COMPARATIVE EVALUATION OF PHYSICAL AND HYDRAULIC PROPERTIES OF SOME LOCAL MATERIALS FOR LINING OF SMALL IRRIGATION CANALS

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ABSTRACT

The physical and hydraulic properties of some local materials for canal lining were evaluated to ascertain their suitability for canal lining. These materials were: (i) Concrete (GC): which comprised of Cement, Sand and Granite of average sizes of between 9.0 mm and 14 mm, in a ratio of 1:2:4. (ii) Termite Mound (TM) (iii) Clay Cement (CLC) (iv) Cementitious Clay (CCL), and (v) Clay Soil (CLS). The compaction characteristics were determined using the standard Proctor compaction mound by subjecting the samples to 5, 15 and 25 hammer blows. Results showed that Concrete sample had the highest maximum dry densities; while Clay soil sample had the lowest. The highest compressive strength was obtained from Concrete (2.373 N/mm^2) and the lowest from Termite Mound sample (0.315 N/mm^2).The seepage losses ranged from 0.034 – 0.092 m^3/$^/$m^2/$^/$day for Clay soil lining, 0.045 – 0.095 m^3/$^/$m$^{2/}$/day for Termite Mound lining, 0.021 – 0.092 m^3/$^/$m$^{2/}$/day for Clay-Cement, 0.020 – 0.068 m^3/$^/$m^2/$^/$day for Burnt Cementitious Clay, and 0.020 – 0.057 m^3/$^/$m^2/$^/$day for Concrete lining. Though concrete, which is conventionally used for canal lining, performed better; other materials also performed adequately well. The results therefore, revealed that these materials have requisite properties for canal lining.

Keywords: canal lining, compaction characteristics, dry density, local materials, seepage loss

1. INTRODUCTION

Unlined channels could be used to convey irrigation water but losses through seepage had been observed to be an impediment to this simple way of conveyance (Mazumder, 1983). In water conveyance, considerable quantity of water is lost on transit. This loss has been a daunting problem facing local farmers because there is an irretrievable loss of valuable water resources. One of the aims of canal lining is to improve water conveyance. When a channel is lined, the roughness of the surfaces of the channel is reduced and the burden of weed infestation is also reduced. Lining is therefore, necessary for controlling seepage losses and also enhancing conveyance efficiency. Adequately lined channel will reduce erosion as well as reduce deposition of sediments along the channel bed.

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Good water management and seepage reduction through proper lining are some of the strategies needed for optimum agricultural productivity. The attainment of self-sufficiency in food production can only be realized through the development of irrigation sector and the encouragement of the small holder farmers in the use of local materials for canal lining. Irrigation should therefore, be seen as a decisive factor in reducing economic vulnerability of farmers, assurances against rainfall inconsistencies and enhancement of rural development. For small holder irrigation farmers, improved water abstraction and conveyance systems are the key to their agricultural production especially in drought prone areas where the limiting factor is water and not land (Mohammed, 2003). Therefore, affordable local low cost irrigation technologies such as canal lining can bring about a sustainable production and enhance income level of resource poor farmers.

These low level local lining materials can bring to the fore an improvement in water conservation compared to unlined channels as well as increase in land for production through the water saved from conveyance losses, thus giving rise to higher productivity and increased yield. Furthermore, for an effective conveyance of irrigation water, there is the need for an extension of the application of innovative low cost approaches in canal lining in order to improve the productivity of irrigation schemes and the sustainability of the methods with the ultimate objective of contributing to better livelihoods for poor resource farmers.

Though, concrete lining has been confirmed through the years of usage to be the best way to reduce seepage (Schwab, 1993), however, the level of financial resources of the small holder farmers has made it imperative to seek new approaches in lining using local available materials. To this end, an unrelenting effort should be made to incorporate indigenous knowledge and practices that would bring about a meaningful irrigation system adaptable to small holder irrigation farmers. There is therefore, the need to utilize emerging indigenous low cost lining materials to advance small scale irrigation development in the Country.

