Use of Vetiver Grass Ash as Cement Replacement Materials

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Abstract

The development of a new building material based on vetiver grass ash (hereinafter referred to as VGA) for use in the rural areas of the developing countries is experimentally investigated. The properties of VGA were experimentally studied to consider the possibility of using VGA as a pozzolanic material. An experimental program was conducted to determine the physical and mechanical properties of VGA and cement mortar containing VGA. Moreover, the possible applications of VGA mortar are indicated.

The parameters considered in the experimental program are the ecotypes of vetiver grass as raw material and percentages of VGA replacement. The ecotypes of vetiver grass used in the parametric study were Vetiveria zizanioides and Vetiveria nemoralis namely Prarajchatan and Nakhon Sawan, respectively. The percentages of VGA replacement used in the parametric study were 0, 20, 40, and 60 percent. For VGA fineness, chemical composition, and setting time were investigated. For mortar, compressive strength, amount of water requirement, water permeability, and resistance of acidic attack were investigated. The test results were compared with this of the ordinary Portland cement (hereinafter referred to as OPC) mixes.

Test results revealed that the silica content of VGA was approximately 7% higher and potassium oxide (K_2O) content about seven times higher than in fly ash. According to ASTM requirement VGA can be classified as class C pozzolana. VGA Mortar can be suitably adopted as a construction material for foundations, marine structures, sewers, and other chemically exposed structures.

KEYWORDS: VETIVER GRASS ASH, FLY ASH, POZZOLANIC MATERIAL, CEMENTITIOUS MATERIAL

1. Introduction

In recognition of the serious problem of soil erosion, particularly on cultivated land, His Majesty King Bhumibhol Adulyadej initiated in 1991 the idea of using vetiver grass as a practical tool to reduce soil erosion and improve water conservation in Thailand. After the Royal initiatives, the Department of Land Development in Thailand has been promoting peasants to cultivate vetiver grass for the vegetative of soil and moisture conservation. The root of vetiver grass has a strong and binds the soil to a depth. After the vetiver hedges have properly established, the leaves of vetiver grass can be cut down up to 20 cm above the ground level to encourage tillering and prevent shading of the food crop when the dry season starts, its leaves are used as a mulch at the base of the fruit trees to help retain stored moistures and feed the young palatable leaves to their livestock. Moreover, many developing countries are attempting to develop substitutes for cement from locally available raw materials like agricultural and industrial wastes. Fly ash, rice hush ash, and rice straw ash (hereinafter referred to as FA, RHA, and RSA, respectively) have been proven to be economical partial substitutes for cement. Consequentially, it is reasonable to assume that VGA possesses similar properties like RSA and can be used as a partial substitute for cement. It would therefore be useful to explore this possibility through research. In this paper a feasibility study on the use of VGA as a pozzolana is conducted experimentally. The properties of VGA, namely the fineness, chemical composition, and setting time were determined. To determine the properties of VGA mortar, all mixes having constant consistence were tested. The water requirement of mortar is greatly influenced by the replacement percentage of the VGA. Higher replacement percentage is higher water requirements of VGA cement. On the other hand, the water to cementitious materials ratios of VGA increase with increasing percentage replacement for mortars having a constant flow value as 110±5%. Test results of VGA mortar on the compressive strength, water permeability, and its resistance against acidic attack at various ages are presented and compared with OPC mortar. It is envisaged that VGA, as well as RSA, can be used as a construction material to satisfy the needs of the people living in the rural areas.

2. Preparation of Vetiver Grass Ash

The vetiver grass was obtained from Nakhon Sawan Province by cutting about 100–120 cm long which was 8-10 months age. This vetiver grass belongs to both species of Vetiveria zizanioides and Vetiveria nemoralis in Prarajchatan and Nakhon Sawan ecotypes. The natural color of leaves was green. The vetiver grass was in a damp and fresh condition. Firstly, the vetiver grass was then spread on the concrete floor and directly exposed to sunshine for 1 to 2 weeks. Subsequently, only dried vetiver grass was collected and burnt within 3 to 5 days.

2.1 Burning of Vetiver Grass

Burning of dried vetiver grass was carried out in the ferrocement incinerator as shown in Figure 1 and 2. It was made from a ferrocement drum having 152 cm in diameter and 127 cm in height. Three ventilation windows, each having size of (15 × 15 cm), were provided at the bottom of the incinerator. Inside the drum were placed two wire-gauzed cylinders, having diameter of 8 cm and 150 cm, respectively, to supply adequate air for combustion and hold the vetiver grass. The top of the drum was covered by a detachable galvanized steel chimney. Since vetiver grass is self-burning, no extra fuel was required except at the igniting stage of burning. The burning of vetiver grass yields approximately 9% of whitish black ash which can easily be pulverized to powdered form. The maximum temperature inside the incinerator was found to be 900 ^{o}C. The burning time for 80 kg of vetiver grass was 9 hours whereas for rice straw and rice husk, 75 minutes and 48 hours were required to burn 35 kg and 100 kg, respectively.

