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Experimental Investigations on Applicability of Eco Friendly, Green and Sustainable Farm/Fish Pond Liner As A Component for Water Storage System

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Abstract: It is a well-known fact that in most of the regions, rainfall shall not meet the crop water requirements. Hence it is very much necessary to have water storage system to meet the water demand. The rate of seepage is considered to be high in case of earth ponds. By considering this, there is an urgent requirement to reduce the seepage in the water storage system and increase the irrigation efficiency. This research studies is based on minimizing the seepage in the ponds by providing a liner material, which is eco-friendly, sustainable, economic with good serviceability. In this experiment the sodium based salts are used in combination with Bauxite Mine Residue (BMR) and Ordinary Portland Cement (OPC) as binder materials for the liner system to decrease the seepage. Three proportions of the binder were used in the study viz. BMR: OPC as 80:20. Sodium carbonate (SC) was used in the proportion of 0%, 2% 4%, 6% 8% 10% and 12% by weight of binder. SEM analysis, pH permeability and compaction tests were conducted to determine the performance of the liner material. Results showed that the binder ratio of BMR: OPC with ratio 80:20 with sodium carbonate content 10% showed the better results with more reduction in seepage, maximum reduction in permeability. Hence the present studies prove that the produced pond liner shall reduce seepage effectively and have more serviceability compared to plastic liners.

Keywords: Farm pond (FP), Sodium Carbonate (SC), Bauxite Mine Residue (BMR), Ordinary Portland Cement (OPC)

1. Introduction

Water demand for irrigation purpose has become necessary for over usage of ground water, which causes depletion in natural resources. Therefore supplementary irrigation can satisfy the water demand for the agricultural practices to stabilize the yields. Farm ponds shall provide long term irrigation requirements to the agricultural lands. Reduction of seepage in the farm ponds is a practical approach to the preserve the stored water available for irrigation to balance the yield. Improvement of irrigation efficiency by minimizing the water losses could be done with careful management. Farm pond is an artificial water storage system used for storing, distributing and capturing water for agriculture purpose, therefore, reduction of seepage is an important parameter. It is very much important to reduce seepage of water into soils and to increase irrigation efficiency. Many research works have been carried out on sustainability in water management (1), modification of geotechnical characteristics for seepage reduction (2) and also to improve shear strength (3). A research was carried out to study the permeability of soil under the action of sodium chloride and calcium sulphate in combined form (4). It was noticed that as sodium chloride content increases, permeability of the

*Corresponding author: nagashreebalu@gmail.com sample was found to be increased with decrease in calcium sulphate content. A researcher also investigated the effect of metakaolin on the permeability performance of flexible wall using soft clay stabilized with cement (5). It was noticed that as the Metakaolin content in the system increases, the permeability was found to be decreased.

In most of the cases polythene based sheets are used as FP liners to avoid seepage of the water into the soil.

Fig. 1 - Farm/Fish Pond with Plastic liner

Usage of plastic based liner material has several disadvantages viz. Poor flexibility, Susceptible to Puncture, Prone to scratches laid on rough surfaces, Poor resistance towards stress cracks, low thermal resistance, danger of micro plastic entry to the food chain etc.

Fig. 2 - Death of Aquatic Life

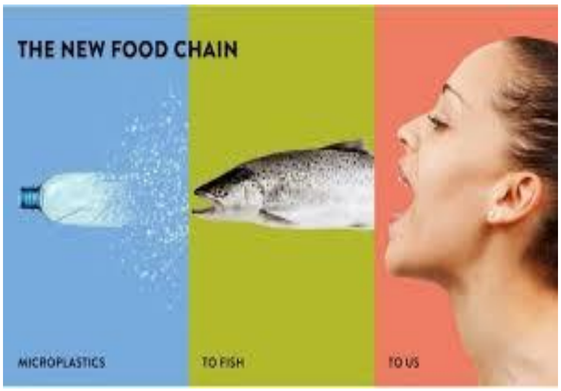


Fig. 3 - Effect of micro plastic in food chain

Present study focuses on usage of eco-friendly and sustainable material for surface lining of FPs, in order to overcome the disadvantage of using plastic liner material. Bauxite Mine Residue (BMR) is the main by-product for extracting alumina from bauxite ore through Bayer process. Production of one ton of alumina results in emission of same amount of BMR. It was noticed that global production of BMR is approximated as around 70 -120 million tons annually. In the past years, the aluminum production companies adopted land filling (Lagoons and drystacks) and marine discharge methods to dispose BMR.