Therefore, the main objective of this project was to study the potential of five selected local materials for irrigation canal lining without compromising the qualities of the canal.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was carried out at the National Centre for Agricultural Mechanization (NCAM), Ilorin. Ilorin is geographically located in the middle belt of Nigeria with a vegetation of derived savannah, and is situated on longitude of 4^0 30' E and latitude of 8^0 26' N. Ilorin receives an average of 1200 mm annual rainfall. The soil of the experimental site is sandy loam and contains 12.48% clay, 18% silt and 69.52% sand. It is classified as Hyplustalf of Eruwa and Odo-owa series, developed from the parent materials consisting of micaceous schist and gneiss of basement complex which are rich in Ferro-magnesium materials (Ahaneku and Sangodoyin, 2003).

2.2 Experimental Lay-out

Five sample materials were considered for study. These materials were: (i) Concrete (GC): which comprised of Cement, Sand and Granite of average size of 12 mm, in a ratio of 1:2:4. (ii) Termite Mound (TM) (iii) Clay - Cement (CLC) (iv) Burnt Cementitious Clay (BCCL), and (v) Clay Soil (CLS). Forty five channels of these treatments were dug and laid in a completely randomized design, in a 5 x 3 x 3 factorial experiment. The five treatments; Concrete, Clay – Cement, Burnt Cementitious Clay, Clay soil and Termite Mound were replicated three times, using three different levels of slope for each of the material. The levels of slope were 2%, 5% and 7%, respectively. Each channel was 15 m long, a length enough for the observation of all the flowing parameters, with side slopes of 2:1.

2.3 Experimental Procedures

2.3.1 Grain Size Distribution

Samples of each of the treatments were collected for particle size distribution and texture analysis. The soil samples were air dried and passed through a 2-mm sieve to remove stones and crumbs. The particle size distribution was obtained through sieve analysis of the grains of the samples to determine the samples' fractions. The textural classes of the samples were obtained using the triangular diagram of the USDA as presented by Murty (1985).

2.3.2 Determination of Chemical Composition

The exchangeable Magnesium was extracted and titrated with sulphuric acid, while available phosphorous and potassium were extracted using double acid solution of 0.05N hydrochloric acid and 0.025N sulphuric acid. Sodium was also extracted and titrated with sulphuric acid. Calcium and Magnesium were determined using absorption spectrophotometer. The organic Matter contents of the samples were estimated from the carbon content of the sample using the method of Walkley and Black (1934).

2.3.3 Consistency Limits and Hydraulic Conductivity

The Atterberg limits were determined using Cassagrande method as described by Arku and Ohu (1991). The difference between the liquid limit (W_L) and the plasticity limit (W_P) gives the plasticity index as follows:

$$PI = W_L - W_P \qquad (1)$$

where:

PI = Plasticity Index

2.3.4 Determination of the saturated hydraulic conductivity of the Samples

The permeability (saturated hydraulic conductivity) of each sample was determined using the falling head permeameter (Anderson, 1953). The hydraulic conductivity was determined as:

$$K = \frac{QL}{Ah} \qquad (2)$$

where:

K = Hydraulic conductivity, cm/s

L = Sample length, cm

A = Area of sample, cm^2

2.3.5 Compaction Characteristics of Samples

The compaction characteristics were determined using the standard compaction mound. The samples were subjected to 5, 15 and 25 blows of a standard proctor hammer of 2.5 kg in cylindrical mould of 105 mm diameter and 115 mm height, at different moisture contents following the proctor compaction procedure (Lambe, 1951).

2. 3.6 Compressive Strength of the Samples

Three samples from across the treatments were removed from the bulk samples for testing. The compressive strengths of the specimens were determined during the 28 - day curing period with the Universal Testing Machine (Testometric, Model M500 – 100AT) at ages of 7, 14, 21 and 28 days, respectively. At each measurement, the load was applied smoothly and gradually at a speed of 25mm/sec. until the sample failed; when it could no longer resist the load acting upon it.

