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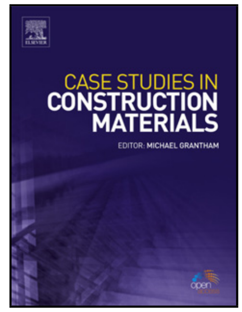

Title: Geopolymerized Self-Compacting Mud concrete masonry units

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Case Studies in Construction Materials

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Case study

Geopolymerized Self-Compacting Mud concrete masonry units

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ABSTRACT

This study was conducted to develop an alternative method of utilizing fly ash as an alternative stabilizer to build affordable earth masonry units named "mud concrete blocks". Mud concrete masonry block is a novel invention in which the mud helps to self-compact the mixture to reduce the production of energy content. This study uses fly ash from electric power generating plant with an alkaline solution made of Sodium hydroxide and Sodium chloride. Different combinations of mixtures (fly ash, sodium chloride, sodium hydroxide and soil) were taken into consideration to study a suitable mix design. And compressive strength was tested to understand each mix suitability.

Results of this study have manifested that suitable mix is to use Fly Ash 20% of the dry weight of soil, Sodium hydroxide 5% and Sodium Chloride 2% of the total dry weight. The suitable water ratio is 15%-20% of the dry weight. And then the suitable soil mix proportion was developed. It was found that the soil mix proportion of Gravel 10 - 20% (sieve size 4.25mm ≤ gravel≤ 20mm) range of (35%-45%), the Sand 70 - 80% (sieve size 0.425mm ≤ sand ≤4.25 mm) proportion of (60%-70%) and Fine ≤ 10% (≤ sieve size 0.425mm) content of 5% makes the best mix to develop. Scanning electron microscope images were taken to understand the geo polymerized fly ash bond result on the total strength of the soil mixture.

1 Introduction

Employing industrial waste as stabilizer or filler material can reduce the environmental contamination [1][2]. And they are economically beneficial as construction materials because they are less expensive[3]. Finally, the waste shall become a shelter for an affordable dwelling which serves the entire humanity. Mud concrete is a novel walling material[4]. A masonry unit made of mud and cement mixture[5]. In Mud-Concrete, the designated parts of sand and metal of concrete are replaced by a fraction of soil. The precise gravel percentage governs the strength of Mud-Concrete. In this research fraction of soil has been classified as follows; 35% Gravel (sieve size 4.25mm ≤ gravel≤ 20mm), 65% Sand (sieve size 0.425mm ≤ and ≤4.25 mm) 5% Fine (silt and clay) –(≤ sieve size 4.25 mm)[4][6][7][8] [9]. The cement in this concrete is also used as a stabilizer in very low quantities. The most popular cementitious materials are the Portland cement and lime. However, both of them have problems including heavy embodied energy and carbon foot print[10][11][12][13]. Therefore, a brand new study was conducted to investigate an alternative stabilizer for mud concrete masonry units.

Fly Ash, as an alternative stabilizer got the attention due to many reasons. Fly ash has some cementitious properties including its chemical composition shown in Figure 1. Cement chemical composition is Calcium oxide (lime), Silicon dioxide (silica), Aluminum oxide (alumina), Iron oxide and Sulphur[14]. Similarly, Fly Ash also has a similar chemical composition such as Silicon dioxide (silica), Aluminum oxide (alumina) shown in the Figure 1.And also the prevalent mineral in the clay/mud is Kaolinite[15]. Kaolinite has very high water absorptive capacity[16][17]. It's an engineering problem which could be resolved by adding fly ash[18]. In addition fly, ash increases the plasticity index.Because fly ash has a shape of a bubble and does not mix with water[19][20]. The high carbon in fly ash help to reduce the linear shrinkage limit in mud based masonry units[21]. But this is not a similar condition to all the soil types. Clay soil oil with high finer percentage doesn't work with fly ash either[22][23].

