Effect Of Mixing Ratios On The Structural Properties Of Awgbu Twin Clay

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ABSTRACT: Awgbu town is in Orumba North local Government Area of Anambra State, South East of Nigeria, located at Latitude 6° 07' N and Longitude 7° 06'E. The town has two types of clay deposits at Ngene-Agu site called Asha and Ajagworo. The Business of pottery making by Awgbu Women is as old as Awgbu and flourished well till late 1980s when lighter plastic containers took over. Their method of preparation of clays and firing of their pots production is the same with Makurdi preparation and firing of bricks except that Ajagworo is used as an additive to Asha in the ratio of 1:3. This work provides an extension of an established ratio (1:3) at 1100°C to further determine the best ratio that will give the highest compressive strength and minimum cold water absorption at the same established temperature, with a view to promote the use of burnt bricks for structural development and other possible applications in Anambra state, Nigeria where the clay is found. The Bricks was moulded using ratios 0:1, 1:0, 1:1, 1:2, 1:3, 1:4 and 1:5 for Ajagworo and Asha clay soils. The mixtures were tagged JSC_i, where i = 1, 2, 3, 4, 5, 6, 7. The work evaluated the compositional characteristics of the soils and engineering properties of derived bricks to assess their suitability and as alternative to sandcrete as load bearing materials in the construction of houses. The Geo-physical investigations revealed that the soils are composed of varying proportions of sand, silt and clay, with the following proportions; sand 23-61% with an average of 35.4%, clay 19-56% with an average of 32.9%, silt 17-50% with an average of 31.7%, plasticity index ranging from 4.0-47.2 with an average of 27.6 while the sand fraction is mainly fine to medium grained. The chemistry of the soils in their order of abundance of major oxides is Silica SiO2 >Alumina Al2O3 > Iron oxide Fe2O3 > Magnesium oxide MgO > SO3 > Titanium oxide TiO2 > other oxides found in little/negligible sizes. The similarities in the Geo-chemical results suggests that they were all derived from a station point and all the samples fall under Alumino-Silicate type of clay because of their high value of Aluminum oxide and silicon oxide. The crushing strength of the fired test cubes ranges from 1.95-4.95N/MM2 and the cold water absorption ranges from 15.53-29.67%. Samples JSC_5- JSC_7 was able to satisfy the requirements specified by relevant Nigerian standards for fired bricks.

1.0 INTRODUCTION

Clay Brick is the first man made and the oldest artificial building materials known (Henry, 1991). Clays are products of intense chemical weathering of different rock types. The characteristics of the resulting clay depends on the physico-chemical factors dominating the environment of formation (Ushie and Anike, 2010). For structural development, bricks are classified mainly by either the average or minimum compressive strength or the percentage of water absorption (Ibanga *et al*., 2007). According to this classification, minimum compressive strength of bricks should be 3.5N/MM^2 and water absorption should not exceed 20%. A lot of research has been carried out about the conversion of clays for industrial uses. A material is refractory in nature if it has a very high melting point in addition to its physical, chemical, mechanical and thermal properties that makes it suitable for use in furnaces, kilns, reactors, and other high temperature vessels. Omowumi (2010) in his investigation concluded that the properties of refractory clay samples from Onibode, Ara-Ekity, Ibamajo and Ijoko compare favorably with imported fire clay refractories. Hassan and Adeware (2008) found that Onibode refactory clays are suitable for the production of refractory bricks for furnace building. Experimental analysis on the refractory properties of local clay materials for furnace building by Olusola (2005) revealed that all the clay samples were classified as low alumina with Kaolinite nature. An investigation carried out by Hussani (1997) on the refractory properties of bricks produced from five Nigerian clays revealed that all samples were found to possess good refractoriness with excellent firing shrinkage value that fall within 3-5% range of the imported bricks. Tse (2012) obtained water absorption of 3-4%, ignition loss of 31-36% and compressive strength of between 38-111N/mm^2 for Benue clays. These parameters satisfy the requirements specified by relevant Nigerian standards for burnt bricks (NIS: 74, 1976) of which the minimum compressive strength of Bricks for Building is 2.5N/mm^2. To produce good quality bricks, various additives have been used by different researchers such as rice husk (Ibanga and Ahmed, 2007), rice husk Ash (Rahman, 1988) and sawdust (Okongwu, 1988). Amah *et al.* (2015) investigated the compressive strengths ◦of the individual and mixed clays of Ajagworo and Asha in Awgbu, Anambra State at different temperatures and obtained the highest compressive strength of 3.81 at 1100°C at a mixed ratio of 1:3. The cold water absorption was 12.2%. This result showed that the burnt bricks produced from Awgbu clay in the ratio of 1:3 (Ajagworo: Asha clay) is good for structural development.

1.2 Experimental Methods

1.2.1 Preparation of Samples

5 kg of Ajagworo (AJA) and 10 kg of Asha (ASH) clays were obtained from Ngene-agu site at depth of 15 cm to 30 cm and at different points. Root remains and other materials were removed by sieving through ASTM number 40(0.425 mm mesh diameter). The two clays were then mixed in the ratios (AJA: ASH) as 0:1,1:0,1:1,1:2,1:3,1:4,1:5. The mixtures were tagged JSC_i, where i = 1, 2, 3, 4, 5, 6, 7. Portions each of JSC_i soil samples were separately mixed thoroughly with water to a uniform consistency. The bricks were molded using cast iron mold of 15 mm x 9 mm x 8 mm dimensions and compressed locally using wooden plank. The molded bricks were extruded by loosening the mold and carefully removing the bricks. The bricks was left to dry for 14 days before analysis.

1.2.2 Determination of physical properties of the clay

(i) Determination of soil particle sizes of the mixtures

200 grams each of the seven soil samples was soaked for 24 hours and washed through 75 mm sieve diameter. 50 g of what settled down was mixed with 125 ml of Sodium hexametaphosphate solution to help the particles settle down to their various particle sizes. Hydrometer analysis was carried out to obtain the grain sizes of the mixed clay at different ratiosby mixing the samples with water into a measuring cylinder with hydrometer bulb. Various readings were then obtained using a timing device after elapsed time of 2, 5, 8, 15, 30, 60, 120 minutes and 24 hours. The percentage of grain sizes that passed through the sieve (%) was plotted against the particle sizes (mm). From the grain

size data curve, the particle ratios were determined for each of the sample ratios.

(ii) Determination of Atterberg limits

(a) Liquid limit

The liquid limit was determined by placing a portion of the paste on a glass pattern and laced in the cup of the liquid limit apparatus and grooved using a standard grooving tool, while preventing air trapped. Grooves were formed in the soil by pushing the grooving tool forward through the top of the cup to the bottom of the cup at the rate of 2 drops per second. This was repeated until the two halves of the soil specimen met each other at the bottom of the groove, and the number of drops required to close the groove was recorded. Each ratio of the samples were then taken in a porcelain evaporating dish and weighed using a balance of sensitive of 0.01 g. The samples were placed in the oven at 105˚C for 24 hours and weighed again to determine the moisture content. The procedure was repeated each time adding little quantity of tap water. The results were presented in a laboratory reporting sheet and plotted on a graph paper (moisture content % against number of blows) and the best straight line drawn between the paints. The moisture content at twenty-five blows which defines the liquid limit was obtained

(b) Plastic limit

The plastic limit was determined by squeezing and rolling 3g of the soil samples into an ellipsoidal shaped mass. The mass was rolled between the fingers and the glass plate with sufficient pressure and little quantity of water added to roll the mass into a thread of uniform diameter throughout its length. The weight of water was recorded as. The thread was broken into six pieces when the diameter of the thread became 3 mm. The samples were squeezed together between the thumbs and fingers into a uniform mass roughly ellipsoidal in shape and rerolled. The procedures were repeated constantly until the soil can no longer be rolled into a thread. The samples were placed in a container and weighed using a balance of sensitive of 0.01g and the weight of dry soil recorded. They were then placed in the oven at 105˚C for twenty-four hours after which they were reweighed and the weight of oven recorded. The weight difference gave the plastic limit.

(c) Plasticity index

The results of the liquid limit and plastic limit were analyzed and the plasticity index obtained as the numerical difference between the liquid limit and the plastic limit.

(iii) Determination of shrinkage limit

10 g of soil samples for each ratio was placed in an evaporating dish and blended with distilled water so that it forms a smooth paste. Care was taken not to entrap air bubbles. The shrinkage dish were cleaned thoroughly and it's mass taken. The mercury of the shrinkage dish was shifted and the weight of the mercury to preciseness of 0.1 g was recorded. The interior part of the shrinkage dish was coated with a layer of Vaseline and the soil samples positioned in the middle of the shrinkage dish equivalent to approximately one-third the size of the shrinkage dish. The shrinkage dish was distorted on a stable cushioned surface and the paste was allowed to flow to the edges. The weight of the wet soil was recorded. The soil was then left to dry and the weight of the dry soil recorded. The dry soil were taken out from the shrinkage dish and placed in the glass plate. The mercury exiled by the dry path in the evaporating dish were gathered and shifted to the measuring dish. The weight of the mercury to a preciseness of 0.1 g was computed and the size of the dry path equivalent to the weight of specimen divided by the specific gravity of the mercury. The procedure was recorded and the linear shrinkage obtained.

(iv) Determination of soil porosity

5 g of dry soil samples of different ratios at fired state where left in a hot air oven at 105˚C for 24 hours and then weighed using a balance. The weights of the dry sample were recorded and the volume of the 100 ml graduated cylinder was also recorded and the bulk density was derived . The sand was transferred in a container, and 60 ml of water was added to the 100 ml graduated cylinder and the exact water volume was recorded. The 5 g of sand was then transferred from the container back into the cylinder and stirred until trapped air was removed and the volume recorded. The difference in the volumes gave the volume of the soil particle. The particle density was calculated by dividing the weight of the sand by the volume of sand particles . The Soil porosity was thus determined.

