept in curing tanks. Testing for compressive strength was then done at ages 3, 7, 14 and 28 days, respectively.

Concrete bio-admixture cubes: Similarly, concrete cubes of size 150×150×150 mm were made by replacing water with bioextract in the ratio of 10, 15 and 20%, respectively. Then again, the cement was replaced in the same ratio as cited above and concrete cubes were also made and after removing from the moulds, they were cured for 7, 14 and 28 days, respectively and the strength was tested.

Sorptivity test: Permeability of cement mortar is determined by its water absorbing capacity through sorptivity test. This test provides the rate of absorption of water by unsaturated mortar. Three specimens of 50 mm diameter and 100 mm thick, each for control, 10, 15 and 20% replacement of water with extract were cast and cured for a period of 28 days. The specimens were surface dried and weighed. All the surfaces except the bottom of the specimens were insulated to have uniform upward movement of water. Specimens were placed in a container which was filled gradually with water to a level of 3 mm. Specimens were weighted at an interval of 5, 10, 20, 30 and 60 min, 2, 3, 4, 5 and 6 h.

GCMS analysis of Water Hyacinth: The identification of components of this aquatic plant was carried out using Gas Chromatography-Mass Spectrometer (GCMS) analysis. The results are tabulated in Table 1.

Sample preparation for GCMS analysis: About 50 g of the cut pieces of the well shade dried whole plant of Water Hyacinth was powdered in a mixer and was soaked in 25-30 mL of alcohol

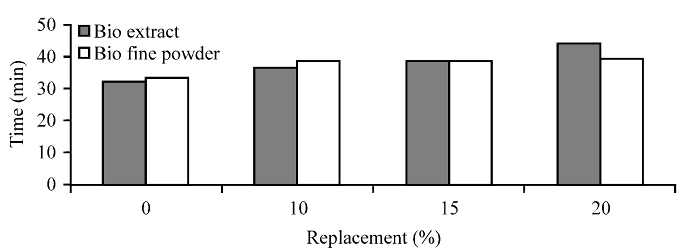

Fig. 1: Setting time for different % replacement with bio extract and bio fine powder

Table 1: Compositional analysis of Water Hyacinth using GCMS

Peak name	Formula	MW	Retention time	Peak area (%)
1-Ethyl-2-pyrrolidinone	$C_6H_{11}NO$	113	6.31	0.5695
2-Pentenal, (E)	C_5H_8O	84	7.55	2.8133
1,2-Cyclohexanedione	$C_6H_8O_2$	112	7.94	7.7914
Piperidine, 2,3-dimethyl	$C_7H_{15}N$	113	8.28	1.9072
2(1H)-Pyridinone, 6-hydroxy	$C_5H_5NO_2$	111	8.39	4.9742
Azetidine, 1-benzyl-2,2,3,3-tetramethyl	$C_{14}H_{21}N$	203	8.80	0.2570
Pantolactone	$C_6H_{10}O_3$	130	9.01	1.2214
1-Butanol, 2-methyl-, acetate	$C_7H_{14}O_2$	130	10.71	2.4218
4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl	$C_6H_8O_4$	144	11.00	0.9091
Octanoic acid, o-hydroxyphenyl ester	$C_{14}H_{20}O_3$	236	12.85	9.4355
2-Methoxy-4-vinylphenol	$C_9H_{10}O_2$	150	13.94	4.0569
N-Phenethyl-2-methylbutylidenimine	$C_{13}H_{19}N$	189	15.48	0.1381
3,7,11,15-Tetramethyl-2-hexadecen-1-ol	$C_{20}H_{40}O$	296	24.54	13.7379
Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	270	26.35	0.6177
9-Hexadecenoic acid	$C_{16}H_{30}O_2$	254	27.16	9.2031
n-Hexadecanoic acid	$C_{16}H_{32}O_2$	256	27.33	33.0531
Phytol	$C_{20}H_{40}O$	296	29.37	1.0546
9,12-Octadecadienoic acid (Z,Z)	$C_{18}H_{32}O_2$	280	29.93	0.5663
9,12,15-Octadecatrien-1-ol, (Z,Z,Z)	$C_{18}H_{32}O$	264	30.03	3.4615
S-[2-[N,N-Dimethylamino]ethyl]N,N-dimethylcarbamoyl thiocarbohydroximate	$C_8H_{17}N_3O_2S$	219	31.58	0.7864
6-Hepten-2-one, 7-phenyl	$C_{13}H_{16}O$	188	33.78	1.0239

for overnight and the extract was filtered and condensed to about 4-5 mL by heating using a water bath. Then, 1 µL of the extract was injected into the injection port of the GCMS instrument using a syringe. Then the GCMS analysis was undertaken using Perkin Elmer make GCMS instrument.