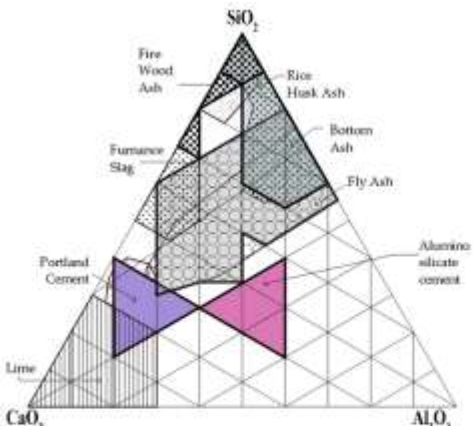


Figure 1: Comrades of cement

1.1 Geopolymer: A Literature review

This study was extended to ameliorate the cementitious property of fly ash. The literature review showed that alkali activation of fly ash can improve the strength of rammed earth[24][25][26]. Prof. Joseph Davidovits is the first person who introduced the concept of geopolymer in 1975[27]. The use of fly ash to stable soil was then developed by him[28]. The term "geopolymer" to classify the fresh ascertained geosynthesis of soil into soil blocks by using alkaline activator. Richard Heitzmann is the first to discover to use fly ash into geopolymer[27]. Several studies were done in order to develop geopolymer by using fly ash [29][30][31][32]. Not only fly ash but also coal fly ash can be developed to geopolymer[33]. Then scholars developed an alkali-geopolymer cement. The meaning of alkaline activation of fly ash is into convert typical fly ash into the cementitious material by using an activator[31][34][35][36][37][38]. But most of these studies were conducted to develop a geopolymer soil block by using compression technology into rammed earth shown in Table 1. This study was conducted to develop self-compacting geopolymer mud based walling block.

Table 1: Prior Art

Description	Source	Year	Application	Stabilizer	Activator
Introduced geopolymer	Joseph Davidovits	1975	Alternative Cement	No stabilizer	Sodium Hydro
Developed the concept of geopolymer	Joseph Davidovits	1976	Construction block	Silicon dioxide	Sodium Hydro
Study alternative activators	Richard Heitzmann [27]	1984	Alternative Cement	Fly ash	Sodium Hydro
Developed geopolymer road stabilizer	Weiguo Shen [29]	2007	Road base material	Fly ash	Gypsum binder
Coal fly ash geopolymer	Konstantinos A[39]	2011	Walling Materials	coal fly ash	Geopolymer
Developed geopolymer with waste ash	Maria Chiara Bignozzi[34]	2011	Alternative Cement	Waste Ash	Sodium Hydro
Experiment with geopolymer rammed	Nuno Cristelo [31]	2012	Earth Walls	Fly ash	sodium-based
Experiment with geopolymer paving block	Aaron Darius Vaz [32]	2012	Paving Blocks	Fly ash	Potassium had
Developed mortar for timber and soil	F. Gouny[40]	2013	Wood and earth	Soil	Silicic acid
Geopolymer recycle concrete mix develop	Patcharapol Posi [35]	2013	Recycle concrete	Fly ash	Sodium Hydro
*Novel walling materials	Patrick Nina Lemougna[41]	2014	Walling materials	Fly Ash	Sodium Hydro
Geopolymer concrete mix development	P.M.Vijaysankar [42]	2014	Concrete blocks	Fly Ash	Sodium Hydro
Developed mortar for timber and soil	Fazia Fouchal[43]	2015	Wood and earth	Soil	Potassium ha
*Geopolymer walling material	Antonella Petrillo[44]	2016	Walling materials	Fly Ash	geopolymer
Geopolymer concrete mix development	Sudipta Naskar[36]	2016	Concrete	Fly Ash	Sodium Hydro
Geopolymer ceramic product development	H. Assaedi[37]	2016	Ceramics	Fly Ash	Sodium Hydro
Geopolymer concrete mix development	Talakokula[38]	2016	Concrete	Fly Ash	Sodium Hydro
*Self-compacting geopolymer concrete	Chameera Udawattha* [45]	2017	Walling materials	Fly Ash	No activator

*Similar studies

1.2 The objective of this study

Sri Lanka has recently started coal combustion plants in large scale. However, planning was not done in order to use the fly ash produced from coal combustion process. They are being dumped into a nearby land without any treatment. This has become a major environmental problem for the people those who are living in those areas. After the civil war in Sri Lanka (1983 –2009) there is a huge demand for affordable housing[46]. This study is aimed to build an affordable walling material for poor people in the country. End of the day this study can give a win-win situation where waste fly ash can be utilized to build useful housing poor people in the country.