2.2 Grinding of VGA

The grinding of vetiver grass ash was carried out using the grinding machine as shown in Figure 3. The grinding conditions are as follows:

- Grinding speed was 50 rpm.
- Grinding media was 6% of volume fraction of grinding chamber. The media consists of 40ϕ12 mm, 40ϕ15 mm, and 20ϕ19 mm mild steel rods with plastic sheath outside.
- Each rod has the same length of 76 cm.
- Input charge of vetiver grass ash was 10 kg.
- The grinding time was 30 minutes.

3. Experimental Program

Through out the experimental work OPC conforming to ASTM as type I was used. The cement used was Elephant brand and is produced by Siam Cement Co. Ltd. The physical and chemical properties of cement are illustrated in Table 1. Natural river sand passing through sieve No. 8 and retaining on sieve No. 100 was used as fine aggregate for entire program. The fineness modulus of fine aggregate was kept constant at 2.75 for all mixes. Ordinary tap water was used for the entire experimental work. The superplasticizer used for the experimental program was Sikament FF, polymer type dispersion, which was supplied by Sika Industry (Thailand) Co. Ltd. The superplasticizer dosage was calculated as the percentage of the cementing materials by weight. Cementing material here refers to cement and pozzolana used. The dosage was kept constant at 2% by weight of cementitious materials.

3.1 Properties of Vetiver Grass Ash

VGA obtained from the burning and grinding process was tested for its fineness and chemical composition. The testing procedures were in accordance with ASTM standard.

3.2 Setting Times of Cement with Partial Pozzolan Replacement

This testing program was carried out in accordance with ASTM C191-92 "Time of Setting of Hydraulic Cement by Vicat Needle". Two different ectypes of vetiver grass ash were separately used to replace 20, 40, and 60 percent of OPC. Both VGA were ground 30 minutes. All the replacement percentages were measured by weight. The results were compared with that of OPC mix. Each specimen paste reached the normal consistency. Results of two conducted test by the same operator on Vicat initial time of setting of same cementitious paste did not differ from each other by more than 34 minutes and on Vicat final time of setting did not differ from each other by more than 56 minutes as specified in ASTM standard.

3.3 Properties of VGA Mortar

In this paper, the compressive strength and water permeability of VGA mortars having seven different mix proportions were tested by varying the percentages of VGA replacement by weight, and ecotype of vetiver grass. Those tests were conducted according to ASTM and JIS standard respectively. The consistency of all mixes was maintained to have a flow of 110±5% as specified by ASTM C 109-80. The detailed mix proportion was tabulated in Table 2. The mixes which contained 0, 20, 40, and 60 percent replacement of cement by each ecotypes of VGA possessed water to cementitious material ratio as illustrated in Table 2. The ratio of sand to cementitious material was kept constant at 2.75 by weight. A control mix, i.e. 0 percent replacement, having w/c = 0.42 was also made. For each mix, nine samples were cast and tested for their compressive strengths at 7, 28, and 91 days. And six samples were cast and tested for their water permeability at 7, 28, and 91 days.

For water permeability test, mould of 150 mm diameter and 40 mm height were cast. Period to testing, the specimens were kept in an oven where the temperature was maintained at 100 ^{o}C. After taking the specimen out of the oven the weight was determined. Then the specimen was kept in the permeability testing machine where pressure of 3 kg/cm^2 was applied into the accumulator by the pump. This pressure was applied for one hour. After an hour the specimen was taken out and the weight of the specimen was determined. After taking the weight, the specimen was broken down into two pieces and the penetration depth of the water was measured. For the calculation of coefficient of water permeability, the empirical formula given by Darcy [8] was used. According to which:

$$K_w^* = \frac{Q}{t}\frac{L}{A}\frac{1}{\Delta h}$$

Where: K_w^* = Coefficient of water permeability (m/s)

Q = Volume of liquid flowing (m^3)

t = Time (s)

L = Thickness of penetrated section (m)

A = Penetrated area (m^2)

Δh = Pressure head (= height of water column) (m)