The compressive strength was determined as:

$$\sigma = \frac{F_{\max}}{A_{ms}} \quad (3)$$

where:

$\sigma =$ Compressive strength (N/mm^2)

F_{max} = Maximum load (N)

A_{ms} = Area of moulded specimen (mm^2)

2.3.7 Determination of Seepage Losses

Test ditches of trapezoidal shape were excavated randomly with the following dimensions: bed width: 0.35 m, depth of ditch: 0.40, side slope: 1:2, length of ditch: 2.50 m, top width: 1.30 m. The ditches were lined with the treatment materials at 5 cm thickness. The test was done in the dry season when the groundwater table could not contribute to the water levels in the ditches by capillary action.

The ditches were filled with water, and the initial depth (d_1) was recorded immediately, while, the final depth (d_2) was recorded after 24 hrs of water drawdown due to seepage loss. The measurements were taken consecutive days at regular interval of 24 hours, until the seepage rate became almost constant. The seepage rates were adjusted for evaporation losses from an evaporation pan at the National Centre for Agricultural Mechanization's meteorological station.

The evaporation losses through the pan were determined as follows (Allen *et al.*, 1998):

$$E_o = K_p . E_{pan} \quad (4)$$

where:

E_o = evaporation loss, mm
K_p = pan coefficient
E_{pan}=pan evaporation, mm

According to Michael (1978), evaporation pans have higher rates of evaporation than larger free surface, a factor of about 0.70 is usually recommended for converting the observed evaporation rate to those of large surface areas. Therefore, K_p, was taken as 0.70. The average evaporation for the impounding days was determined and subtracted from the daily seepage losses to give the seepage rate for each day.

The seepage losses were obtained through the ponding method and were determined by the following formula as expressed by Khair and Daulat (1978):

$$S = \frac{24w(d_1 - d_2)L}{PLT} \quad (5)$$

where:

S = Seepage rate in m^3/m^2/day
w = Average width of water surface (m)
d_1 = Depth of water (m) at the beginning of measurement
d_2 = Depth of water (m) after time T
P = Average wetted perimeter (m)
T = Time interval between d_1 and d_2 (hr); and
L = Length of canal (m)

3. RESULTS AND DISCUSSION

3.1 Texture, Consistency Limits and Hydraulic Conductivity

From the grain size analysis, it was found that the grain seizes of the five samples were distributed within the following ranges; 6-38% silt, 8.48-38.43 clay and 43.57-82.52 % sand. The liquid limit, plastic limit and the plasticity index values representing the sample types were found to be in the range of 34-49%, 17-24.3% and 19-24.7%, respectively. The textural classifications and the chemical composition of the samples are in Tables 1 and 2, respectively, while the consistency limits; liquid limits, plastic limits and the plasticity indices of the samples are in Table 3. Table 3 shows that the samples have average values of liquid limits and plasticity index. Clay-cement mixture has the highest plasticity index of 24.7%, while, Termite Mound, Cementitious - Clay and Clay Soil samples have 19.2%, 19.5% and 19.6%, respectively.

In general, the value of plasticity index of a sample reflects the clay contents in the sample and hence the workability of the sample due to cohesion between the sample's grain particles. The plasticity indices of the Clay-Cement and clay soil were the highest of the samples which might be due to the higher silt and the lower sand percentage than other samples. Similarly, increase in plasticity index with an increase in clay content was observed. This trend in results was in conformity with the results obtained by Adekalu *et al.* (2007) and Ekwue *et al.* (2002).