RESULTS AND DISCUSSION

Effect on setting time: The plant extract was found to contain specific components and substances which retard the hydration rate and the hardening of cement mortar and concrete. Results confirm that hydro extract of Water Hyacinth acts as a retardant because the setting time of the cubes made with the 10, 15 and 20% replacement ratios were more than the conventional setting time of 0% replacement as seen in Fig. 1. The setting time ranges from 32-44 min for 0-20% bioextract replacement cubes, respectively and the setting time for bio fine powder replacement was found to vary from 33-39 min, respectively implying that the retardant effect of bioextract was more than that of bio fine powder.

Effect on workability: Concrete mix 1:0.9:2.2 with w/c ratio 0.38 was used to check the workability through slump test. The results clearly depict the progressive increase in workability Fig. 2, as the percentage of bio admixture was increased both with bio extract as well as with bio fine powder of Water Hyacinth.

Effect on compressive strength in cement mortar cubes: Graphical form of results are presented in Fig. 3 and 4 which shows the plot of 28 days compressive strength values against

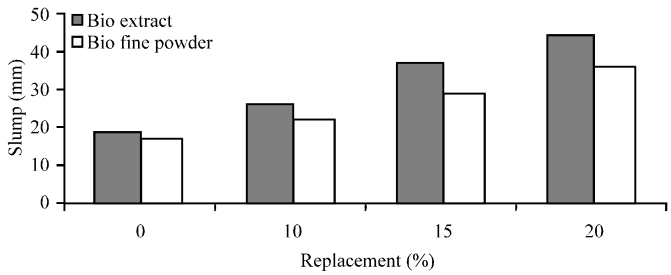

Fig. 2: Workability for different % replacement with bio extract and bio fine powder

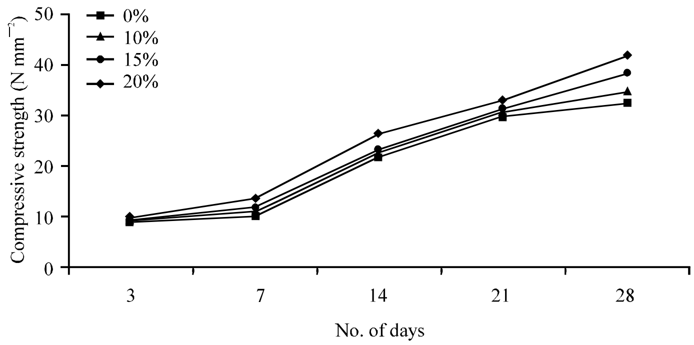

Fig. 3: Compressive strength of cement mortar for different % replacement with bio extract

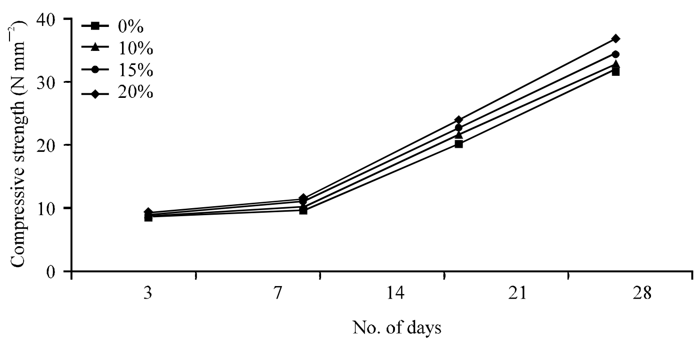

Fig. 4: Compressive strength of cement mortar for different % replacement with bio fine powder

percentage replacement of plant extract as to that of water content for the cement mortar cubes. Similar results were observed in compressive strength of concrete. Moreover, it was also observed that the crushing strength displayed progressive increase in strength as the number of days of curing increased gradually viz., 3, 7, 14 and 28, respectively.

It could be well perceived that the cube with 20% replacement by bio admixture was able to withstand stress upto 41.6 N mm^{-2} in case of replacement with bio extract whereas, the cube with 0% replacement could display compressive strength only upto 32.4 N mm^{-2}. Similarly, maximum compressive strength in cement mortar was observed at 35.7 N mm^{-2} for cement replacement with bio fine powder of Water Hyacinth. This clearly indicates that the components of the Water Hyacinth plant extract were able to improve the high stress tolerance capacity of the tested cubes than the cubes replaced with bio fine powder.