The resistance to acidic attack of mortar was also determined. All specimens were kept in the saturated lime water for 28 days after casting. Subsequently the specimens were immersed in water for 48 hours. Then all the specimens were weighed and kept in 5% hydrochloric solution (hereinafter referred to as HCl) and 5% sulfuric solution (hereinafter referred to as H_2SO_4) separately for 7, 28, and 91 days. Before weighting to determine the weight loss, the specimens which were in water initially, were again immersed in water for 48 hours. The weight loss development was also determined. The percentage of weight loss was calculated as follows:

$$\text{Percentage of Weight Loss} \quad = \quad \frac{W_1 - W_2}{W_1}$$

Where: W_1 = Weight of specimen before immersing in the acidic solution
W_2 = Weight of specimen after immersing in the acidic solution

3.4 Code of Mixture Proportions

The percentage of cement replacement by pozzolan, type of pozzolan, and ecotype of vetiver grass are used to assign a code of mixture proportions. The code of "MMYYY-X" gives the details as follows:

MM : represents the percentage of cement replacement
YYY : represents the type of pozzolan.
"VGA" is the vetiver grass ash
X : represents the ecotype of vetiver grass.
"P" is the Prarajchatan ecotype.
"N" is the Nakhon Sawan ecotype.

4. Test Results and Discussion

4.1 Properties of VGA

The chemical composition and some physical properties of VGA were tabulated in Table 1. The results revealed that the silica content of VGA was approximately 13% lower and potassium oxide (K_2O) content about 33% higher than in RSA. Moreover, the results revealed that the silica content of VGA was approximately 7% higher and potassium oxide (K_2O) content about seven times higher than in FA. From the results can be seen that VGA does not exactly belong to any of the pozzolana classes given by ASTM standard, however VGA may be group into pozzolana class C if the loss on ignition is not taken into account. The blain fineness of VGA was about 2 and 5 times higher than in RSA and FA respectively.

4.2 Setting Time

The setting time results were tabulated in Table 3. The initial setting time as well as the final setting time was higher than that of the control mix, which contained VGA as cement replacement. As anticipated the final setting time increased as the amount of VGA was increased. The maximum final setting time was for 60 percent replacement by VGA which was 7 hours. However, initial setting time was not effected by the amount of VGA as cement replacement. Moreover, the initial and final setting time were not influenced by ecotype of vetiver grass.

4.3 Water Demand

The observations made for water demand were shown in Figure 1. Comparison was made for different mixed with respect to the control mix. The trend which can be observed from these results is that VGA-Portland cement had much higher water requirement than OPC. Moreover, the trend showed that the amount of water demand increased with the increased amount of VGA content in the mix. The reason for higher water demand for the mix containing VGA is because of the nature of the particle. Since they are porous therefore the surface area becomes high hence more water is needed in order to achieve the required flow value. Moreover, water demand was not affected by ecotype of vetiver grass.

4.4 Compressive Strength

The results of compressive strength at various ages of VGA-Portland cement mortar as compared with that of OPC mortar were presented in Table 4 and Figures 5 and 6. The results can be observed that the higher the content of VGA, the lower compressive strength of mortars. On the other hand, the mixes of VGA as cement replacement have comparatively less strength at early ages as compared to the OPC mix. This is due to lime poor nature of VGA. Therefore making they truly pozzolanic and they need an activator to become hydraulic. The other reason for the lower compressive strength in the case of mixes containing higher amount of VGA as cement replacement being the water to cementitious ratio. It is because as the amount of water increases the strength decreases and this phenomenon can be observed in this research study also. The other important factor governing the strength criteria is the permeability as it being the function of porosity and water to cementitious ratio. Thus for the mix containing only VGA as cement replacement the permeability was high which accounts for it being porous and in turn showed lower compressive strength. For the mix containing the mixture of VGA permeability increased as the amount of VGA was increased. Hence resulting was decreased in the compressive strength. Twenty percent of cement replacement by VGA showed the best results. Moreover, compressive strength was not affected by ecotype of vetiver grass.

The hydration of the Portland cement commences the principal silicates namely tricalcium silicate and dicalcium silicate, and tricalcium aluninate which are in crystalline in the nature decomposes rapidly in water to provide the desired silicate and aluminate ions for the formation of the cementitious hydrates. Therefore for the mix containing higher amount of cement, higher compressive strength can be expected. The slow strength gain in VGA-Portland cement mortar is probably due to the fact that the reaction of active silica with calcium hydroxide is secondary to the hydration of the main compounds namely the tricalcium silicate and dicalcium silicate. The chemical reactions of these two compounds can be written as follows:

$$2(3CaO \bullet SiO_2) + 6H_2O \rightarrow 3CaO \bullet 2SiO_2 \bullet 3H_2O + 3Ca(OH)_2$$

Tricalcium Silicate + Water → Calcium Silicate Hydrate + Calcium Hydroxide

$$2(2CaO \bullet SiO_2) + 4H_2O \rightarrow 3CaO \bullet 2SiO_2 \bullet 3H_2O + Ca(OH)_2$$