1.2.3 Determination of chemical contents of soil mixtures

(i) Determination of elemental contents

The elemental contents of the clay samples were determined at raw state and fired state (1100˚C) using X-ray fluorescent (XRF) analysis at the soil science laboratory of Ahmadu Bello University Zaria.1 gram of clay sample was added to 10 grams of lithium tetra borate anhydrous solution ($Li_2B_4O_7$) which act as a fluxing agent. The constituents were mixed inside a crucible which was already cleansed with methylated spirit to prevent contamination and heated up to 500˚C for 8 minutes and allowed to cool at room temperature. The fused samples were placed in a tinted glass and were analyzed by the x-ray fluorescent.

1.2.4 Determination of mechanical properties of the brick

(i) Cold water absorption

24 hours cold water absorption of the fired bricks at 1100˚Cwere analyzed at the Civil Engineering laboratory, University of Agriculture Makurdi, by a 24 hour immersion in cold water as specified by the standard organization of Nigeria. The seven bricks were preconditioned each, one after the other by drying in a ventilated oven at 10˚C until it attained constant mass and then cooled to a room temperature and weighed to note its initial weight. The weight of the initial mass was subtracted from the weight of dried sample and recorded. The preconditioned test piece was immersed in cold water at room temperature (29˚C ± 2˚C) for 24 hours and there after removed and traces of water wiped off. The test piece was then weighed to note its increased weight. The increased weight was subtracted from the dry sample and recorded. Water absorption defined as the relative increase in weight, was determined.

(ii) Compressive strength

The compressive strengths of each brick were determined in accordance with the specifications of the standard organization of Nigeria (SON) as contained in test for compressive strength of solid bricks using the testing machine at the Civil Engineering department, University of Agriculture Makudi. A 40 mm platen was used on the compressive testing machines. The seven cubes were preconditioned by immersion in cold water at room temperature (29°C ± 2°C) for 24 hours, removed and all traces of water wiped off and then stored under moist conditions for 24 hours prior to testing. Each test piece was centrally positioned between the platens of the testing machine, and the load was gradually increased until failure occurred.

2.0 Results

Table 1: *Grain Size Analysis Result (0:1) Initial mass 200g*

Sieve Diameter (mm)	Mass Retained (g)	% Retained	%Passing
10.0000000	-	-	100.0
6.3000000	-	-	100.0
5.0000000	-	-	100,0
3.3500000	12.0	6.0	94.0
2.3600000	10.6	5.0	89.0
1.7000000	8.8	4.0	85.0
1.1800000	11.0	5.5	79.5
0.0850000	14.0	7.0	72.5
0.0600000	23.0	11.5	61.0
0.0425000	18.5	9.0	52.0
0.0300000	17.9	8.5	43.5
0.0150000	12.4	6.0	37.5
0.0075000	9.5	4.5	33.0
0.0000034	5.9	3.9	21.0
0.0000017	6.9	7.2	19.0
0.0000012	7.0	7.8	19.0
0.0000009	5.8	6.7	19.0
0.0000007	6.7	5.5	20.0
0.0000005	4.7	2.7	18.0

Table 2: *Grain Size Analysis Result (1: 0)*

Sieve Diameter (mm)	Mass Retained (g)	% Retained	%Passing
10.0000000	-	-	100.0
6.3000000	-	-	100.0
5.0000000	-	-	100.0
3.3500000	2.6	1.3	98.7
2.3600000	4.6	2.3	96.4
1.7000000	10.6	5.3	91.1
1.1800000	7.4	3.7	87.4
0.0850000	50.2	25.1	62.3
0.0600000	10.2	5.1	57.2
0.0425000	7.6	3.8	53.4
0.0300000	10.6	5.3	48.1
0.0150000	12.8	6.4	41.7
0.0075000	9.4	4.7	37.0
0.0000034	7.5	6.7	35.1
0.0000017	9.5	8.9	34.0
0.0000012	7.8	6.8	34.0
0.0000009	6.7	6.9	33.5
0.0000007	5.8	3.9	32.4
0.0000005	8.9	7.9	31.0

Table 3: *Grain Size Analysis Result (1: 1)*

Sieve Diameter (mm)	Mass Retained (g)	% Retained	% Passing
20.0000000	-	-	100.0
14.0000000	-	-	100.0
10.0000000	-	-	100.0
6.3000000	-	-	100.0
5.0000000	-	-	100.0
3.3500000	8.4	4.0	96.0
2.3600000	6.4	3.0	93.0
1.7000000	6.5	3.0	90.0
1.1800000	7.8	3.5	86.5
0.0850000	5.9	2.5	84.0
0.0600000	5.2	2.5	81.5
0.0425000	7.4	3.5	78.0
0.0300000	8.4	4.0	74.0
0.0150000	5.6	2.5	71.5
0.0075000	3.5	1.5	70.0
0.0000034	4.7	6.8	49.0
0.0000017	5.4	6.8	45.0
0.0000012	6.7	5.9	39.0
0.0000009	4.8	6.8	38.0
0.0000005	7.3	7.8	32.0

Table 4: *Grain Size Analysis Result (1: 2)*

Sieve Diameter (mm)	Mass Retained (g)	% Retained	% Passing
6.3000000	-	-	100.0
5.0000000	-	-	100.0
3.3500000	7.0	3.5	96.5
2.3600000	5.0	2.5	94.0
1.7000000	5.7	2.5	91.5
1.1800000	6.5	3.0	88.5
0.0850000	5.5	2.5	86.0
0.0600000	5.6	2.5	83.5
0.0425000	4.0	2.0	81.5
0.0300000	8.0	4.0	77.5
0.0150000	9.0	4.5	73.0
0.0075000	2.0	1.0	72.0
0.0000034	5.7	6.0	59.0
0.0000024	6.3	7.2	55.0
0.0000017	3.4	7.8	51.0
0.0000012	5.2	5.6	45.0
0.0000009	7.4	5.3	43.0
0.0000007	9.2	4.9	42.0
0.0000005	5.3	4.3	34.0

Table 5: *Grain Size Analysis Result (1: 3)*

Sieve Diameter (mm)	Mass Retained (g)	% Retained	%Passing
10.0000000	-	-	100.0
6.3000000	-	-	100.0
5.0000000	-	-	100.0
3.3500000	10.0	5.0	95.0
2.3600000	8.0	4.0	91.0
1.7000000	8.0	4.0	87.0
1.1800000	11.0	5.5	81.5
0.0850000	10.0	5.0	76.5
0.0600000	9.0	4.5	72.0
0.0425000	12.0	6.0	66.0
0.0300000	8.0	4.0	62.0
0.0150000	7.0	3.5	58.5
0.0075000	4.0	2.0	56.5
0.0000034	5.7	9.5	33.0
0.0000017	4.0	4.8	27.0
0.0000012	9.5	6.9	23.0
0.0000090	7.8	5.8	21.0
0.0000070	4.7	8.2	19.0
0.0000005	6.8	3.8	18.0

Table 6: *Grain Size Analysis Result (1: 4)*

Sieve Diameter (mm)	Mass Retained (g)	% Retained	% Passing
20.0000000	-	-	100.0
14.0000000	-	-	100.0
10.0000000	-	-	100.0
6.3000000	-	-	100.0
5.0000000	-	-	100.0
3.3500000	11.0	5.5	94.5
2.3600000	6.0	3.0	91.5
1.7000000	6.8	3.0	88.5
1.1800000	5.9	2.5	86.0
0.0850000	5.6	2.5	83.5
0.0600000	5.4	2.5	81.0
0.0425000	4.5	2.0	79.0
0.0300000	8.6	4.0	75.0
0.0150000	8.7	4.0	71.0
0.0075000	2.8	1.0	70.0
0.0000034	5.6	5.0	33.0
0.0000017	7.4	4.0	31.0
0.0000012	9.7	7.8	29.0
0.0000009	3.8	5.3	24.0
0.0000005	84	6.4	20.0

Table 7: *Grain Size Analysis Result (1: 5)*

Sieve Diameter (mm)	Mass Retained (g)	% Retained	% Passing
6.3000000	-	-	100.0
5.0000000	-	-	100.0
3.3500000	7.0	3.5	96.5
2.3600000	6.0	3.0	93.5
1.7000000	10.0	5.0	88.5
1.1800000	16.0	8.0	80.5
0.0850000	15.0	7.5	73.0
0.0600000	13.0	6.5	66.5
0.0425000	8.0	4.0	62.5
0.0300000	7.0	3.5	59.0
0.0150000	5.0	2.5	56.5
0.0075000	6.0	3.0	53.5
0.0000034	8.0	5.0	25.0
0.0000024	3.0	7.0	25.0
0.0000017	7.0	9.0	25.0
0.0000012	2.0	8.4	23.0
0.0000009	4.0	9.2	23.0
0.0000007	5.0	8.4	22.0
0.0000005	8.0	7.8	18.0