Effect on compressive strength in concrete cubes: The compressive strength of concrete cubes were progressively increasing along with increase in replacement percentage, both in the case of cubes replaced with bioextract as well as for cubes replaced with bio fine powder. The cube of 20% replacement with bio extract recorded a maximum compressive strength of 42.6 N mm^{-2}, whereas the cubes replaced with 20% of bio fine powder of Water Hyacinth could withstand only upto 37.12 N mm^{-2} of compressive strength. This also highlights that the mechanical property exhibited by concrete cubes which were replaced with bio extract was more than that of bio fine powder replaced cubes.

Effect on sorptivity: Sorptivity was calculated and plotted against time duration as shown in Fig. 5-8. Sorptivity test was under taken for cement mortar cubes with bio extract replacement alone as the compressive strength was observed to increase appreciably with bio extract replacement percentage rather than the bio fine replacement. The sorptivity results indicated that the water absorption increased in 10% replacement with bioextract upto 3½ h and then remained stable after that. But, for other replacement ratios, it displayed similar water absorption pattern as

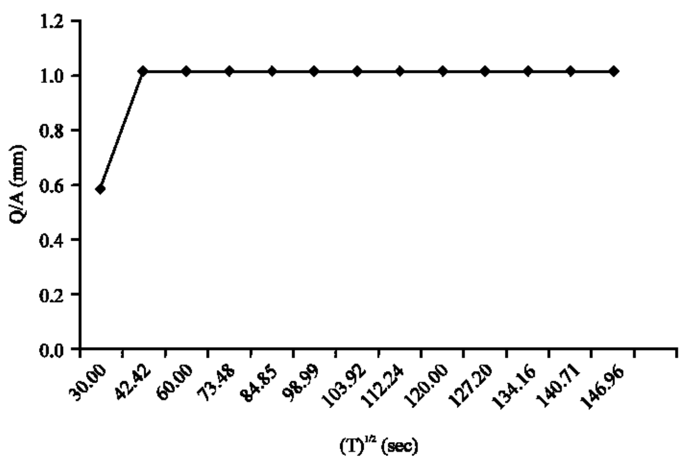

Fig. 5: Sorptivity graph for 0% replacement of extract in concrete

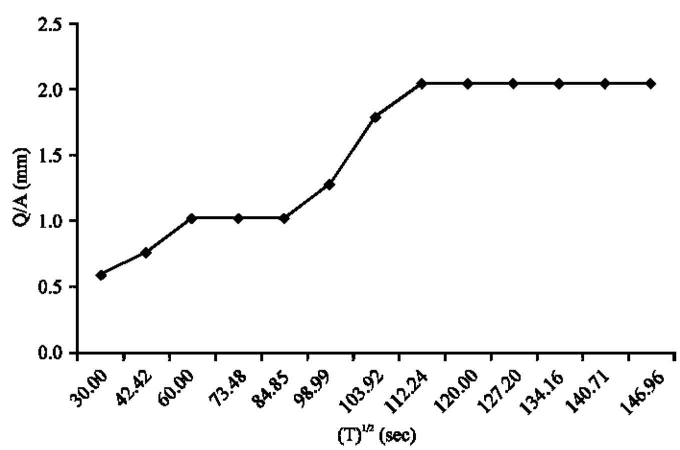

Fig. 6: Sorptivity graph for 10% replacement of extract in concrete

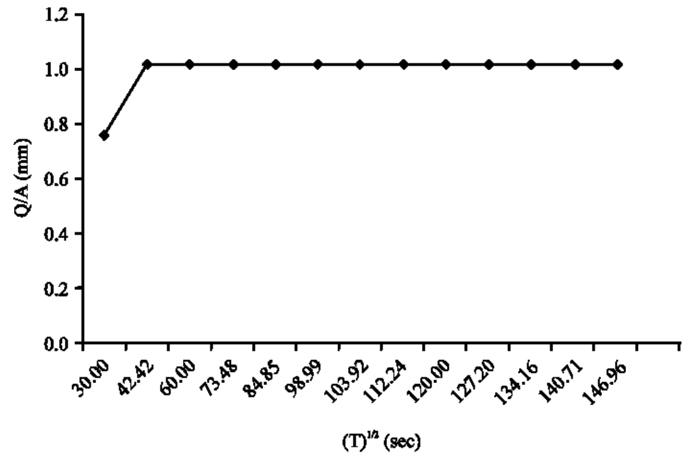

Fig. 7: Sorptivity graph for 15% replacement of extract in concrete

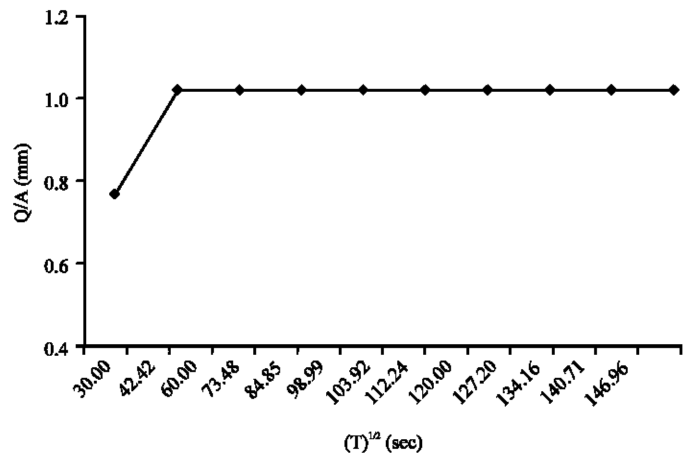

Fig. 8: Sorptivity graph for 20% replacement of extract in concrete

to that of control. Hence, this result shows that reduced water absorption with increasing replacement percentage with bioextract could be enhancing the mechanical property of cubes replaced with bio extract.

Compositional analysis of Water Hyacinth: About 21 components were identified in this analysis. Compounds belonging to ketones, aldehydes, alcohols and fatty acids were recorded. Out of these, the components highlighted in S. No. 14, 15 and 16 namely: Hexadecanoic acid, methyl ester, 9-Hexadecenoic acid and n-Hexadecanoic acid are Palmitic acid groups. Moreover, the fatty acid components-Octadecadienoic acid (common name linoleic acid) is also identified. The possible components identified are presented in Table 1. Chromatogram of GCMS analysis of Water Hyacinth is presented in Fig. 9.

In general, lignin, cellulose and hemi cellulose improves the binding and cementing of the grains of cement compounds as observed in the scanning electron micrograph of cement mortar cubes replaced with bio extract as shown in Fig. 10. The filtrate of water extract of Water Hyacinth could contain dissolved small fragments of lignocelluloses which could have partially