Dicalcium Silicate + Water → Calcium Silicate Hydrate + Calcium Hydroxide

The silica in the pozzolana reacts with the liberated calcium hydroxide to form silica gel as follows:

$$3Ca(OH)_2 + SiO_2 \rightarrow 3CaO \bullet 2SiO_2 \bullet 3H_2O$$

Calcium Hydroxide + Silica from pozzolana → Calcium Silicate Hydrate

4.5 Water Permeability

The results of water permeability at various ages of VGA-Portland cement mortar as compared with that of control mortar were presented in Table 5 and Figures 5 and 6. For the mix containing the mixture of VGA the coefficient of water permeability increased as the amount of VGA was increased. Furthermore, the coefficient of water permeability decreased with the age of the mortar. Moreover, water permeability was not affected by ecotype of vetiver grass. Neville[7] has pointed out that this is because at any stage of hydration, the hardened paste consists of very poorly crystallized hydrates of various compounds, which is referred collective as gel, crystals of calcium hydroxide, unhydrated cement and the residue of the water filled spaces in the fresh concrete called capillary pores. The capillary pores represent that part of the gross volume, which has not been filled by the products of hydration. Since these products of hydration occupy more than twice the volume of the original solid phase (cement) alone, therefore the volume of the capillary system is reduced with the progress of hydration. It has been seen that the mature cement paste contains few pores larger than 1 µm, with most pores being smaller than 100 nm. They vary in shape but as shown by measurement of water permeability, forms an interconnected system randomly distributed throughout the cement paste. These interconnected capillary pores are mainly responsible for the water permeability of the hardened cement paste. The way to have low volume of pores the mix should contain particles graded down to the finest size, this is achieved by the use of VGA which fills the space between the cement particles and between the aggregate and cement particles. However it should be considered that this is possible only when the mix has lower water to cement ratio, adequate cement content, proper compaction, and curing condition. Hence the capillary porosity of the paste depends both on the water to cement ratio of the mix and on the degree of hydration. According to Neville[7], if the water to cement ratio is higher than 0.38, the volume of the gel is not sufficient to fill all the space available to it so that there will be some volume of capillary pores left even after the process of hydration has been completed. It was seen that when the water to cement ratio varied from 0.75 to 0.26 the coefficient of water permeability decreases by up to 4 orders of magnitude.

4.6 Specimen Immersed in 5% Sulfuric Acid Solution

The results of acid-resistance of VGA-Portland cement mortar and OPC mortar in term of weight loss were presented in Table 6 and Figures 9 and 10. The mortar cubes were submerged in 5% H_2SO_4 solution for 7, 28, and 91 days. The acid attack on the OPC mortar specimens was much more vigorous than on VGA-Portland cement mortar. By increasing the replacement of VGA, the weight loss of specimens was decreased. Moreover, the weight loss was not affected by ecotype of vetiver grass.

As unhydrated cement paste being an alkaline material therefore they are very much vulnerable to acid attack. When concrete is subjected to acid attack, it may cause cracking or scaling in the mortar. The nature and amount of cracking and scaling mainly depends upon the presence of reactive hydration products of the cement in sufficient concentration. These reactive hydration products are namely calcium hydroxide and reactive alumina phase. In this research, it can be clearly seen that the amount of weight loss for the mix containing 100 percent of cement is maximum. This is mainly because of the higher degree of formation of the calcium hydroxide as hydrated compound upon hydration, which is easily attacked by acids. Mehta [5] in his research also pointed out that as pozzolanic reaction occurs it consumes calcium hydroxide, theoretically 25 percent reactive silica present in a Portland-pozzolan mixture is enough to consume all the available calcium hydroxide from Portland cement hydration. Hence it is obvious to observe more weight loss for the mix containing 100 percent of cement than for the mix containing pozzolan.

Regarding the effect of sulfuric acid on mortar, it is aggressive because in addition to the sulphate attack of the aluminate phase, acid attack on calcium hydroxide can calcium silicate hydrate also takes place. The chemical reaction involved can be written as:

$$H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 + H_2O$$

Sulfuric Acid + Calcium Hydroxide → Calcium Sulphate (Gypsum) + Water

$$3CaO{\cdot}2SiO_2{\cdot}3H_2O + 3H_2SO_4 \rightarrow 3CaSO_4 + 2(SiO_2{\cdot}nH_2O) + 6H_2O$$

Calcium Silicate Hydrate + Sulfuric Acid → Gypsum + Silica Gel + Water

$$3CaSO_4{\cdot}2H_2O + 3CaO{\cdot}Al_2O_3 + nH_2O \rightarrow 3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}31H_2O$$

Gypsum + Tricalcium Aluminate → Calcium Sulfoaluminate (Ettringite)

The products that are formed namely gypsum and ettringite is insoluble salt of calcium and hence leads to expansion and consequent disruption of the set cement paste.