2 The testing method, phases of experimental study and materials.

Several mix proportions were tested according to the experimental hierarchy shown in Figure 2. The experimental sequence is based on the literature survey and following previous studies. Compressive strength is the basal requirement for a masonry unit. Unconfined Compressive Strength (UCS) test was conducted according to BS-EN-772-1, a method of test for masonry units[47]. The load is normally applied uniformly through two stiff and flat hardened steel plates.In order to confirm the suitable mix design several mixtures (fly ash, sodium chloride, sodium hydroxide and soil) were taken into experimental study . Each mix was prepared according to the experimenting schedule shown in Table 2,3 and 4. Soil sieved and separated into three different sieves such as Gravel - sieve size 4.25mm to 20mm, Sand - sieve size 0.425mm to 4.25 mm and Fine (silt and clay) - sieve size below 4.25 mm. Then they were mixed back according to the experimental schedule shown in Table 4. Developed soil and fly ash were mixed together along with Sodium Hydroxide and sodium chloride. Finally, water was added in an order to make the geopolymer mud concrete mix. The mix was mixed by using small-scale concrete mixing machine. Then they were poured into 150mm X 150mm X150mm steel mould to make cubes to check the unconfined compressive strength (UCS)[48]. Each mix, three blocks were prepared to get the average strength of the mix. Finally, each block was placed compressive strength testing machine to monitor the breaking load. Both wet and dry strength was measured to understand the strength in both conditions[49]. Novel techniques used to understand the self-compacting nature of the mixture by using slump test. To measure the workability of soil samples, slump cone test and vibration test were conducted. Because it encountered practical issues due to the cohesiveness of mud. Small-scale plastic cone, which has about 100mm height was used to measure the workability. Workability is indicated by the drop height of slump after giving 5 blows.