Generally, conductivity is affected by the size and distribution of soil particles which generally influence the size of voids conducting flow (Taha and Kabir, 2006; Ige and Ogunsanwo, 2009). The factors that affect hydraulic conductivity are mineral composition, texture, particle size distribution, characteristics of wetting fluid, exchangeable cation, void ratio and degree of saturation of medium. According to Koncagul and Santi (1999), a high value of hydraulic conductivity indicates a well- interconnected pore network, hence a poor seepage control. Contrarily, results from Table 3 show that all the samples have medium permeability and could be good materials for canal lining, if properly compacted. It is therefore expected that these materials will reduce seepage considerably when employed as canal lining materials.

Tab. 1: Textural and organic properties of the samples

Components (%)	Samples+				
	GC	**TM**	**CLS**	**CCL**	**CLC**
Organic Carbon	0.02	0.51	1.40	0.6	0.24
Organic Matter	0.05	0.87	2.42	4.76	0.67
Sand	82.52	59.52	47.52	53.52	43.57
Silt	6.0	30.0	20.0	38.0	18.0
Clay	11.48	10.48	32.48	8.48	38.43
Texture (USDAstdΔ)	SL	SL	CL	L	CL

+**GC**= Concrete; **TM**= Termite Mound; **CLC**= Clay- Cement ; **CCL**= Cementitious Clay; **CLS** = Clay Soil; **SL**= Sandy Loam; **CL**= Clay Loam; **L** = Loam

Tab. 2: Chemical properties of samples

Components (mg/kg)	Samples				
	GC	**TM**	**CLC**	**CCL**	**CLS**
N(%)	0.003	0.07	0.03	0.6	0.09
Ca^{2+}	32.52	67.52	16.43	77.9	36.36
Mg^{2+}	2.58	31.17	1.60	41.56	20.78
Na^{+}	0.05	125.11	129.0	142.0	136.42
P	0.13	120.54	203.25	154.78	133.36
Ph	34.0	33.97	27.55	58.05	34.97
Cl^{2-}	0.03	20.38	12.65	29.26	32.07
Co_3^{2-}	2.81	8.81	12.93	46.90	21.45
Si^{2-}	4.38	-	6.62	-	-

GC= Concrete **TM**= Termite Mound **CLC**= Clay- Cement **CCL**= Cementitious Clay **CLS**= Clay Soil

Tab. 3: Physical and index properties of the samples

Properties	Samples+				
	GC	**TM**	**CLC**	**CCL**	**CLS**
Bulk Density (kg/m^3)	1.50	1.49	1.50	1.47	1.57
Dry Density (kg/m^3)	1.45	1.47	1.45	1.43	1.49
Specific Gravity	2.68	2.65	2.60	2.67	2.63
Liquid Limit (%)	-	39.0	49.0	41.0	37.0
Plastic Limit (%)	-	19.8	24.3	21.5	17.4
Plasticity Index (%)	-	19.2	24.7	19.5	19.6
Permeability (cm/sec)	8.57×10^{-5}	2.55×10^{-4}	5.63×10^{-5}	1.07×10^{-5}	8.65×10^{-5}

GC= Concrete **TM**= Termite Mound **CLC**= Clay- Cement **CCL**= Cementitious Clay **CLS**= Clay Soil

3.2 Compaction Characteristics

The compaction tests reveal that the dry densities of the samples increased with compactive efforts, which shows that dry density is a function of moisture content and compactive effort. The results of the compactive efforts were as shown in Figures 1 – 5. The peak of each curve shows the maximum dry density for a given compactive effort. The results of the compaction test as revealed from the graphs could be explained by the fact that at the dry side of the optimum water content, the dry density increases with the increasing water content. This is probably due to the development of large water film around the particles, which tends to lubricate the particles and makes them easier to be moved about and re-orientate into a denser configuration (Holz and Kowacs, 1981).