4.7 Specimen Immersed in 5% Hydrochloric Acid Solution

The results of acid-resistance of VGA-Portland cement mortar and OPC mortar in term of weight loss were presented in Table 7 and Figures 11 and 12. The mortar cubes were submerged in 5% HCl solution for 7, 28, and 91 days. The acid attack on the OPC mortar specimens was much more vigorous than on VGA-Portland cement mortar. By increasing the replacement of VGA, the weight loss of specimens was decreased. Moreover, the weight loss was not affected by ecotype of vetiver grass.

The chemical reaction associated with the reaction of hydrochloric acid on acid can be summarized as:

$$2HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O$$

Hydrochloric Acid + Calcium Hydroxide → Calcium Chloride + Water

$$CaCl_2 + 3CaO{\cdot}Al_2O_3 + nH_2O \rightarrow 3CaO{\cdot}Al_2O_3{\cdot}CaCl_2{\cdot}10H_2O$$

Calcium Chloride + Tri Calcium Aluminate → Calcium Chloroaluminate (Friedel's Salt)

The chemical compound, calcium chloride and calcium chloroaluminate formed as a result of the chemical reaction is soluble salts of calcium.

5. Conclusion

From the experimental results it can be concluded that:

1. VGA does not exactly belong to any of the pozzolana classes given by ASTM standard; however VGA may be group into pozzolana class C if the loss on ignition is not taken into account.
2. The final setting time increased with the increase in the percentage of VGA as cement replacement but did not different on initial setting time. Moreover, the mix associated with VGA as cement replacement shown the setting time higher than the OPC mix.
3. VGA increased the water demand with increase in its replacement percentage.
4. The compressive strength was higher for the mix, which contained lower percentage of VGA as cement replacement. The development of strengths for VGA was significant with the age.
5. For the mix containing the mixture of VGA the coefficient of water permeability increased as the amount of VGA was increased. Furthermore, the coefficient of water permeability decreased with the age of the mortar. Moreover, the OPC mortar showed higher water permeability than VGA-Portland cement mortar.
6. With regard to the resistance against 5% H_2SO_4 and 5%HCl, VGA increased the weight loss of mortar with decreased in its replacement percentage. The results indicated that the introduction of VGA in mortar considerable improved its resistance against acidic attack.
7. In the case of VGA-Portland cement mortar, the calcium hydroxide reacts with the silica in VGA to form silica gel. This results in a reduction in the amount of calcium hydroxide, thus making VGA-Portland cement mortar more resistant to acid attack.
8. It is evident that VGA can be used as a partial substitute for cement. The production of VGA requires neither high technology nor sophisticated hardware. The process is simple, economical and well suited for rural areas in the developing countries.

6. References

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Table 1 Physical and Chemical Properties of Cement, VGA, RSA, Mae Moh-FA

Chemical Composition	Cement	VGA	RSA	MM-FA
Silicon Dioxide (SiO_2), %	21.45	57.48	65.94	40.66
Aluminum Oxide (Al_2O_3), %	4.64	3.73	0.99	21.71
Iron Oxide (Fe_2O_3)	3.05	1.71	0.65	11.18
Calcium Oxide (CaO), %	64.99	5.45	4.27	16.45
Magnesium Oxide (MgO), %	0.88	1.24	1.97	3.18
Loss On Ignition (LOI), %	1.33	11.76	13.46	0.11
Sodium Oxide (Na_2O)	0.09	0.12	0.23	1.30
Potassium Oxide (K_2O), %	0.59	15.46	11.66	2.28
Free Lime (CaO), %	0.86	1.79	-	0.38
Physical Properties	**Cement**	**VGA**	**RSA**	**MM-FA**
Specific Gravity	3.15	-	2.240	2.12
Blaine Fineness, cm^2/g	3,200	24,607*	12,860*	5,231
Fineness, Passing Sieve #325, %	8.6	-	5	34.56
Moisture, %	0.11	3.54	2.55	1.26
Color	Green Gray	Whitish Black	Gray	Tan

* Depends on the degree of grinding

Table 2 Mix Proportions of Mortar

Mix Description	Cement (kg/m^3)	Pozzolan (kg/m^3)	Water* to Binder Ratio	Sand (kg/m^3)	Superplasticizer (kg/m^3)
OPC	350	-	0.42	962.50	7
20VGA-P	280	70	0.53	962.50	7
40VGA-P	210	140	0.59	962.50	7
60VGA-P	140	210	0.69	962.50	7
20VGA-N	280	70	0.54	962.50	7
40VGA-N	210	140	0.60	962.50	7
60VGA-N	140	210	0.69	962.50	7

* Water was added such that flow of 110±5% was achieved.