Gunny bag has extreme strength, durability and is used for carrying heavy weights. These are extremely flexible, since it is made of natural fibers and it is non- toxic, bio-degradable and can be recycled.

Addition of sodium carbonate (SC) into the binder material .i.e., BMR and OPC (in combination) not only decreases the permeability of the liner, but also increases the serviceability of the material without causing any harm to the surrounding environment. Hence SC is chosen to be added to the binder, so that the sodium particles present in SC will be absorbed by the binder and shall be sealed into the pores of gunny bags by making a dense liner with less porosity which is eco-friendly and economic compared to conventional polyethylene liners.

2. Materials Used

2.1 Bauxite Mine Residue (BMR)

It is the byproduct obtained during production process of alumina from bauxite ore through multiple Bayers' process. Table 1 represents the physical and chemical properties of BMR.

Fig. 4 - Bauxite Mine Residue (BMR)

Table 1 - Physical and Chemical Properties of BMR

Particulars	Quantity (in %)
Silica (SiO_2)	24.02
Alumina (Al_2O_3)	42.80
Lime	18.51
Iron Oxide (Fe_2O_3)	8.5
Magnesia (MgO)	1.37
Titanium Oxide (TiO_2)	4.80
Specific Gravity	2.4
pH	10.5-12
Color	Red
Fineness passing through 45 micron	65

2.2 Ordinary Portland Cement (OPC)

OPC is a binder material used in the field of construction to adhere to other materials and bind them together. The setting and hardening of cement after addition of water happens due to dissolution and reaction of its constituent. Table 2 represents the physical and chemical properties of OPC.

Fig. 5 - Ordinary Portland Cement (OPC)

Table 2 - Physical and Chemical Properties of OPC

Particulars	Quantity (in %)
Silica (SiO_2)	21.10
Alumina (Al_2O_3)	5.24
Lime	64.39
Iron Oxide (Fe_2O_3)	3.10
Magnesia (MgO)	1.10
Sulphate (SO_3)	2.52
Sodium di Oxide (Na_2O)	0.23
Phosphate (K_2O)	0.57
LOI	1.22

Specific Gravity	3.12
pH	10-12
Color	Grey
Fineness passing through 45 micron	75

2.3. Sodium Silicate (SS)

Sodium silicate is a crystalline and colorless glassy liquid. SS contain high amount of silicon which can easily dissolve in water. Sodium silicate is termed as ideal for the treatment of concrete. It helps in minimizing porosity in plasters, concrete and stucco.

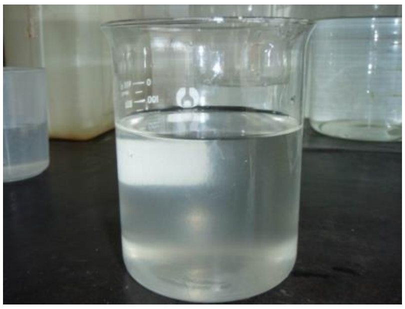


Fig. 6 - Sodium Silicate (SS)

2.4. Sodium Carbonate (SC)

Sodium carbonate is an inorganic compound, which is alkaline in nature. The present study aims in producing low cost eco-friendly, seepage proof liner to improve irrigation efficiency. Hence, instead of using heavy machines to compact the soil in ponds, liner with SC could be the best choice. It helps in minimizing porosity in plasters, concrete and stucco. This effect further helps in reducing the penetration of water.