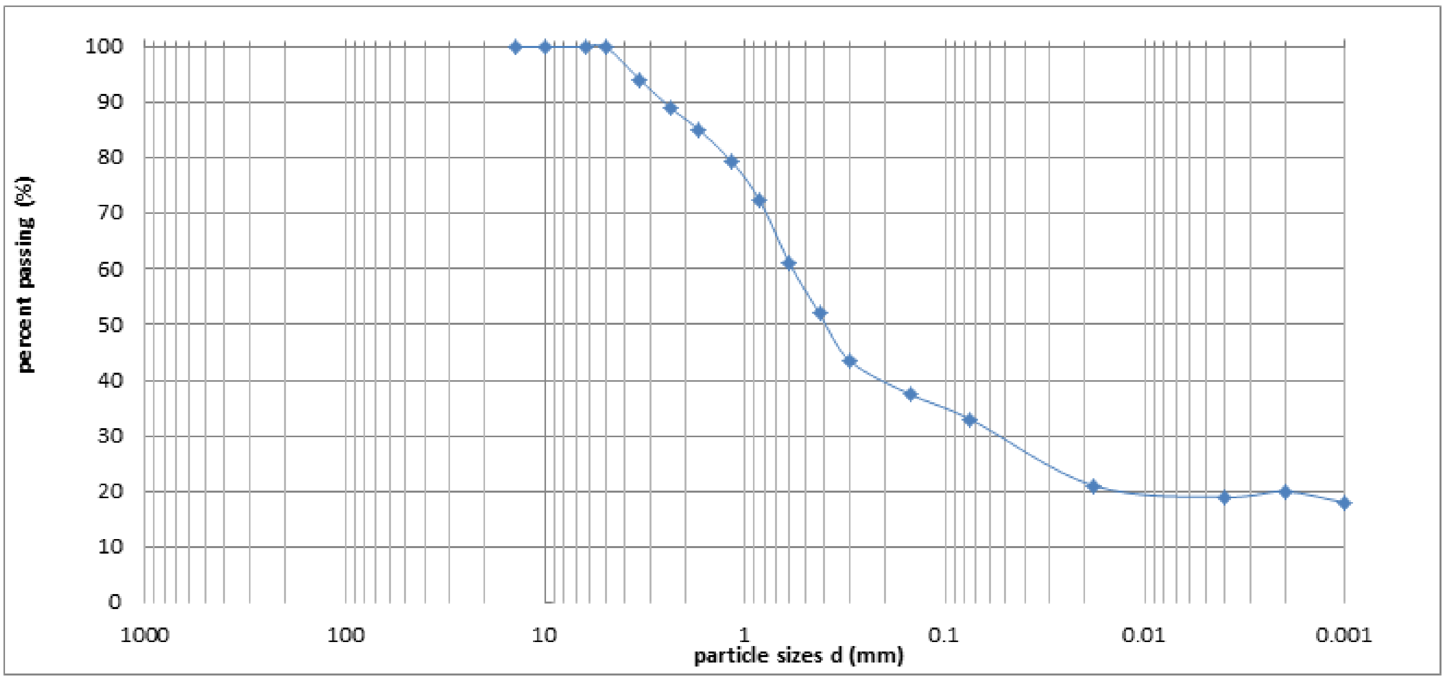

Figure 1: *Grain Size Data Curve of Sample Ratio 0:1*

<table>
<tr><td rowspan="2">Cobles</td><td colspan="2">Gravel</td><td>Sand</td><td>Sand</td><td>Sand</td><td rowspan="2">Silt</td><td rowspan="2">Clay</td></tr>
<tr><td>Coarse</td><td>Fine</td><td>Coarse</td><td>Medium</td><td>Fine</td></tr>
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Percentage Sand: 36%
Percentage Clay: 39%
Percentage Silt: 25%