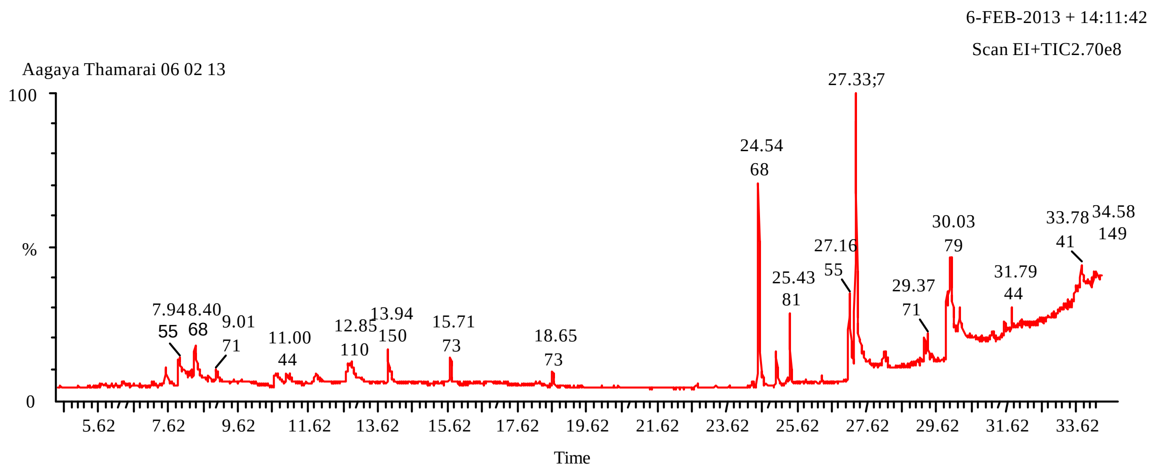

Fig. 9: Chromatogram of GCMS analysis of water hyacinth

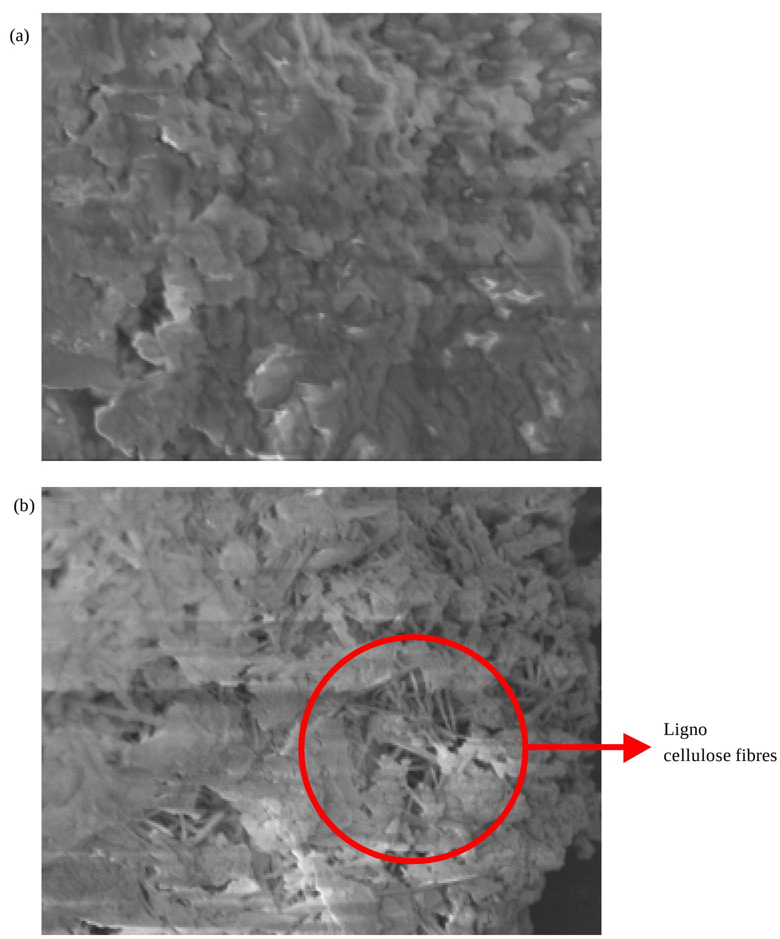

Fig. 10(a-b): Scanning electron micrograph crystallisation pattern of bio extract and cement mortar (a) Control 0% replacement and (b) 20% replacement with bioentract dissolved in water could multiply the binding effect of these compounds on cement. According to Hewlett (1988), lignin is a water-reducing agent but accelerator of setting of cement due to increased binding.

The second main component is the fatty acid groups. Presence of fatty acids such as palmitic acid and linoleic acid could very well answer the reason for delayed setting time and increased compressive strength. The squeezed out extract from Water Hyacinth which contains suspended insoluble molecules of fatty acids hampers the rate of setting time by hampering the evaporation of water molecules from the mixed paste. As the amount of percentage of bio admixture increased, the setting time also increased as fatty acid content increases with increase in extract volume.

Moreover, the fatty acid components improve the binding capacity among the grains of cement owing to their complex fatty acid chain structure. It has been reported by CCAA (2009) that admixtures consisting fatty acids, such as oleic acid; stearic acid; salts of calcium oleate and esters, such as butyloleate, are typically used to reduce the penetration of corrosive agents into concrete clinker and moreover, as the palmitic acid and linoleic acid are insoluble in water, they could not possibly penetrate into cubes thereby delaying the setting time and prevents the penetration of other corrosive agents and hence the reduction in sorptivity has been observed with increase in time.