Fig. 7 - Sodium Carbonate (SC)

2.5. Jute/Gunny Bag

Jute fiber is a type of plant fiber. The chemical components of jute fibers are lignin and cellulose. The term ‘lignin’ is used to refer to a class of complex organic polymers. Jute bag have extreme strength and durability, it is used widely for carrying heavy weights.

Fig. 8 - Jute Bags

3. Mix Proportion

In order to prepare binder/paste for lining the FPs; the raw materials viz. BMR, OPC are mixed along with SS , SC and water proportionately. BMR: OPC is mixed at the proportion of 80:20 by weight of the sample and 0.45 was opted to be the ratio of SS to binder (BMR+OPC) and further the SC was varied as 0%, 2%, 4%, 6%, 8% , 10% and 12% to the total weight of paste (OPC+BMR+SS). Further, water was added to the binder to achieve required consistency for ease of operation.

4. Laboratory Model

In order to determine the infiltration rate of the liner material for FPs, a small scale down model was constructed at laboratory. The materials included in making the lab model are as follows: Earthen pot, BMR, OPC, SS, SC and jute bags. The quantity of BMR, OPC, jute bags, SC and SS was estimated for lab model. The binder was prepared for the ratio of 80:20 (BMR: OPC). The estimated quantity of materials is mixed in proportion with water in the form of slurry. The prepared binder is first coated inside the pot, then the jute bags of dimension 10x10cm are dipped inside the slurry and laid inside the pot, a part of the next gunny bag should overlap on the previous one and ensure no gaps are provided. The joints between the jute bags are filled up with remaining binder material so that water is not allowed to percolate out and finally the finishing is done. The model was allowed to dry for 2-3 days based on the weather condition.

Fig. 9 - Casting the Specimens

Fig. 10 - Casted Specimens

Fig. 11 - Lab Model

5. On Site Model

Initially, Farm Pond construction involves land survey and clearing of vegetation from the earth excavation site. The pond was excavated from the middle where the central rectangular portion is dug first and then the side slopes were made in reference with the depth in order to attain uniformly formed slopes. The rectangular layout for excavation was done and the dimension of excavation of onsite model was opted as 1m3.

Fig. 12 - Site Marking for Onsite Model

Fig. 13 - Onsite Model

6. Methodology of Laying the Lining Material

The excavated surface is sprayed with one coat of binder to make the surface ready for application of jute bags immersed in binder. The binder is prepared with of binder .i.e., BMR: OPC (80:20) and SS/binder ratio of 0.45 (Sodium Silicate) along with SC proportion is mixed with water by keeping water to binder ratio of 0.21 to make it fine slurry without lumps. Further the gunny bags are dipped one by one in binder and are laid on the surface which was made ready with one coat of binder. In order to remove the entrapped air, it was made sure to pat the surface after application of liner material. To prevent seepage losses and infiltration of water from the liner material, gunny bags were placed in such a way that one bag should overlap on the other partly to ensure a good bond. The binder is applied on the joints to improve bonding and reduce risk of seepage losses. The pond is allowed to completely dry for 3-4 days and later it can be utilized for storage of water.