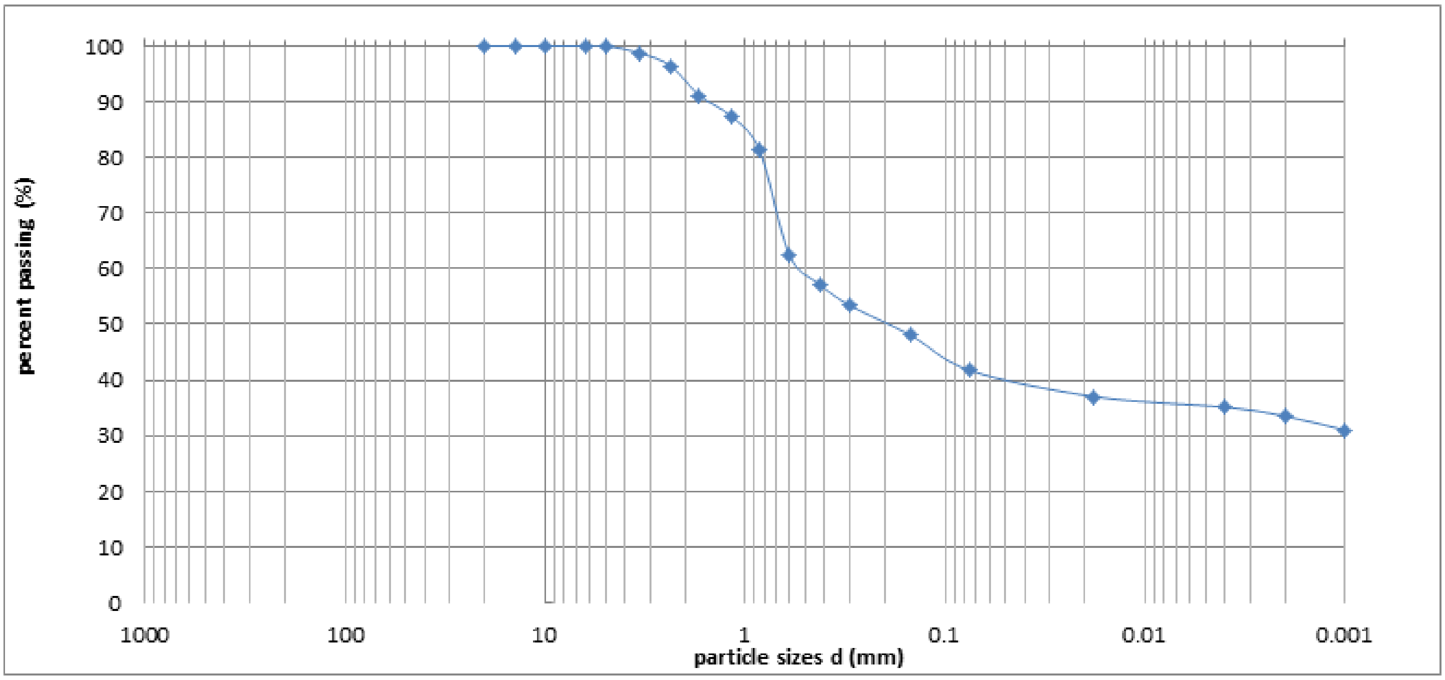

Figure 2: *Grain Size Data Curve of Sample Ratio 1:0*

Cobles	Gravel		Sand			Silt	Clay
	Coarse	Fine	Coarse	Medium	Fine		

Percentage sand: 61%
Percentage clay: 19%
Percentage silt: 20%

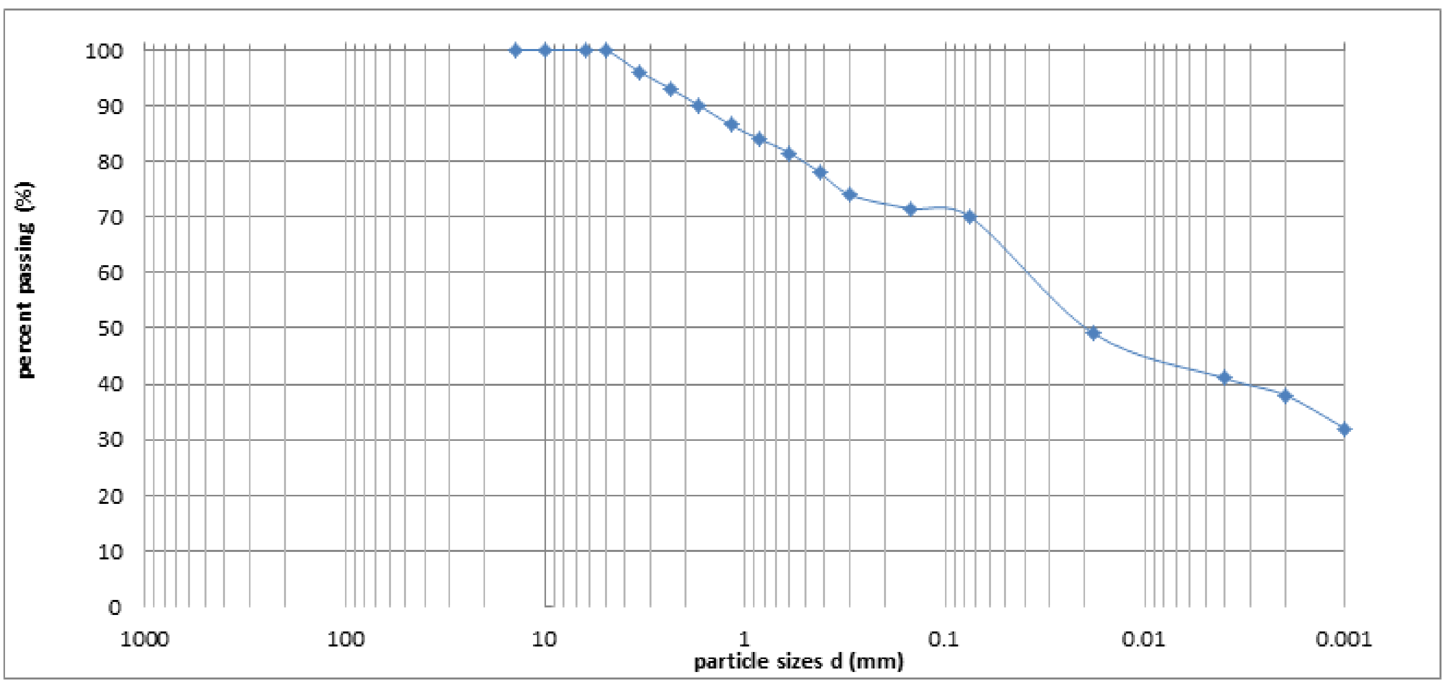

Figure 3: *Grain Size Data Curve of Sample Ratio 1:1*

Cobles	Gravel		Sand	Sand	Sand	Silt	Clay
	Coarse	Fine	Coarse	Medium	Fine		

Percentage Sand: 27%
Percentage Clay: 46%
Percentage Silt: 27%

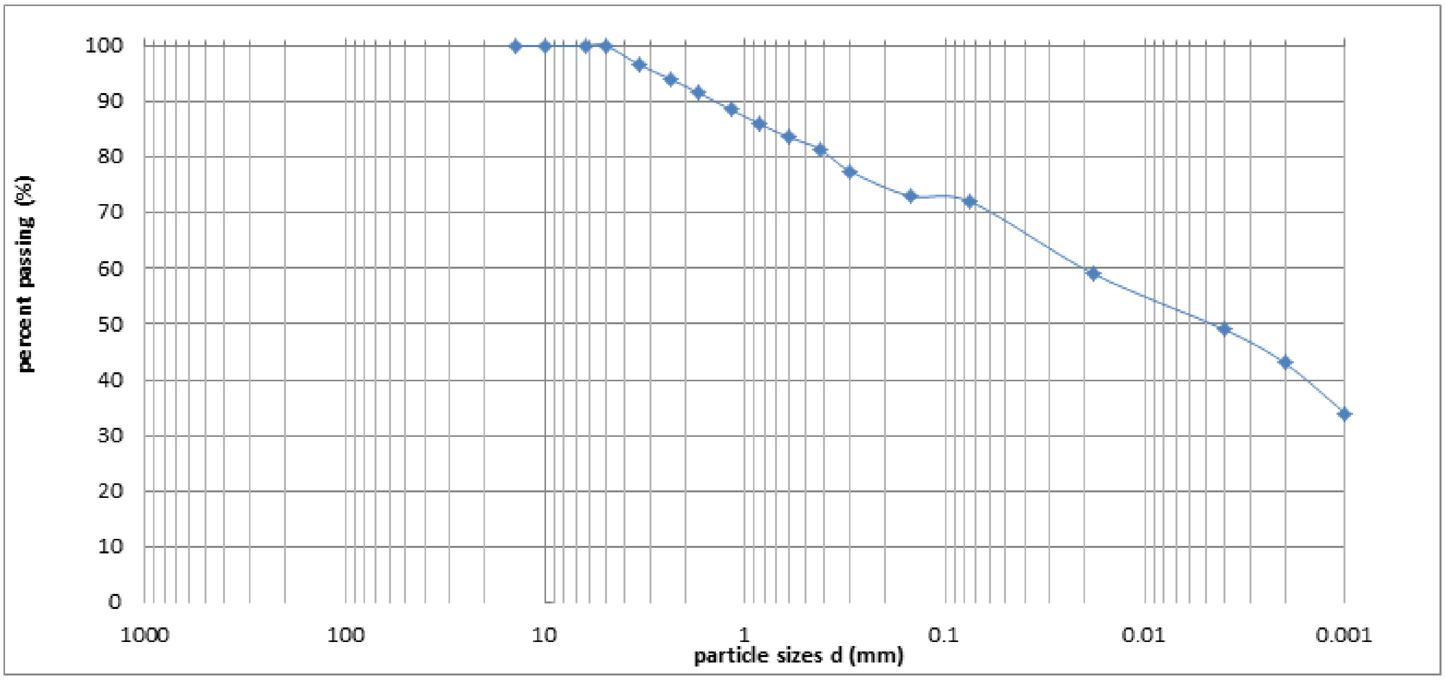

Figure 4: *Grain Size Data Curve of Sample Ratio 1:2*

Cobles	Gravel		Sand	Sand	Sand	Silt	Clay
	Coarse	Fine	Coarse	Medium	Fine		

Percentage Sand: 27%
Percentage Clay: 56%
Percentage Silt: 17%

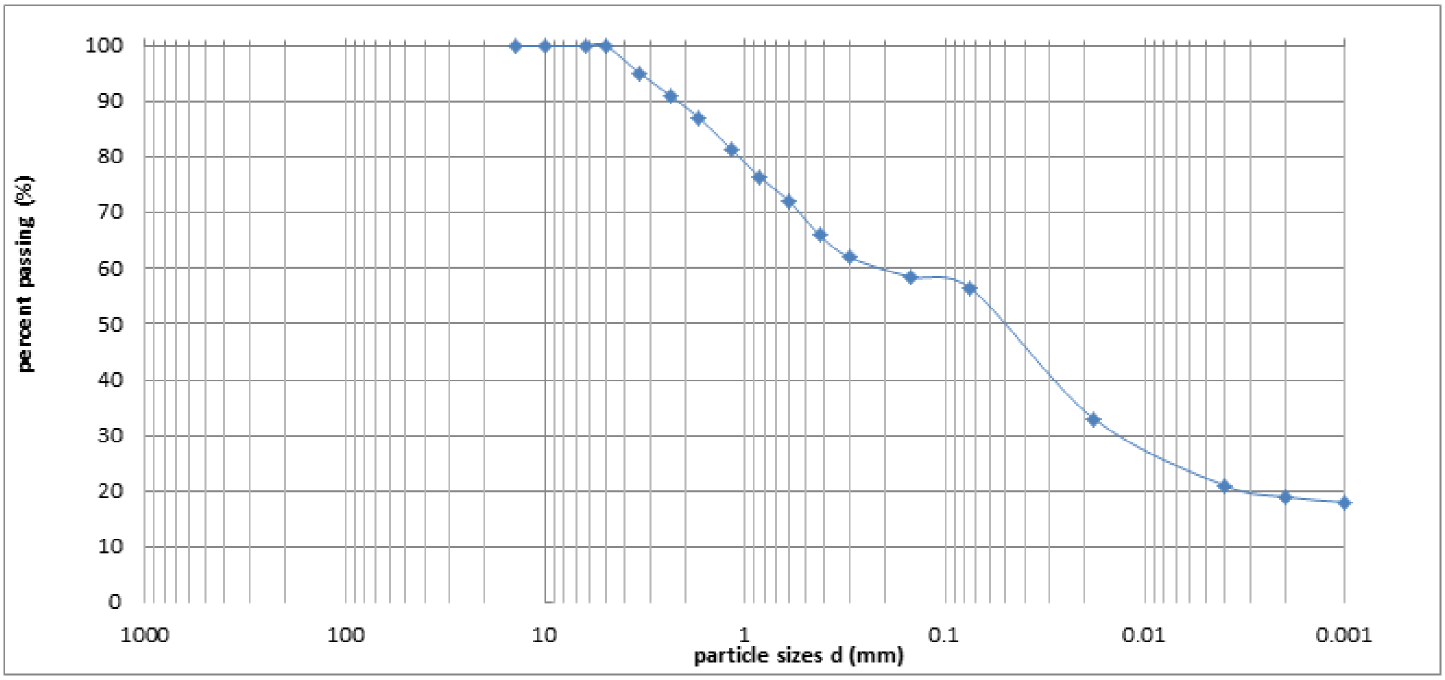

Figure 5: *Grain Size Data Curve of Sample Ratio 1:3*

Cobles	Gravel		Sand	Sand	Sand	Silt	Clay
	Coarse	Fine	Coarse	Medium	Fine		

Percentage Sand: 30%
Percentage Clay: 50%
Percentage Silt: 20%

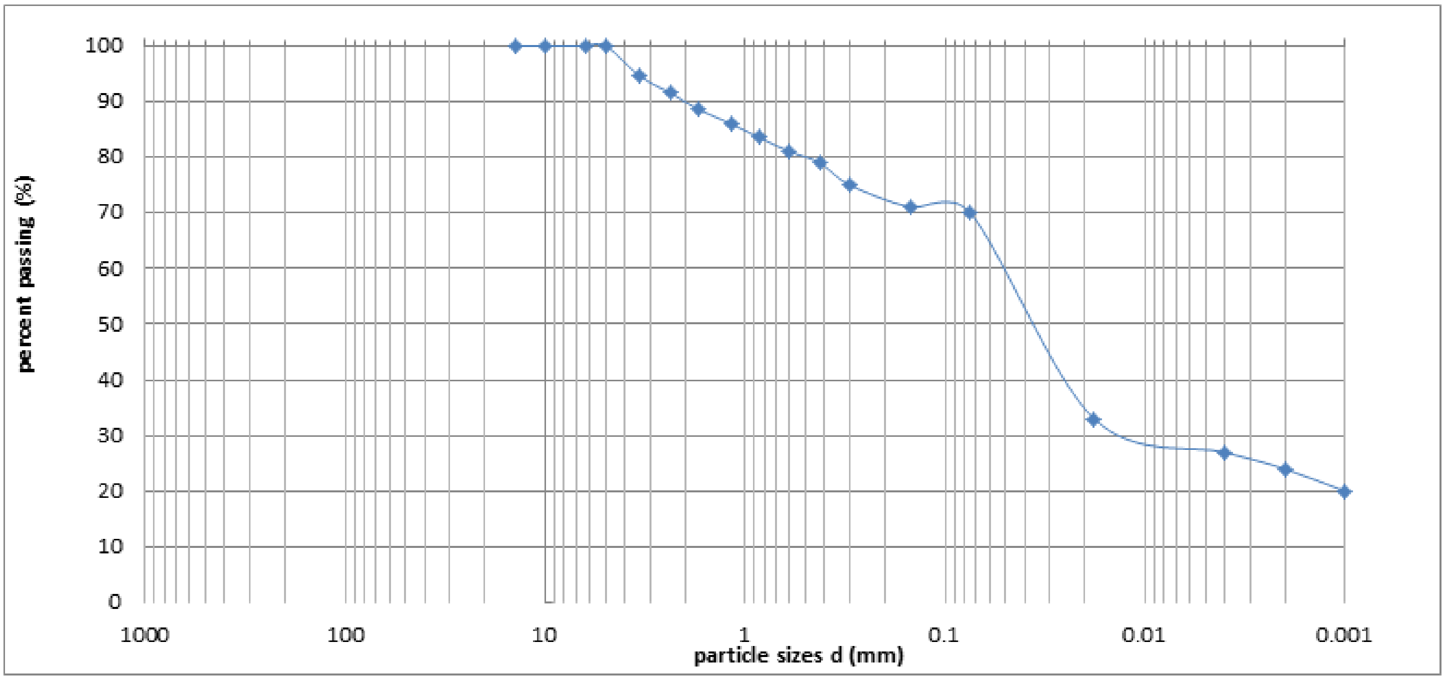

Figure 6: *Grain Size Data Curve of Sample Ratio 1:4*

Cobles	Gravel		Sand	Sand	Sand	Silt	Clay
	Coarse	Fine	Coarse	Medium	Fine		

Percentage Sand: 22%
Percentage Clay: 48%
Percentage Silt: 30%

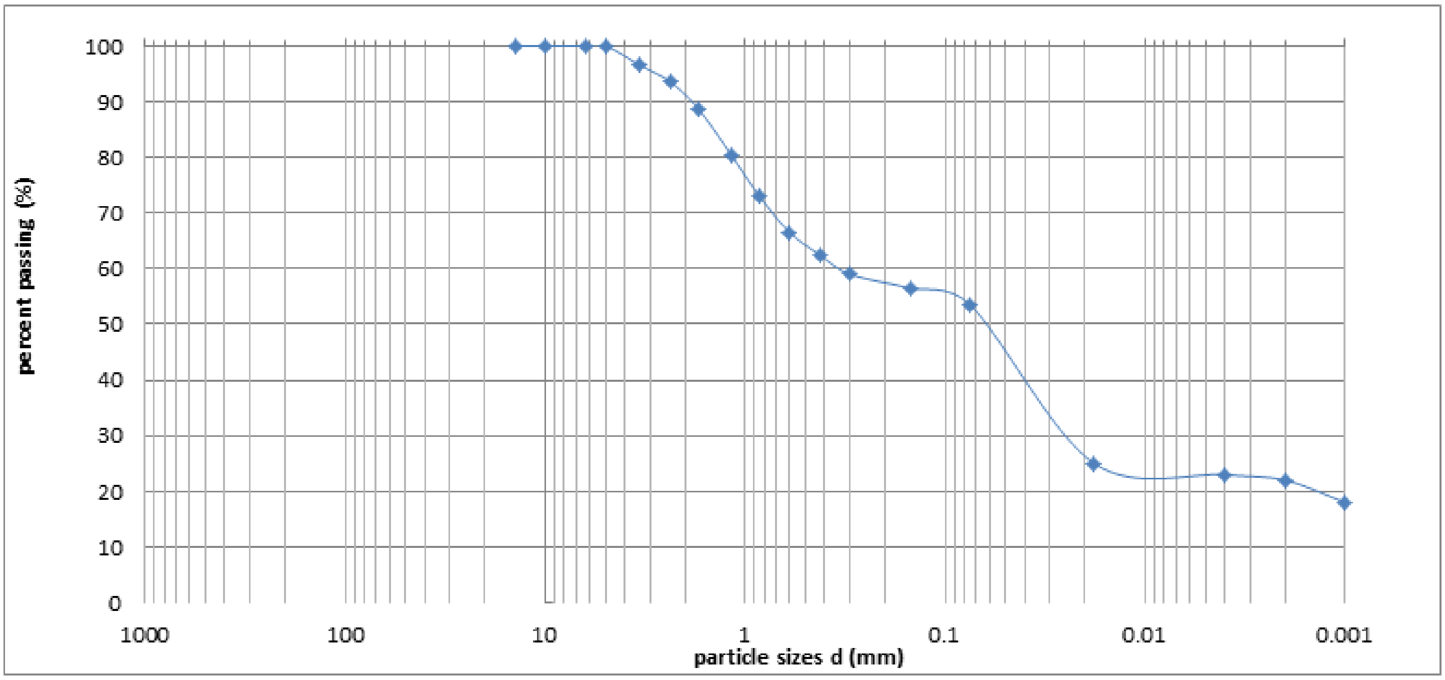

Figure 7: *Grain Size Data Curve of Sample Ratio 1:5*

Cobles	Gravel		Sand	Sand	Sand	Silt	Clay
	Coarse	Fine	Coarse	Medium	Fine		

Percentage Sand: 25%
Percentage Clay: 55%
Percentage Silt: 20%

***Table 8:** Atterbergs Limits for 0:1 Ratio*

Borehole No:		Sample No.			Depth (m)			m
Total weight of sample (g)			Weight passing No.40(0.425mm) sieve					
Soil/water curing time(hr.)			%passing No.40(0.425mm sieve					
Test		Plastic Limits			Liquid limit			
Can number/No .of blows		16	21		46/14	6/23	P2/35	46/46
Weight of Can + wet soil	g	13.2	14.7		25.5	32.5	21.2	27.5
Weight of Can + Dry soil	g	13.1	14.6		20.4	25.9	18.2	24.6
Weight of moisture	g	0.1	0.1		5.1	6.6	3.0	2.9
Wt. of container	g	12.9	14.2		13.5	15.6	12.6	13.6
Weight of dry soil	g	0.3	0.4		6.9	10.3	5.6	11.0
Wt. of moisture	%	33.3	25.0		73.9	64.1	54.6	26.4

Liquid limit (LL)	%	**61.0**	Linear shrinkage LS =(L_1-L_2/ L_1) x 100	
Plastic limit (PL)	%	**29.2**	L_1= Initial length of specimen (mm)	**140**
Plastic Index(PI)	%	**31.8**	L_2= Final length of specimen (mm)	**119**
Liquid Index(LI)	%			
Linear Shrinkage (LS)	%	**15.0**		

***Table 9:** Atterbergs Limits for 1:0 Ratio*

Borehole No:		Sample No.			Depth (m)			m
Total weight of sample (g)			Weight passing No.40(0.425mm) sieve					
Soil/water curing time(hr.)			%passing No.40(0.425mm sieve					
Test		Plastic Limits			Liquid limit			
Can number/No .of blows		77	103		5/9	8/16	4/29	46/45
Weight of Can + wet soil	g	7.8	8.2		20.3	23.2	22.6	23.0
Weight of Can + Dry soil	g	7.5	7.8		18.0	21.1	20.4	20.6
Weight of moisture	g	0.3	0.4		2.3	2.1	2.2	2.4
Wt. of container	g	6.7	6.9		14	16.6	15	14
Weight of dry soil	g	0.8	0.9		4.0	4.5	5.4	6.6
Wt. of moisture	%	37.5	44.4		57.5	46.7	40.1	36.4

Liquid limit (LL)	%	**45.0**	Linear shrinkage LS =(L_1-L_2/ L_1) x 100	
Plastic limit (PL)	%	**41.0**	L_1= Initial length of specimen (mm)	**140**
Plastic Index(PI)	%	**4.0**	L_2= Final length of specimen (mm)	**134**
Liquid Index(LI)	%			
Linear Shrinkage (LS)	%	**4.3**		

***Table 10:** Atterbergs Limits for 1:1 Ratio*

Borehole No:		Sample No.			Depth (m)			m