At the wet side of the Optimum Moisture Content (OMC), water starts to replace soil particles in the compaction mould and since the unit weight of water is much less than the unit weight of sample, dry density decreases with the increasing water content. The table shows that the maximum dry densities of 1.55gcm^{-3}, 1.57gcm^{-3} and 1.58gcm^{-3} were exhibited by Concrete sample at 5, 10 and 25 blows, respectively, at the lowest level of moistures of 6.7%, 6.5 % and 7.0%, respectively. This was followed by Termite Mound sample with maximum dry densities of 1.45gcm^{-3}, 1.51gcm^{-3}, and 1.63gcm^{-3} at moisture levels of 10.4%, 10.1 % and 9.0%, respectively. Clay soil sample has maximum dry densities of 1.5gcm^{-3}, 1.57gcm^{-3} and 1.56gcm^{-3} at moistures of 11.6 %, 11.1 % and 10.1 %, respectively; Cementitious - Clay samples with densities of 1.34 gcm^{-3}, 1.38 gcm^{-3} and 1.44 gcm^{-3} at moisture content of 14.0 %, 15.2 % and 13.5 %, respectively, while the Clay - Cement sample has the least densities of 1.27 gcm^{-3}, 1.30 gcm^{-3}

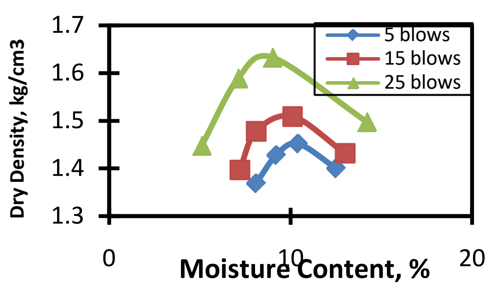

Fig. 1: Effect of moisture content on dry density of termite mound

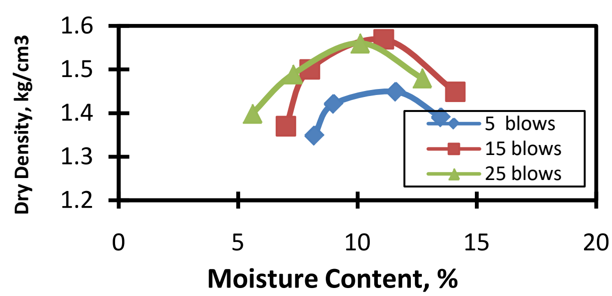

Fig. 2: Effect of moisture content on dry density of clay soil

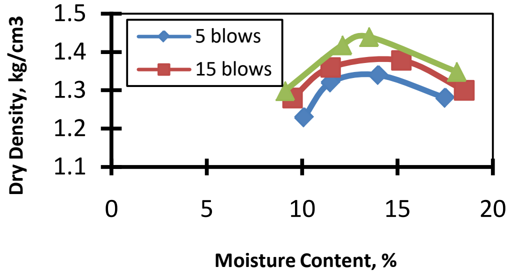

Fig. 3: Effect of moisture content on dry density of cementitious clay

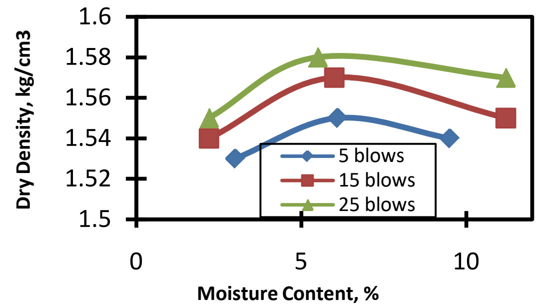

Fig. 4: Effect of moisture content on dry density of clay cement

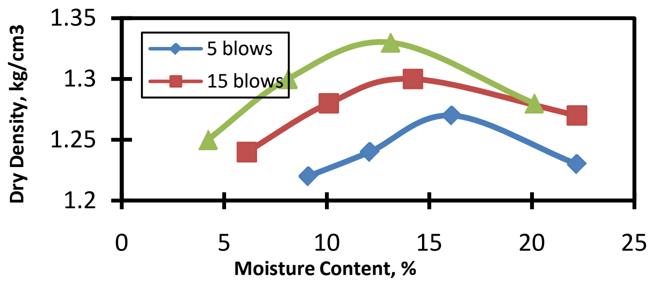

Fig. 5: Effect of moisture content on dry density of concrete

and 1.33 gcm^{-3}, respectively.