7. Results and Discussions

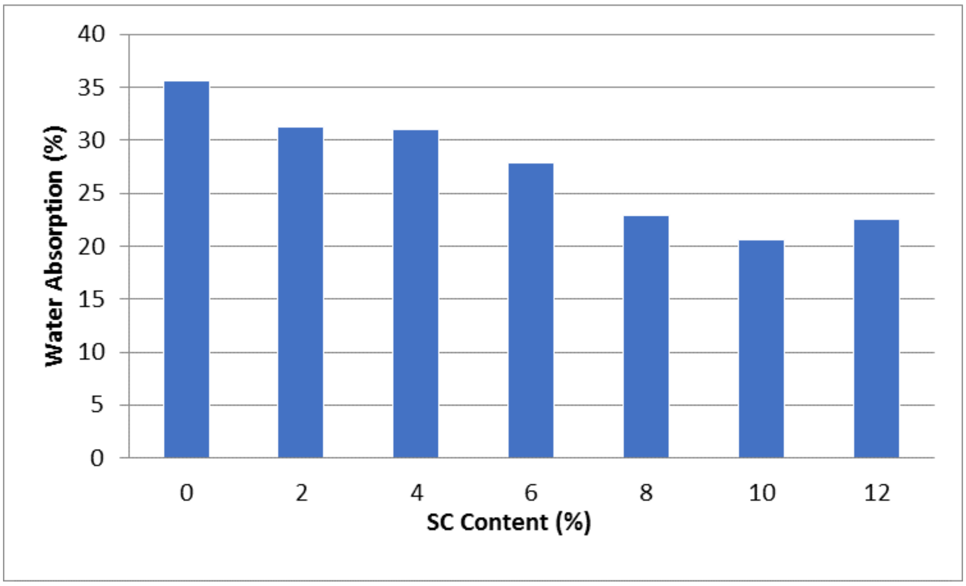
Test and Results

7.1. Water Absorption Test – For Laboratory Model

The specimens were cast for the different percentage of SC viz. 0%, 2%, 4%, 6%, 8%, 10% and 12% of total weight of binder. Initial weight of the specimens was recorded as W1. The specimens were immersed in water for 24 hours. The specimens, after completing the time duration, were taken out and surface dried. The weight of surface dried specimens was noted as W2.

The water absorption was calculated

$$\frac{(W2 - W1\ )}{W1} X100$$



Graph 1 - Percentage of water absorption for different samples

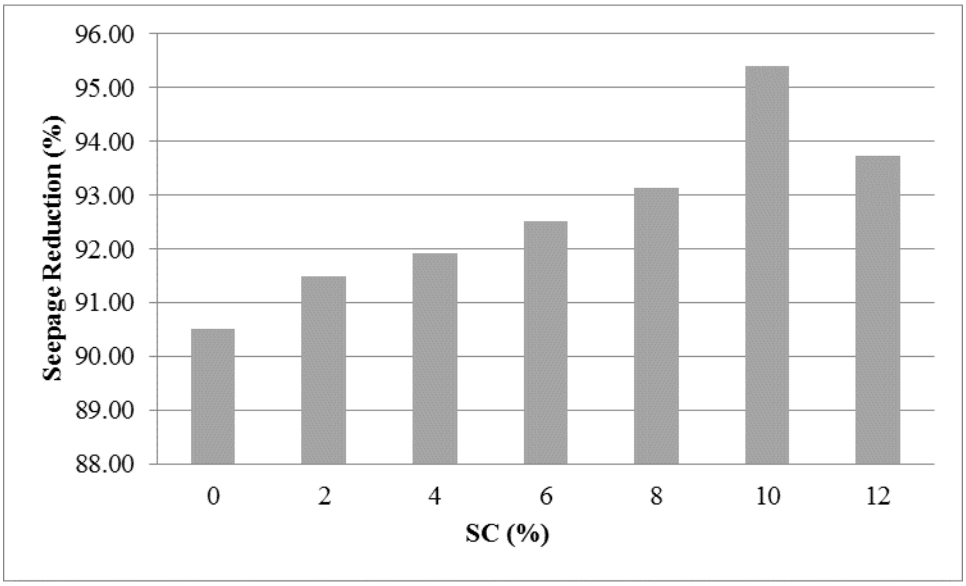
From graph 1, it was observed that the water absorption of the test specimens (lab model) was found to be decreased with increase in the SC content from 0% to 10% and further beyond 10% it was found to be increased. This is because that as the SC content increases the alkalinity was found to be increased up to 10%. Beyond 10% of the SC content the mix composite contained more alkalinity, which caused more shrinkage cracks on the surface of the material, which resulted in more water absorption.

7.2. Seepage Test – For Onsite Model

The loss of water for the field model, applied with the liner material for different proportions of OPC: BMR in presence of SS was measured. The seepage was measured daily for the total duration of three months. The mean seepage is represented in graph for every week for different proportions.