Total weight of sample (g)			Weight passing No.40(0.425mm) sieve					
Soil/water curing time(hr.)			%passing No.40(0.425mm sieve					
Test		Plastic Limits			Liquid limit			
Can number/No .of blows		36	P6		3/14	32/20	31/34	13/45
Weight of Can + wet soil	g	14.4	16.2		23.9	26.6	24.2	22.3
Weight of Can + Dry soil	g	14.1	15.8		20.6	23.8	19.2	20.3
Weight of moisture	g	0.4	0.4		3.3	2.8	2.4	2.0
Wt. of container	g	13.0	14.6		14.0	17.6	13.2	15.0
Weight of dry soil	g	1.1	1.2		6.6	6.2	6.0	5.3
Wt. of moisture	%	36.4	33.3		50.0	45.2	40.0	37.7

Liquid limit (LL)	%	**44.0**	Linear shrinkage LS =(L_1-L_2/ L_1) x 100	
Plastic limit (PL)	%	**34.9**	L_1= Initial length of specimen (mm)	**140**
Plastic Index(PI)	%	**9.1**	L_2= Final length of specimen (mm)	**130**
Liquid Index(LI)	%			
Linear Shrinkage (LS)	%	**7.1**		

***Table 11:** Atterbergs Limits for 1:2 Ratio*

Borehole No:		Sample No.			Depth (m)			m
Total weight of sample (g)			Weight passing No.40(0.425mm) sieve					
Soil/water curing time(hr.)			%passing No.40(0.425mm sieve					
Test		Plastic Limits			Liquid limit			
Can number/No .of blows		7	6		43/15	3X/22	11/33	14/47
Weight of Can + wet soil	g	15.4	17.6		30.4	23.8	22.8	26.7
Weight of Can + Dry soil	g	15.1	17.6		25.0	19.8	19.0	23.3
Weight of moisture	g	0.3	0.2		5.4	4.0	3.8	3.4
Wt. of container	g	14.0	16.7		18.1	14.2	13.6	17.9
Weight of dry soil	g	1.1	0.9		6.9	5.6	5.4	5.4
Wt. of moisture	%	27.3	22.2		78.3	71.4	70.4	63.0

Liquid limit (LL)	%	**72.0**	Linear shrinkage LS =(L_1-L_2/ L_1) x 100	
Plastic limit (PL)	%	**24.8**	L_1= Initial length of specimen (mm)	**24.8**
Plastic Index(PI)	%	**47.2**	L_2= Final length of specimen (mm)	**47.2**
Liquid Index(LI)	%			
Linear Shrinkage (LS)	%	**12.1**		

Table 12: *Atterbergs Limits for 1:3 Ratio*

Borehole No:	Sample No.			Depth (m)			m
Total weight of sample (g)		Weight passing No.40(0.425mm) sieve					
Soil/water curing time(hr.)		%passing No.40(0.425mm sieve					
Test	Plastic Limits			Liquid limit			
Can number/No .of blows	3	13		41/15	5/24	51/32	58/43
Weight of Can + wet soil g	16.8	14.8		25.0	24.5	26.4	23.5
Weight of Can + Dry soil g	16.6	14.6		20.0	20.6	21.3	19.7
Weight of moisture g	0.2	0.2		5.0	3.9	5.1	3.8
Wt. of container g	15.9	14.1		13.9	15.8	14.0	13.6
Weight of dry soil g	0.7	0.5		6.1	4.8	7.3	6.1
Wt. of moisture %	28.6	40		82.0	81.3	69.9	62.3

Liquid limit (LL) %	**77.0**	Linear shrinkage LS =(L_1-L_2/ L_1) x 100	
Plastic limit (PL) %	**34.3**	L_1= Initial length of specimen (mm)	**34.3**
Plastic Index(PI) %	**42.7**	L_2= Final length of specimen (mm)	**42.7**
Liquid Index(LI) %			
Linear Shrinkage (LS) %	**13.6**		

Table 13: *Waterberg Limits for 1:4 Ratio*

Borehole No:	Sample No.			Depth (m)			m
Total weight of sample (g)		Weight passing No.40(0.425mm) sieve					
Soil/water curing time(hr.)		%passing No.40(0.425mm sieve					
Test	Plastic Limits			Liquid limit			
Can number/No .of blows	10	82		23/15	31/27	12/35	16/52
Weight of Can + wet soil g	14.8	14.6		33.0	38.2	32.6	30.4
Weight of Can + Dry soil g	14.7	14.5		27.8	32.6	29.7	27.6
Weight of moisture g	0.1	0.1		5.2	5.6	2.9	2.8
Wt. of container g	14.3	14.2		14.2	15.5	17.9	16.3
Weight of dry soil g	0.4	0.3		13.6	17.1	11.8	11.3
Wt. of moisture %	55.0	53.3		84.7	77.3	61.8	48.5