Table 3 Setting Time of Cement Paste

Mix Description	Ecotype	Initial Setting Time (Hrs:Min)	Final Setting Time (Hrs:Min)
OPC	-	1:48	3:35
20% Replacement by PVGA	Prarajchatan	2:34	4:30
40% Replacement by PVGA	Prarajchatan	2:32	6:30
60% Replacement by PVGA	Prarajchatan	2:18	7:00
20% Replacement by NVGA	Nakhon Sawan	2:26	5:00
40% Replacement by NVGA	Nakhon Sawan	2:02	7:00
60% Replacement by NVGA	Nakhon Sawan	2:08	7:00

Table 4 Compressive Strength Results

Mix Description	Compressive Strength (MPa)		
	7 Days	28 Days	91 Days
OPC	58.62	67.53	72.11
20VGA-P	47.06	55.07	63.52
40VGA-P	30.47	39.29	49.72
60VGA-P	21.46	24.16	27.34
20VGA-N	41.90	50.06	56.68
40VGA-N	29.97	39.11	46.89
60VGA-N	19.59	25.06	27.65

Table 5 Water Permeability Results

Mix Description	Coefficient or Water Permeability (m/s)		
	7 Days	28 Days	91 Days
OPC	6.763E-07	3.690E-07	3.650E-07
20VGA-P-30	1.264E-06	7.985E-07	3.468E-07
40VGA-P-30	1.837E-06	6.371E-07	5.536E-07
60VGA-P-30	1.963E-06	1.814E-06	1.219E-06
20VGA-N-30	9.985E-07	5.920E-07	2.675E-07
40VGA-N-30	1.025E-06	6.414E-07	5.053E-07
60VGA-N-30	2.232E-06	1.131E-06	9.874E-07

Table 6 Weight Loss in 5% H_2SO_4 Solution Results

Mix Description	Weight Loss (%)		
	7 Days	28 Days	91 Days
OPC	0.12	0.35	0.69
20VGA-P	0.06	0.17	0.31
40VGA-P	0.01	0.06	0.13
60VGA-P	0.00	0.03	0.09
20VGA-N	0.04	0.12	0.26
40VGA-N	0.01	0.06	0.15
60VGA-N	0.02	0.04	0.06

Table 7 Weight Loss in 5% HCl Solution Results

Mix Description	Weight Loss (%)		
	7 Days	28 Days	91 Days
OPC	0.10	0.12	0.15
20VGA-P	0.07	0.11	0.14
40VGA-P	0.07	0.11	0.14
60VGA-P	0.06	0.10	0.12
20VGA-N	0.06	0.09	0.14
40VGA-N	0.06	0.09	0.13
60VGA-N	0.06	0.09	0.12