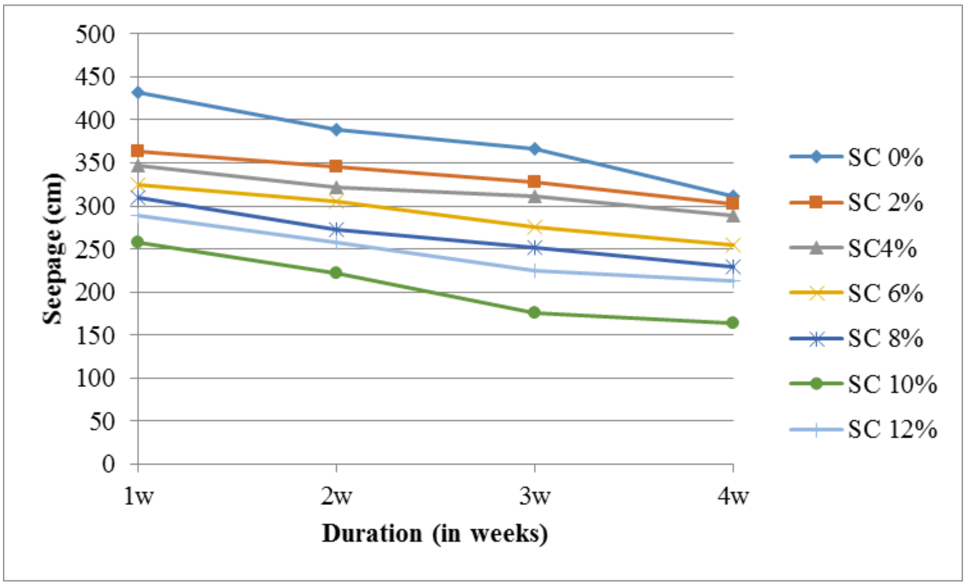
Table 3 - Seepage of the prepared Onsite Model

SC (%)	Reduction in depth of water (cm/day)	difference in seepage (cm/day)	Percentage of Seepage reduction
0	109	1041	90.52
2	98	1052	91.48
4	93	1057	91.91
6	86	1064	92.52
8	79	1071	93.13
10	53	1097	95.39
12	72	1078	93.74



Graph 2 - Seepage reduction for variation in SC quantity

Graph 2 shows the seepage reduction for different SC quantity in the mix. It was noticed that the percentage of seepage reduction was found to be increased with increase in SC quantity from 0% to 10%. Further beyond 10%, the mean seepage rate of the ecofriendly pond liner was found to be 109 cm/day and the seepage reduction was found to be 90.52%. It was noticed that the graph 2 shows the seepage reduction versus duration for different proportions of binder. It was observed that the seepage was found to more from first week to second week of duration. It was noticed that the initial sealing of FPs was by blockage of soil pores physically and further clogging is due to biological slime formed by organisms.



Graph 3 - Seepage versus duration for different samples

7.3. Scanning Electron Microscope Test

SEM test is used to determine the microstructure and texture of the binder material of the optimum proportion of the mix.