Liquid limit (LL) %	**76.0**	Linear shrinkage LS =(L_1-L_2/ L_1) x 100	
Plastic limit (PL) %	**54.2**	L_1= Initial length of specimen (mm)	**140**
Plastic Index(PI) %	**21.8**	L_2= Final length of specimen (mm)	**134**
Liquid Index(LI) %			
Linear Shrinkage (LS) %	**10.7**		

Table 14: *Atterbergs Limits for 1:5 Ratio*

Borehole No:	Sample No.			Depth (m)			m
Total weight of sample (g)		Weight passing No.40(0.425mm) sieve					
Soil/water curing time(hr.)		%passing No.40(0.425mm sieve					
Test	Plastic Limits			Liquid limit			
Can number/No .of blows	17	08		36/13	44/24	4/32	28/44
Weight of Can + wet soil g	17.2	19.1		26.8	28.8	27.5	33.4
Weight of Can + Dry soil g	16.3	17.6		20.0	22.0	21.3	25.9
Weight of moisture g	0.9	1.5		6.8	6.8	6.2	7.5
Wt. of container g	15.0	13.1		13.0	14.6	16.2	17.5
Weight of dry soil g	1.3	4.5		7.0	7.4	5.1	84
Wt. of moisture %	69.2	33.3		97.1	91.9	86.6	69.2

Liquid limit (LL) %	**88.0**	Linear shrinkage LS =(L_1-L_2/ L_1) x 100	
Plastic limit (PL) %	**51.3**	L_1= Initial length of specimen (mm)	**140**
Plastic Index(PI) %	**36.7**	L_2= Final length of specimen (mm)	**134**
Liquid Index(LI) %			
Linear Shrinkage (LS) %	**12.1**		