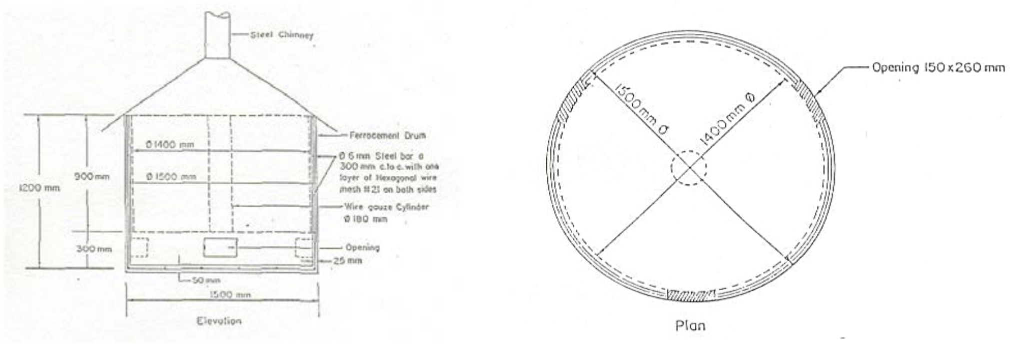

Figure 1 Details of Ferrocement Incinerator

Figure 2 Ferrocement Incinerator

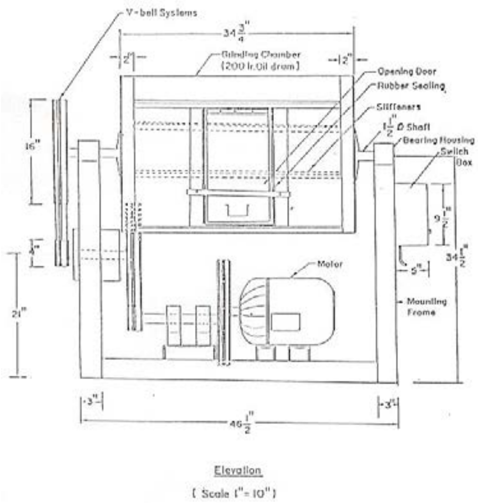

Figure 3 Details of Grinding Machine

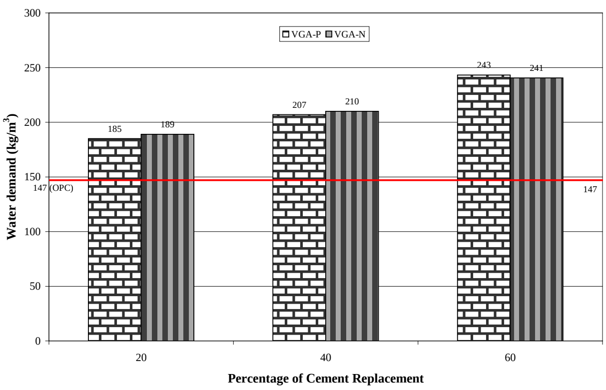

Figure 4 Water Demand for Various Mixed Compared with the Control Mix

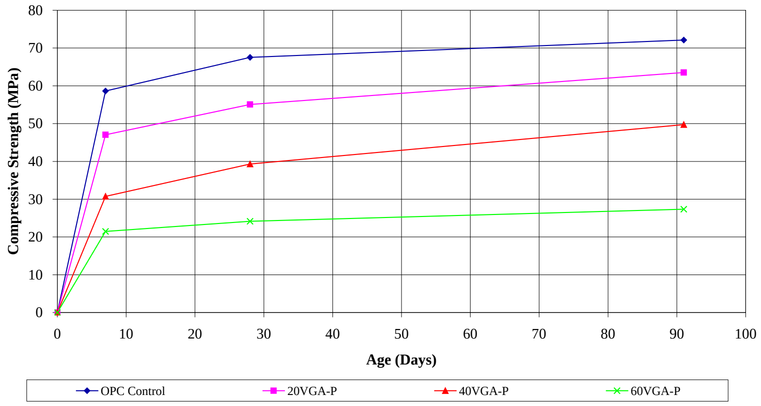

Figure 5 Strength Development

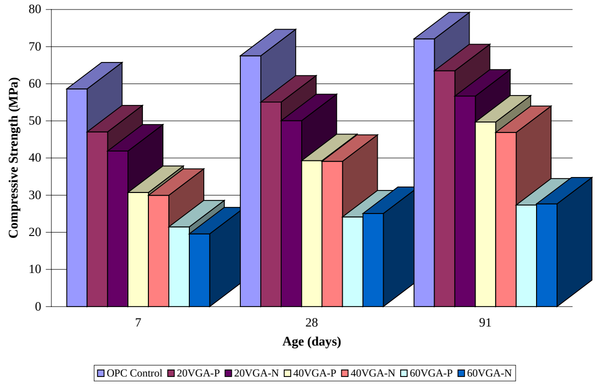

Figure 6 Effect of Ecotype of Vetiver Grass on Compressive Strength

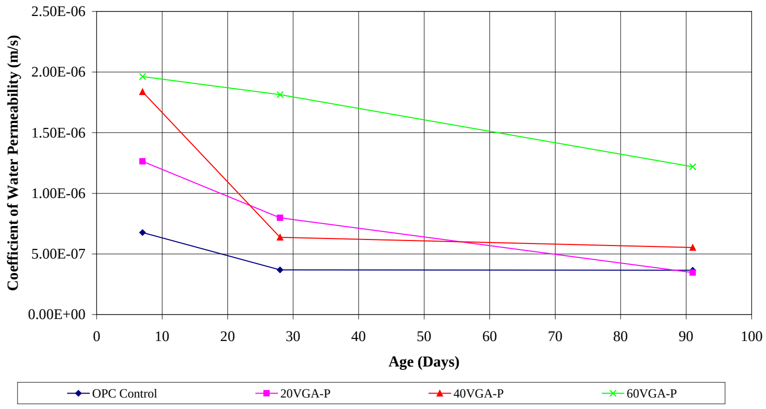

Figure 7 Coefficient of Water Permeability Development