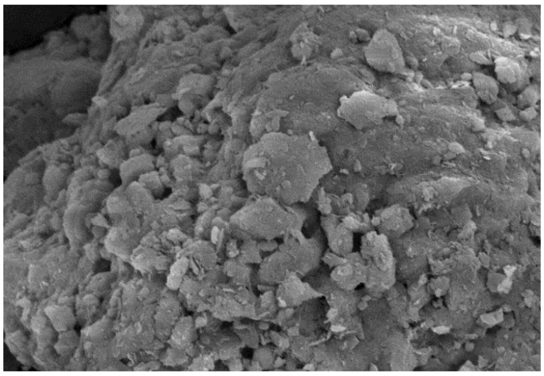


Fig. 14 - Binder without SS and SC

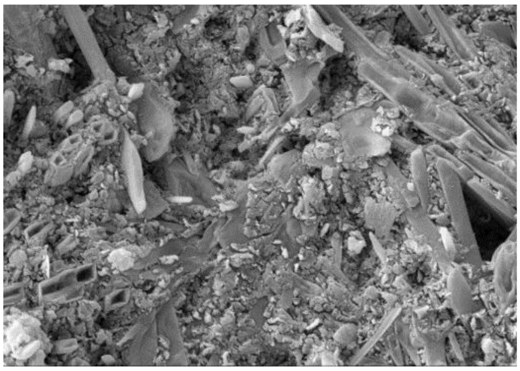


Fig. 15 - Binder structure with 10% SC after one day casting

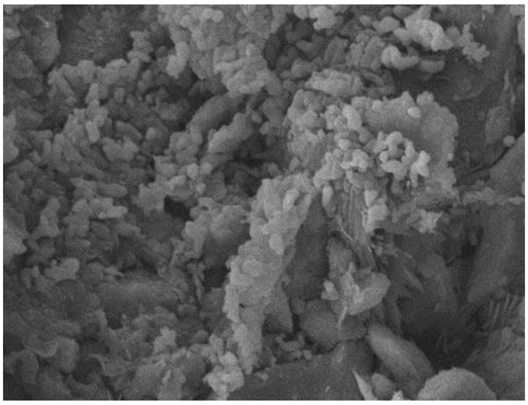


Fig. 16 - Binder structure with 10% SC after three days casting

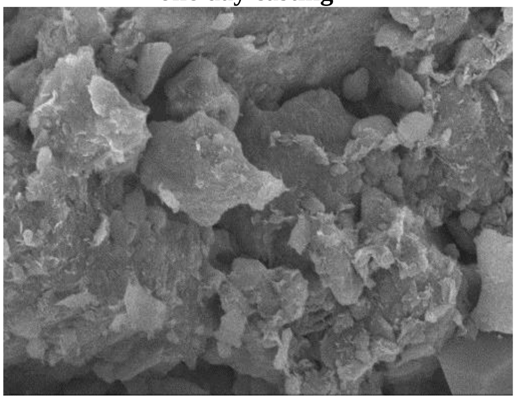
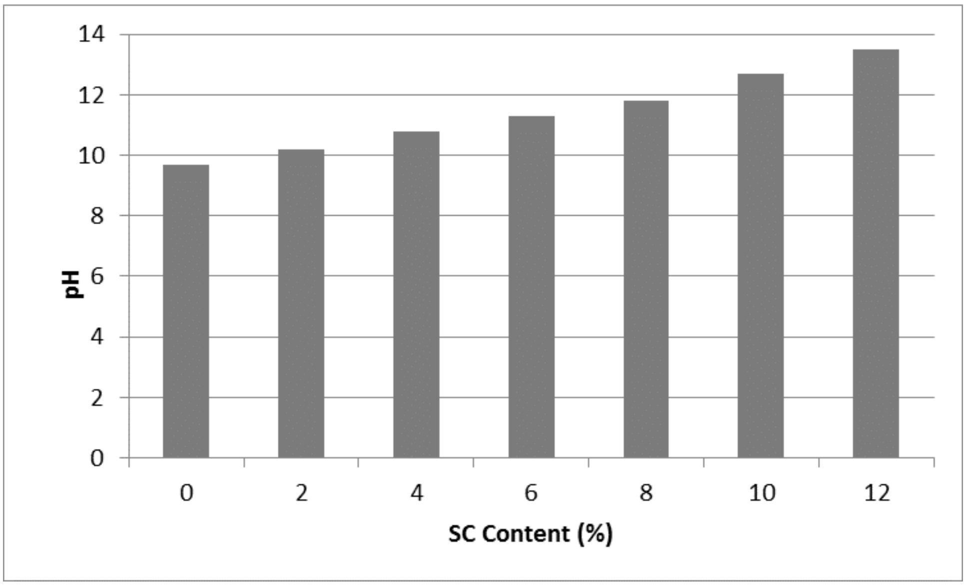


Fig. 17 - Binder structure with 10% SC after seven days casting

Fig 15 shows the reaction of binder structure after one day of casting, which indicates that there was no reactions initiated in the binder material. Similarly fig 16 shows the binder structure mixed with 10% SC after 3 days of casting period, which indicates that there is a fine texture due to dispersion of soil resulted in dense structure with decrease in porosity. Further fig 17 shows the binder structure with 10% SC after seven days of casting indicating more dense structure with less porosity.