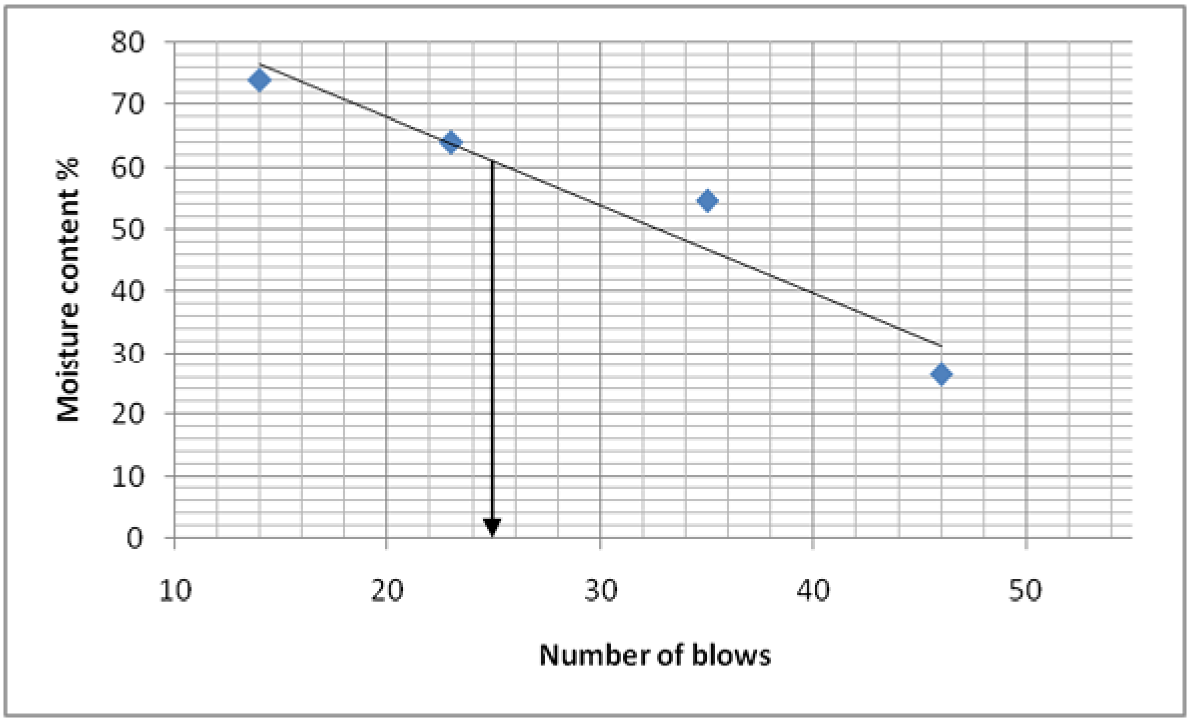

Figure 8: *Liquid Limit Graph Sheet for Sample Ratio 0:1*

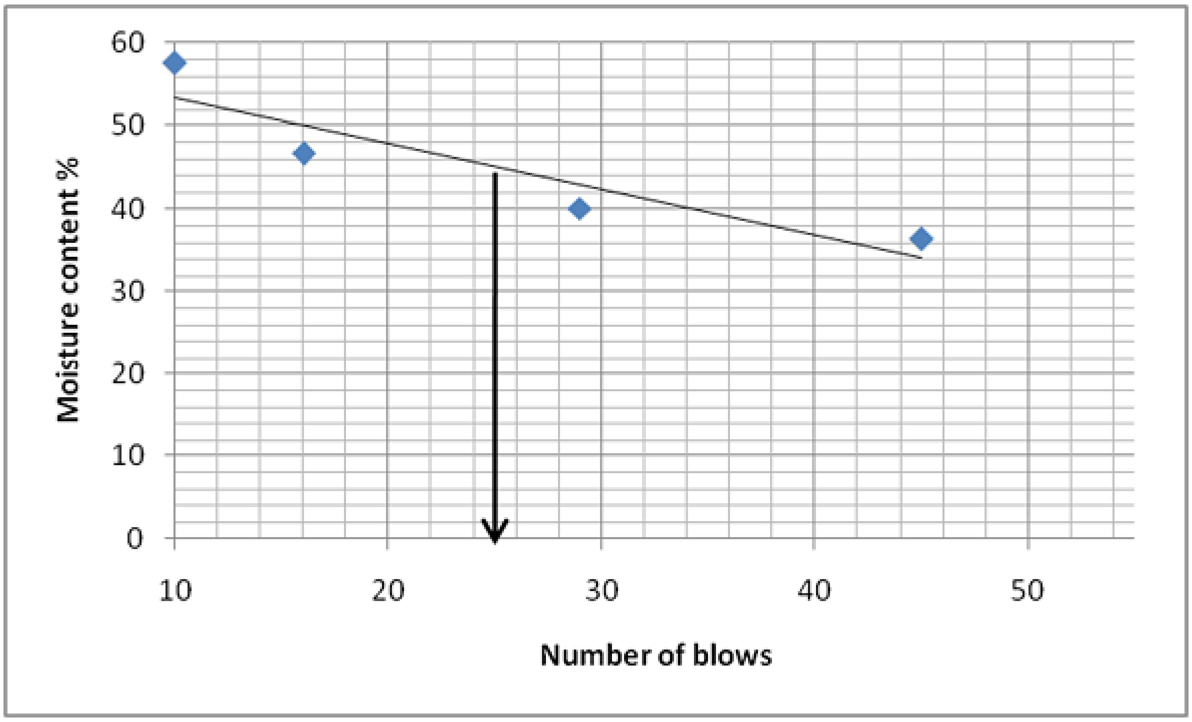

Figure 9: *Liquid Limit Graph Sheet for Sample Ratio 1:0*

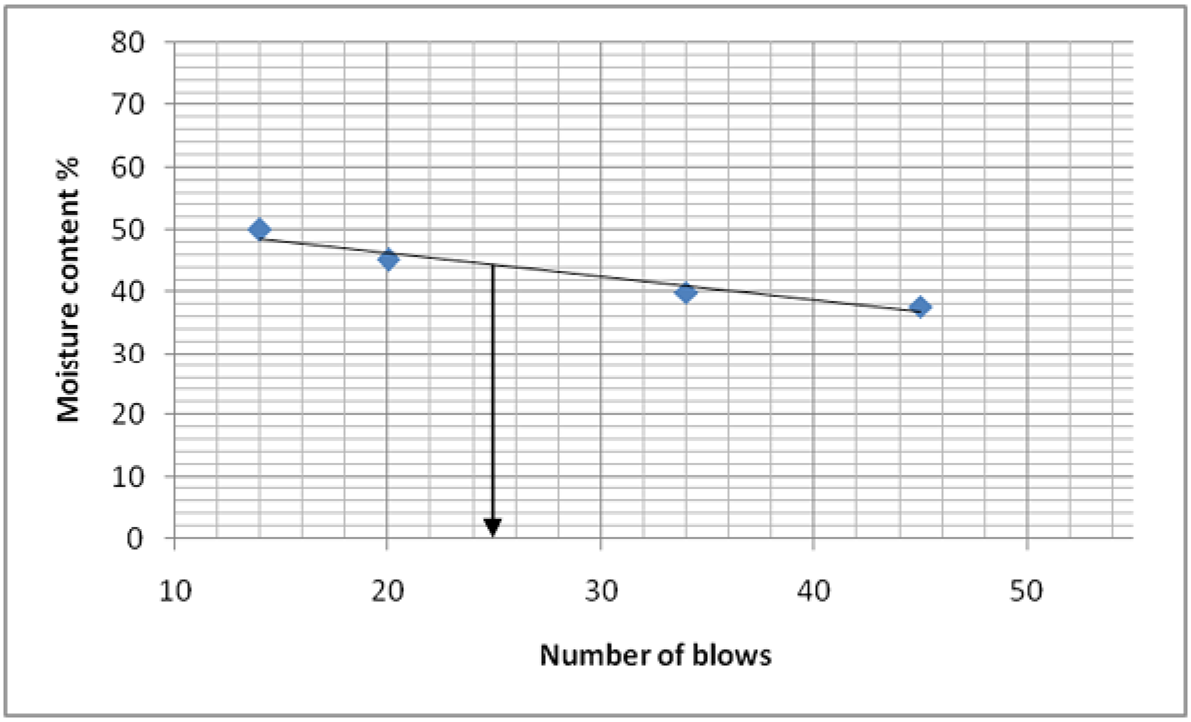

Figure 10: *Liquid Limit Graph Sheet for Sample Ratio 1:1*

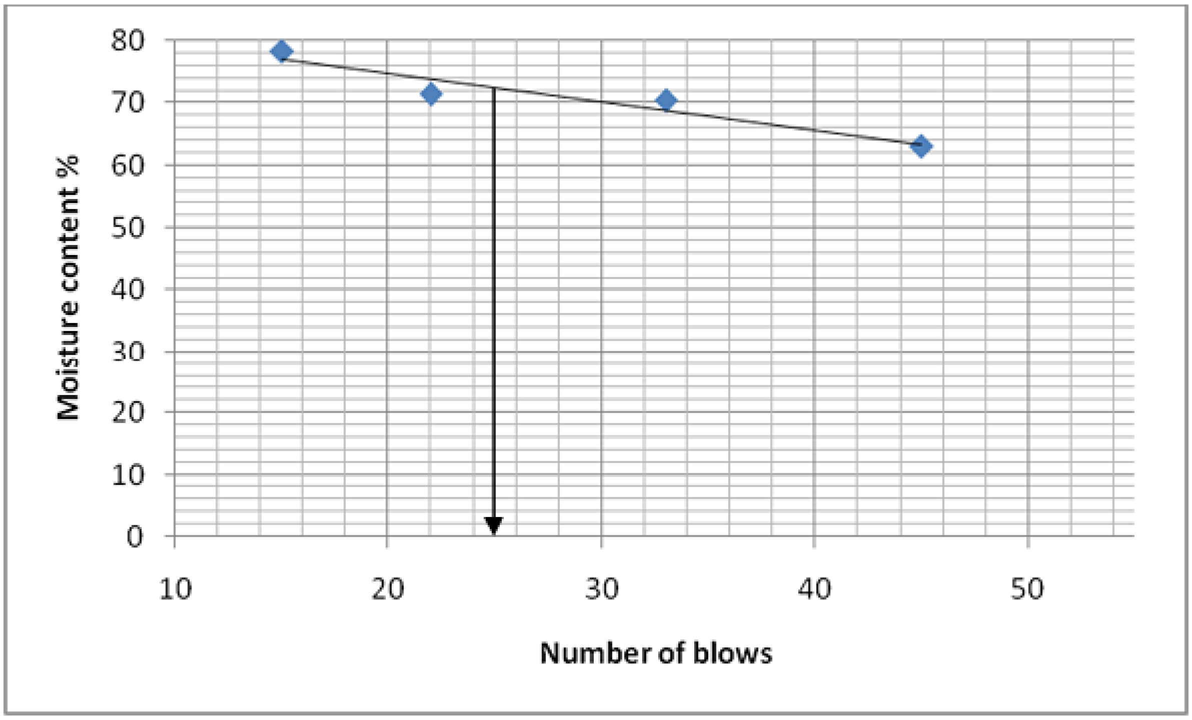

Figure 11: *Liquid Limit Graph Sheet for Sample Ratio 1:2*

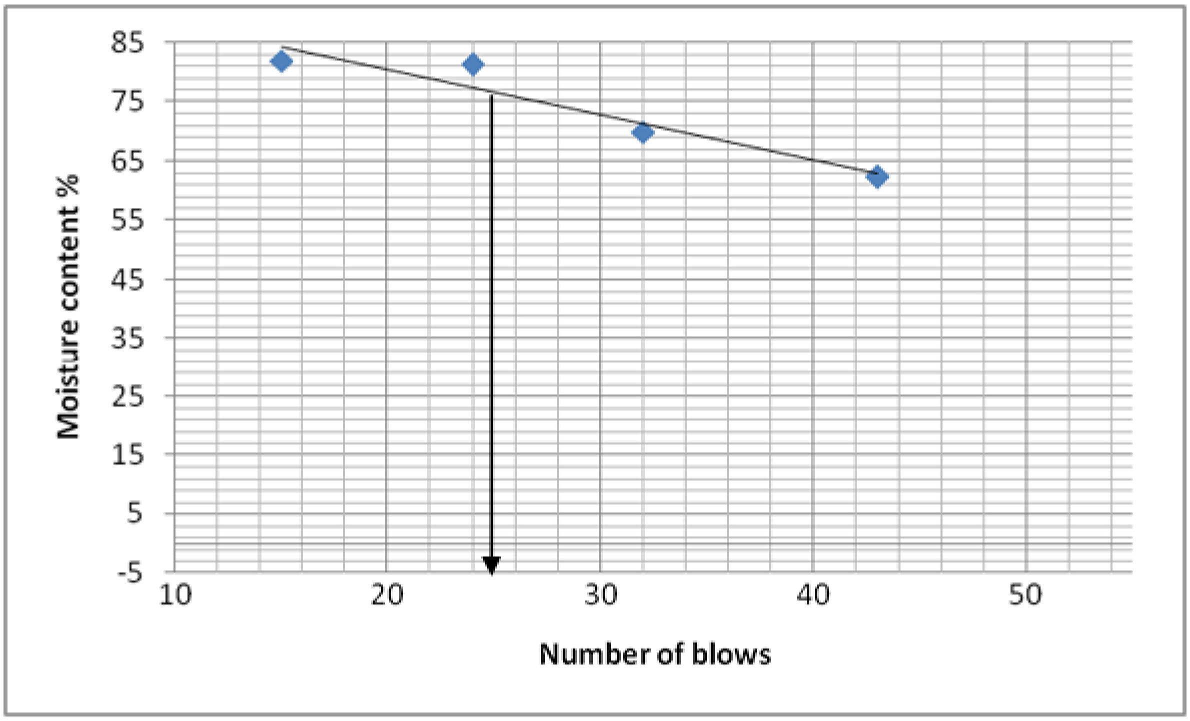

Figure 12: *Liquid Limit Graph Sheet for Sample Ratio 1:3*

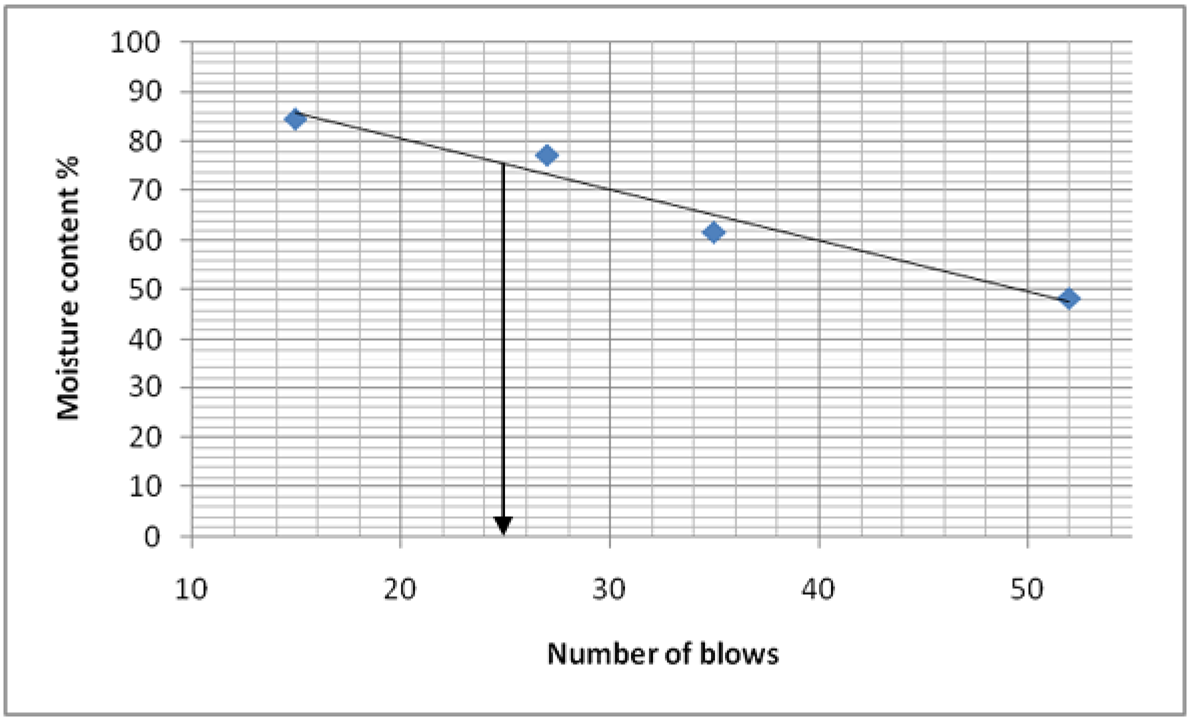

Figure 13: *Liquid Limit Graph Sheet for Sample Ratio 1:4*

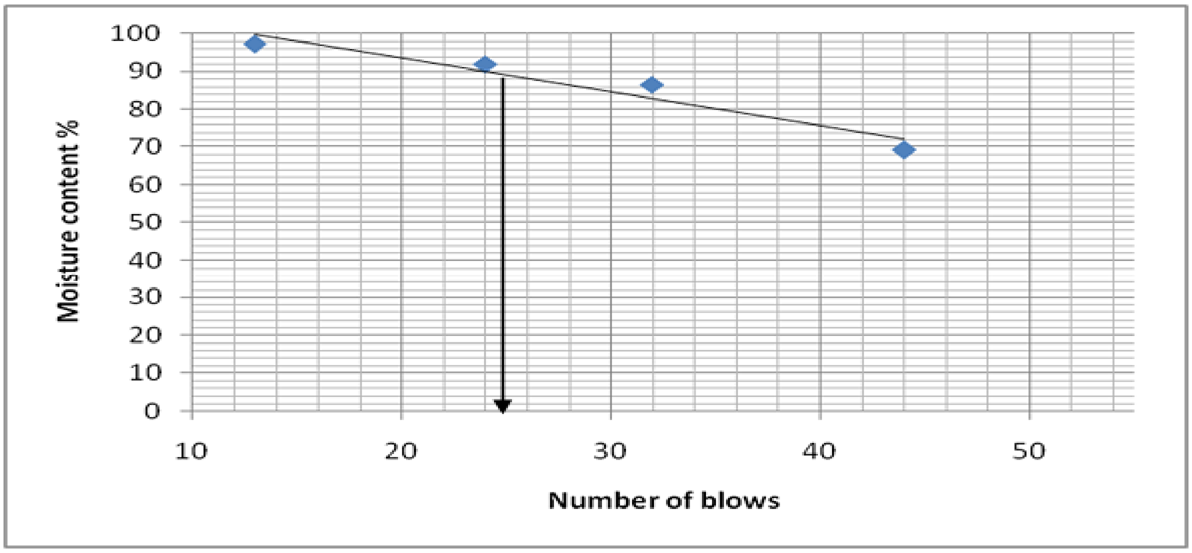

Figure 14: *Liquid Limit Graph Sheet for Sample Ratio 1:5*

Table 15: *Summary of Porosity Test of the Samples at 1100^{0}C*

	Bulk density	Particle density	Porosity
Ratio 0:1 (Raw state)	1.03	2.04	0.495
(Fired state)	1.09	3.59	0.579
Ratio 1:0 (Raw state)	0.79	2.11	0.626
(Fired state)	0.79	2.81	0.719
Ratio 1:1 (Raw state)	0.94	2.15	0.645
(Fired state)	0.82	2.6	0.685
Ratio 1:2 (Raw state)	0.9	2.57	0.650
(Fired state)	0.97	2.38	0.592
Ratio 1:3 (Raw state)	1.26	2.15	0.414
(Fired state)	1.07	2.44	0.561
Ratio 1:4 (Raw state)	0.95	2.2	0.568
(Fired state)	1.05	3.1	0.661
Ratio 1:5 (Raw state)	0.62	2.45	0.747
(Fired state)	1.26	3	0.580

Table 16: *Summary of the Geo-chemical Results*

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	Mn_2O_3	Fe_2O_3	ZnO	SrO
Ratio 0:1 (Raw State)	0.000	1.860	24.934	52.319	0.262	0.374	0.004	0.710	0.587	2.805	0.035	0.164	15.876	0.043	0.027
(Fired State)	0.000	1.943	25.131	53.719	0.158	0.279	0.004	0.708	0.484	2.521	0.034	0.155	14.803	0.040	0.023
Ratio 1:0 (Raw State)	0.000	4.770	17.769	57.643	0.063	4.325	0.020	0.740	0.531	1.596	0.030	0.191	12.271	0.037	0.013
(Fired state)	0.000	5.314	18.963	59.863	0.088	1.025	0.002	0.718	0.782	1.505	0.030	0.176	11.470	0.048	0.014
Ratio 1:1 (Raw State)	0.000	2.844	22.687	54.149	0.175	2.358	0.009	0.697	0.561	2.341	0.033	0.157	13.931	0.036	0.020
(Fired State)	0.000	3.432	22.647	56.257	0.131	0.954	0.004	0.725	0.614	2.171	0.032	0.158	12.798	0.059	0.018
Ratio 1:2 (Raw State)	0.000	3.233	21.385	54.298	0.150	2.977	0.007	0.724	0.508	2.173	0.033	0.174	14.279	0.039	0.021
(Fired State)	0.000	3.135	22.944	55.892	0.124	0.827	0.008	0.734	0.552	2.226	0.034	0.170	13.286	0.050	0.018
Ratio 1:3 (Raw State)	0.000	3.589	20.829	55.429	0.123	3.202	0.011	0.691	0.508	2.017	0.033	0.178	13.338	0.035	0.018
(Fired State)	0.000	2.928	23.440	55.539	0.132	0.872	0.006	0.714	0.579	2.200	0.031	0.168	13.329	0.044	0.018
Ratio 1:4 (Raw State)	0.000	3.789	20.145	55.452	0.133	3.277	0.026	0.776	0.634	1.969	0.032	0.179	13.532	0.039	0.017
(Fired State)	0.000	2.841	23.649	55.137	0.131	0.833	0.006	0.713	0.569	2.316	0.033	0.161	13.545	0.047	0.020
Ratio 1:5 (Raw State)	0.000	3.458	20.850	55.460	0.128	3.384	0.005	0.741	0.517	2.022	0.036	0.174	13.174	0.036	0.016
(Fired State)	0.000	2.586	23.844	54.196	0.146	0.890	0.007	0.706	0.671	2.381	0.030	0.166	14.306	0.055	0.017

Table 19: *Summary of the Results.*

Ratios	0:1	1:0	1:1	1:2	1:3	1:4	1:5
% of sand	61	36	27	27	30	22	25
% of clay	19	39	46	56	50	48	55
% of silt	20	25	27	17	20	30	20
Liquid limit	61.0	45.0	44.0	72.0	77	76	88.0
Plasticity index	31.8	4.0	9.1	47.2	42.7	21.8	36.7
Linear shrinkage	15.0	4.3	7.1	12.1	13.6	10.7	12.1
Compressive Strength (Nmm^2)	2.88	1.95	3.42	3.90	4.15	3.78	4.95
Cold water Absorption (%)	17.24	29.67	23.76	21.36	16.35	19.81	15.53

3.0 Discussion

3.1 Physical Properties of the Samples

The results of the liquid limit for the various soil samples for JSC_1 to JSC_7 are 61.0, 45.0, 44.0, 72.0, 77.0, 76.0, and 88.0 respectively. JSC_2 and JSC_3 belong to A-5 group while JSC_1, JSC_4 to JSC_7 belong to A-7 group according to AASHTO classification for coarse grained soils. The group of material under A-5 has the least values of liquid limit and may not be recommended for structural development because of the cracking effect after firing which reduces the strength of the bricks produced from such samples. The group of materials under A-7 is normally noted with high liquid limit characteristics. The soil samples at different ratios exhibited different degrees of plasticity index as a result of the clay, sand and silt content evident in the samples. Table 21 showed that the plasticity indices of sand, clay and silt for JSC_1 to JSC_7 are 31.8, 4.0, 9.1, 47.2, 47.2, 21.8 and 36.7 