The composition clearly highlights about the presence of saturated fatty acid-palmitic acid which poses threat to the stability of cement cubes as it could remain 'non-drying' so, there is chance for development of rancidity which attacks the concrete. But the action of palmitic acid could have been well balanced by the presence of another component-'linoleic acid' which is an unsaturated fatty acid which reacts with exposed air and moisture and takes up the oxygen to form fully saturated hydroxy acids which could provide an impervious skin to the surface of cement cubes thereby preventing any instability in structure. Moreover, presence of appreciable content of di-unsaturated esters of linoleic acid is prone to polymerization reactions when exposed to oxygen in air (Hewlett, 1988). Thus, polymerization which is called "drying," could result in the rigidification of the cement cubes displaying increase in compressive strength with the increase in percentage of bioadmixture-the hydro-extract of Water Hyacinth.

CONCLUSION

The present study reveals that the compressive strength and setting time of cement are influenced by the bio admixture-hydro extract and bio fine powder of Water Hyacinth. This is a novel approach evaluating the role of Water Hyacinth on mechanical properties of concrete and cement. The setting time was found to be delayed with increase in replacement percentage of bio admixture where as, the compressive strength and workability increased with increasing concentration of bio admixture. Sorptivity was also reduced with increased replacement percentage. The presence of photochemical such as lingo-cellulose, saturated and unsaturated fatty acids have enabled to identify this bio admixture as retarding but strengthening agent of cement and concrete.

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