7.4. pH Test of the Sample

pH of the test specimens were determined after adding different percentage of SC to the mix. pH meter was used to determine the pH of the test samples. Further after addition of SC to the mix, pH of the test specimens was found to be increased. It was noticed that increase in SC percentage increases the pH of the mix proportion and makes the binder material more alkaline. It was observed that the permeability of the binder material was found to be decreased with increase in alkalinity of the mix. The following shows the description of alkalization caused due to addition of SC and SS to water resulted in forming the binder material. In presence of water sodium carbonate reacts and decomposes to sodium ions (cation) and carbonate ions (anions). Similarly the presence of sodium silicate in the mix will increase the alkalinity and improves the texture of the material by making it denser with less porosity.



Graph 4 - pH of the specimens for different SC content

Graph 4 shows the pH of the specimens for different SC contents. It can be observed that as the SC content increases, pH of the specimens were found to increase. It was also noticed that the SC content from 0% to 10% the pH was increased, which further decreases the porosity and water seepage of the specimen. But beyond SC content 10%, it was observed that, the pH was increased but the seepage was increased compared to the previous SC content. This may be due to reason that though pH was the increased with respect to increase in SC content, there was presence of shrinkage cracks, resulted in increase in seepage through the specimen.

7.5. Cost Estimation

Cost estimation is prepared for 1m3 size for onsite model as follows.

Table 4 - Cost estimation is prepared for 1m3 size for onsite model

Sl no	Particulars of Items	Qty	Unit	Rate per unit	Amount
1	Excavation (labour)	1	No.	1000/day	1000/-
2	OPC	0.084bag	Bags	450/bag	40/-
3	BMR	19.2kg	Kg	2/kg	39/-
4	Sodium silicate	8.4	Litre	15/litre	126/-
	Sodium Carbonate	8.06 kg	kg	10/kg	81/-
5	Jute bag (0.9*0.65)	5	Bags	10/bag	50/-
6	Laying of bags (labour)	1 for $1/_2\ day$	No.	1000/day	500/-
Total amount for onsite model with Eco friendly material as liner ($1m^3$) = 1836/- **Total amount for onsite model with conventional plastic liner($1m^3$) – 2665/-** **Total cost reduction : 45.15%**					

8. Conclusions

According to the results and discussions, the following are the conclusions drawn

1. Water absorption for lab model was observed to be decreased with increase in SC content from 0% to 10%. Beyond 10%, the water absorption was found to be increased.
2. It was noticed that there was maximum reduction in seepage corresponding to `10% SC content.
3. It was observed that the seepage was found to be more initially at 1st and 2nd week duration. Beyond 2nd week, the seepage was found to be reduced, due to blockage of liner by binder material, surface

soil and biological slime formed by organisms.

4. With respect to SEM test results, it was observed that the microstructures of the specimens were found to be denser after completion of seven days from casting compared to one day and three days. This may be due to dispersion of soil and binder with respect to the action of alkali contents .i.e., SS and SC in the sample.
5. pH of the test specimens were found to increase with increase in SC content in the specimen. This may be due to alkaline nature of SC in the samples. It was also noticed that up to 10% of SC content the seepage was found to be reduced. But beyond 10% the seepage was found to be increased for the onsite model. This is due to the presence of shrinkage cracks on the surface of the sample beyond the optimum content.
6. The liner prepared by using eco-friendly materials were found to be economic with 45.15% reduction in cost compared to the conventional plastic liner material.

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