respectively. Large values of plasticity indices indicate relative stability over a wider range of moisture content compared to those samples with small plasticity index. Soils with low plasticity index will be difficult to handle for brick molding, the soil will be too stiff to remold if it lacks sufficient water. A high plasticity is therefore preferred (Sower, 1979). He further explains that soils with a high Pi tend to be clay, those with a lower Pi tend to be silt and those with a Pi of 0 (non- plastic) tend to have little or no silt or clay. Soils with low plasticity index will be difficult to handle for brick molding. A high plasticity is therefore preferred (Sower, 1979).

3.2 Elemental Contents

The chemistry of the soils as shown in Table 18 shows that the order of abundance of the major oxides is $SiO_2 > Al_2O_3 > Fe_2O_3 > MgO > SO_3 > TiO_2$. The overall results of the chemical composition (in their oxides) of Ngene-agu twin clay deposits in Awgbu, Orumba North local government area, Anambra state South East Nigeria, indicates high Silica and Alumina contents. Al_2O_3 slightly increased in all the samples after firing, because Alumina is the chief constituents of every kind of clay. A good brick should contain 20% to 30% of alumina. This constituent imparts plasticity to the clay so that it can be molded.

3.3 Mechanical Properties of the Samples

From Table 21, the 24-hour cold water absorption for JSC_1- JSC_7 is 29.67, 17.24, 23.76, 21.36, 16.35, 19.81 and 15.53 respectively. JSC7 has the least cold water absorption followed by JSC5. For structural development, the 24-hour cold water absorption should be minimum. Samples JSC_5 - JSC_7 were noted to be very strong and harder than the other remaining four samples, implying that they were able to meet up with the 20 % maximum cold water absorption as specified by (BDA, 1974: IS 1077 and Ibanga and Ahmed 2007). From Table 21, the compressive strengths are 1.95, 2.88, 3.42, 3.90, 4.15, 3.78, and 4.95 respectively. Samples JSC_5- JSC_7 was able to satisfy the basic requirements for structural development (BDA, 1974: IS 1077 and Ibanga and Ahmed 2007). According to this classification, minimum compressive strength of fired bricks should be 3.5 N/MM^2. A close analysis of the compressive strength of the seven moulded fired bricks of the twin clay deposits obtained at Ngene-agu in Awgbu, Anambra state South East of Nigeria revealed that Asha clay soil has a better characteristic quality than Ajagworo clay soil and that explains why the villagers in Ngene-agu village in Awgbu town has it as an ancient practice to mix the both samples at the ratio of 1:3 (Ajagworo:Asha) to improve the compressive strength of the sample.

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

The properties of the seven soil ratios investigated in this study from Ngene-agu village in Awgbu, Anambra state indicates that the best ratios from the seven soil ratio samples that met the minimum standard for structural development are JSC_5- JSC_7. JSC_7 is the best because of the highest compressive strength and least 24-hour cold water absorption. This is followed by JSC_5 and JSC_6. Their compressive strength is as follows 4.95, 4.15, 3.78 respectively, and cold water absorption 15.53, 16.35 and 19.81 respectively. The compressive strength of these burnt bricks surpass the minimum strength requirements of 3.5 N/MM^2 and their 24 hours cold water absorption were all less than the 20% maximum cold water absorption as specified by BDA, 1974: IS 1077 and Ibanga and Ahmed, 2007 for burnt bricks. The plasticity index of the samples falls within the high plastic soils according to AASHTO classifications. This work has also shown that the addition of Ajagworo clay to Asha as an additive has improved the quality of the clay.

4.2 Recommendations

Though the use of burnt clay brick presents significant potential benefits, these are yet to be fully explored by professionals in the Nigerian construction industry. Retraining of professionals in the construction industry is recommended to ensure sustainability and better appreciation of the use of these materials. The authors also recommend that other additives should be exploited with a view to improving on the quality of Awgbu clays for structural developments and other applications.

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