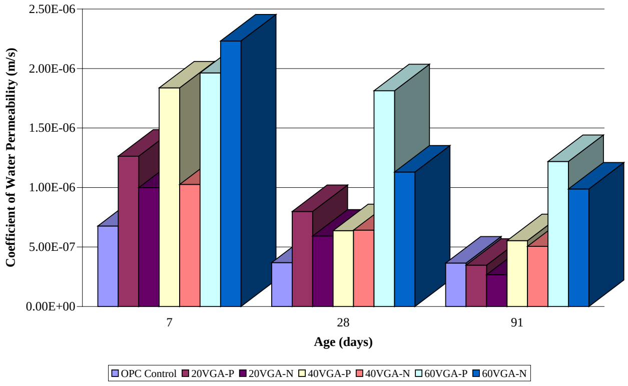

Figure 8 Effect of Ecotype of Vetiver Grass on Coefficient of Water Permeability

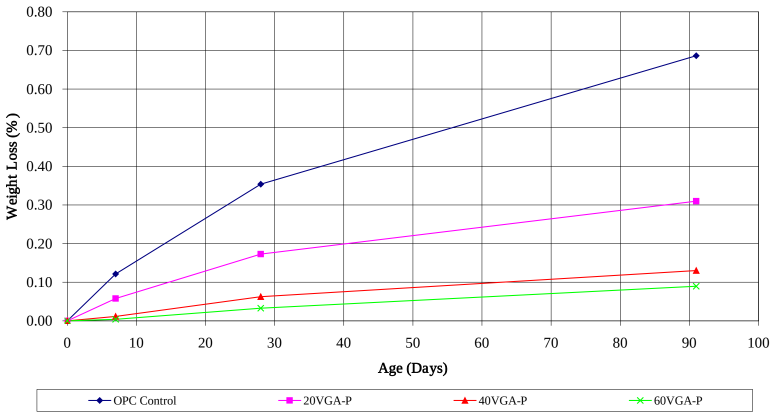

Figure 9 Development of Weight Loss in 5% H_2SO_4 Solution

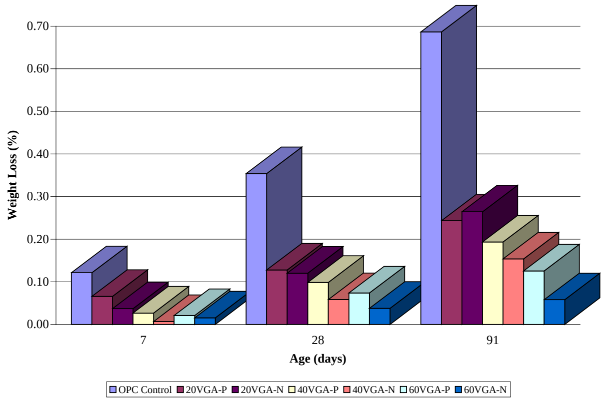

Figure 10 Effect of Ecotype of Vetiver Grass on Weight Loss in 5% H_2SO_4 Solution

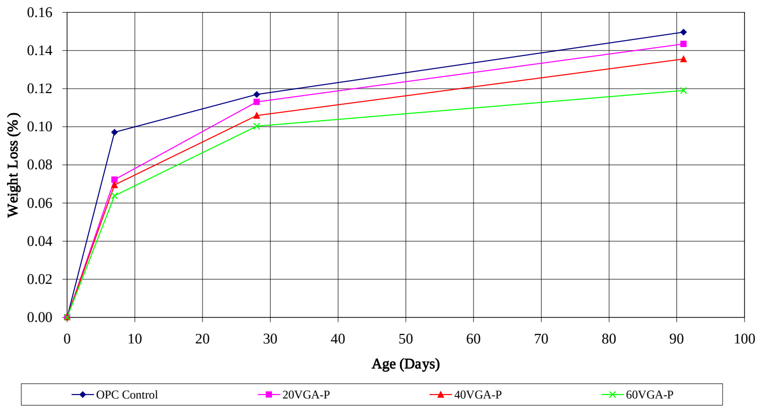

Figure 11 Development of Weight Loss in 5% HCl Solution

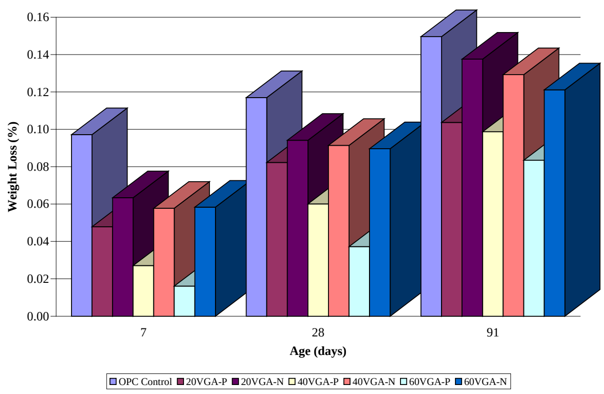

Figure 12 Effect of Ecotype of Vetiver Grass on Weight Loss in 5% HCl Solution