The highest moisture level was exhibited by the Clay - Cement sample. Results further revealed that an increase in compactive effort increases the maximum dry density but decreases the optimum water content. This was because higher compactive effort yielded more parallel orientation of the sample particles, which allowed for closer particle orientation and hence a higher unit weight of the sample (Holz and Kowacs, 1981; Ige and Ogunsanwo, 2009). This was manifested in all the samples. These results conform with the results obtained by Ige and Ogunsanwo (2009). This implied that channels with adequate compaction will reduce hydraulic conductivity and hence drastic reduction in seepage.

3.3 Compressive Strength of the Lining Materials

Figure 6 shows the compressive strengths of treatments at 7, 14, 21 and 28 days after lining. The graph shows that the compressive strengths of all the treatments increased with increasing days of curing. This is expected because as the days of curing increased, the void in the specimen continued to reduce due to loss of moisture leading to loss of weight of samples and hence reduction in dry density.

The compressive strength of Concrete of 2.373 N/mm^2 was the highest after 28 days, followed by Burnt Cementitious Clay, Clay Soil, Clay – Cement and Termite Mound, with values of 1.233 N/mm^2, 1.188 N/mm^2,0.692 N/mm^2 and 0.315 N/mm^2, respectively. The values of the compressive strength of the samples were indicative of the stiffness of the composites of the samples and its resilience to scour and cracks that might lead to seepage. The low compressive strength of Termite Mound sample might be due to the high level of organic matter in the sample while, that of Clay - Cement sample might be due to the stabilization of the clay with cement.

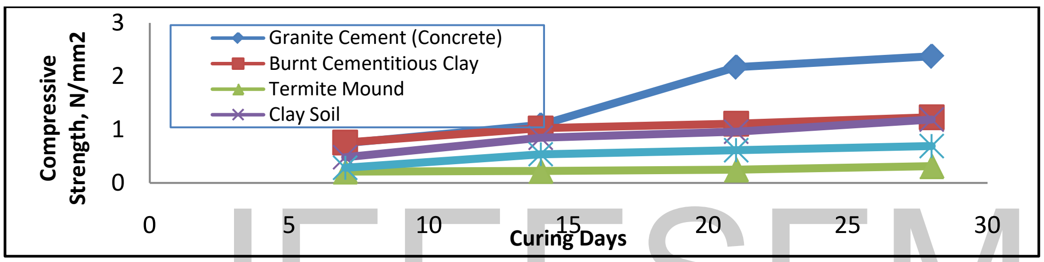

Fig. 6: Compressive strengths of lining materials

Ata *et al.*, 2007, observed a decrease in compressive strength of sandcrete block as the percentage of laterite content increased. Contrary to this, Aguwa (2009) reported a decrease in strength of stabilized laterite as the cement content increased. It could be deduced that the low value of the compressive strength of Clay – Cement might not be unconnected with the low proportion of cement in the clay in conformity with the results of Ata *et al.* (2007). Ithnin (2008), using various ratios of cement, sand and clay, obtained compressive strengths ranging between 0.29 N/mm^2 and 1.38 N/mm^2, which were similar to the range of results obtained in this study.

3.4 Seepage Losses in the Channels

Figure 7 shows the rates of seepage loss plotted against time in days elapsed after the commencement of the ponding. The results of seepage studies of the linings with the different lining materials revealed that seepage losses through the linings decreased appreciably with age of the linings. At different days, the rate of these losses was reduced to nearly constant values.

The losses ranged from 0.034 – 0.092 m^3/m^2/day for Clay soil lining, 0.045 – 0.095 m^3/m^2/day for Termite Mound lining, 0.021 – 0.092 m^3/m^2/day for Clay-Cement, 0.020 – 0.068 m^3/m^2/day for Burnt Cementitious Clay, and 0.020 – 0.057 m^3/m^2/day for Concrete lining. The lowest seepage loss was obtained on Concrete lining, while the highest was obtained on Clay lining. The magnitude of the losses is of the order:

Termite > Clay > Burnt Cementitious Clay >Clay - Cement > Concrete

There was sudden drop in seepage rates in all the treatments from the commencement of ponding till the 7th day, and the seepage losses were at steady rates after a period of between 7 and 9 days in all the linings.

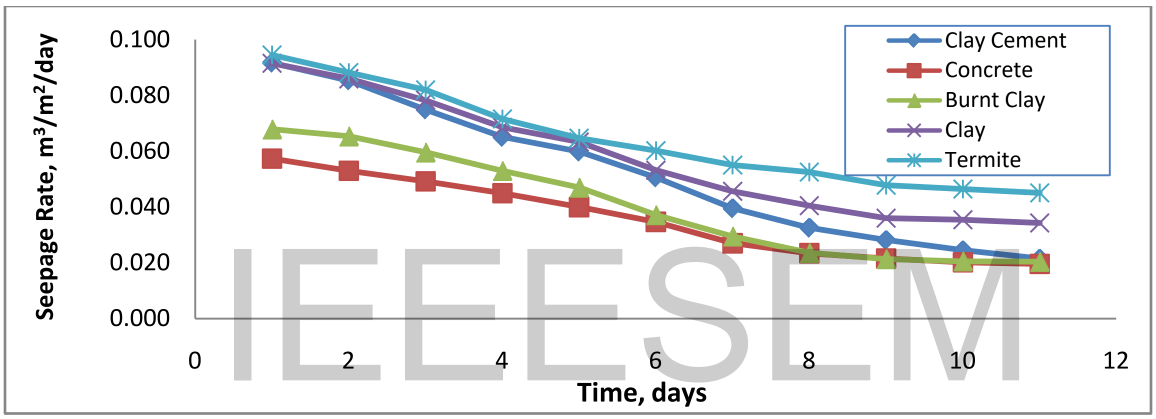

Fig. 7: Seepage rate and time for the channels

The results indicate that Burnt Cementious Clay performed well in comparison with Concrete lining, while Clay – Cement also performed considerably well as the age of lining increased. This shows that Burnt Cementitious Clay and Clay – Cement linings can conveniently replace Concrete for canal lining, however they will not compare with concrete in terms of durability as reflected in the compressive strengths. The results were closed to the values obtained by Khair *et al.*(1984), with seepage rates of 0.037 - 0.125 m^3/m^2/day for unlined channel, 0.033 – 0.063 m^3/m^2/day for Clay Soil and 0.045 – 0.072 m^3/m^2/day for Clay – Jute linings, respectively.

Khair *et al.* (1991) obtained lower values of seepage between 0.00123 – 0.00343 m^3/m^2/day; however, this is expected because these values were obtained in the laboratory with a controlled environment. Hong *et al*. (2007) obtained lower value of seepage rate of 2.33 x $10^{-4}m^3/m^2$/day for termite Mound lining.

4. CONCLUSION

The study revealed the potentials of the local lining materials along with concrete which has conventionally been used for lining. These materials are very promising for utilization in irrigation canal lining because they showed good comparative performances vis-a-vis concrete in terms of consistency, strengths and seepage losses. It can therefore be concluded that linings made of local materials have the potential of reducing seepage on a permanent basis, though not as satisfactory as that of concrete but the need for economy and homeward exploitation of these materials that are indigenous and available in the farmers' environs has supported their utilization.

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