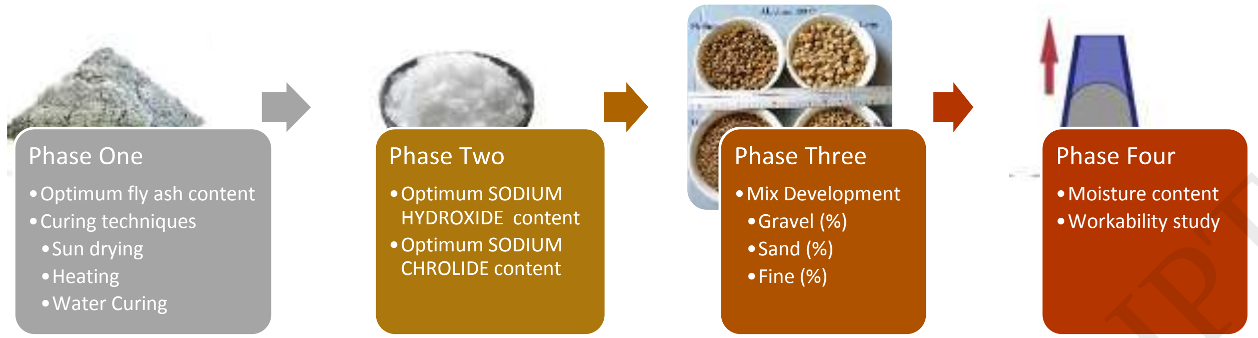


Figure 2: Experimental Phases

The experiment was conducted in four phases shown in Figure 2. The first step is to study the optimum fly ash content and the curing method. Ten different fly ash content (0% -35%) were mixed with soil and studied against the strength development. Then the optimum fly ash content was chosen. After that, the optimized mix was subjected to three different curing techniques such as sun drying, heating, and water curing. Phase two of the study was conducted to understand the activator content. First, Sodium hydroxide content was optimized by using five different composition of Sodium hydroxide (0%, 1%, 2%, 3%4% and 5%). Then salt content was optimized in the similar manner after studying five different sodium chloride content of (0%,0.5%,1%,1.5% and 2%). In the third phase, the soil mix developed to gain the optimum strength. Because, the soil comes in different particle sizes such as gravel, sand, and fine. Three different soil compositions were tested considering their sieve size composition. And finally, the moisture content and workability study was conducted to optimize the manufacturing technology for the self-compacting geopolymer mud concrete block. Self-compacting nature was studied and optimized by experimenting with moisture content. The workability and quick flow were studied by using novel slump test developed by a sister research[5].

2.1 Materials

2.1.1 Soil

The soil was collected from the University premises a homogeneous layer 600mm below the existing ground level to remove the organic matter. First, the selected soil sample was subjected to sieve analysis shown in figure 4. Oversize gravel particles were removed by using a 20mm sieve. Then the chemical composition of the soil was studied by conducting X-ray Powder Diffraction (XRD) figure 3 and XRF (X-ray fluorescence) analysis shown in figure 5.

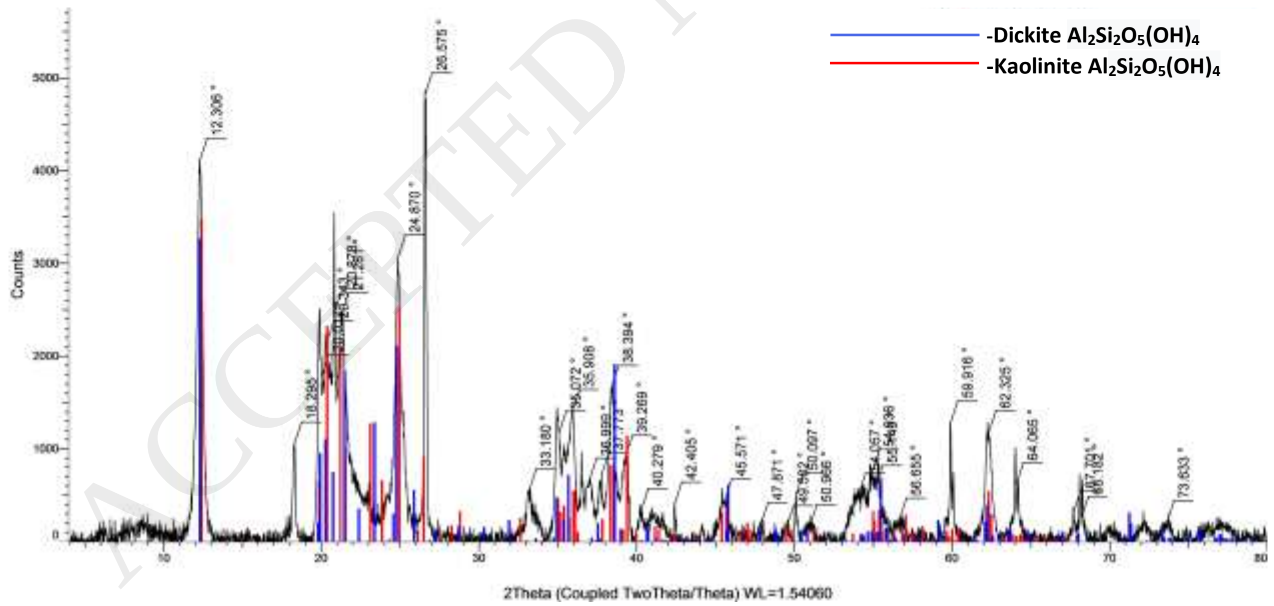


Figure 3: Soil Mineralogy

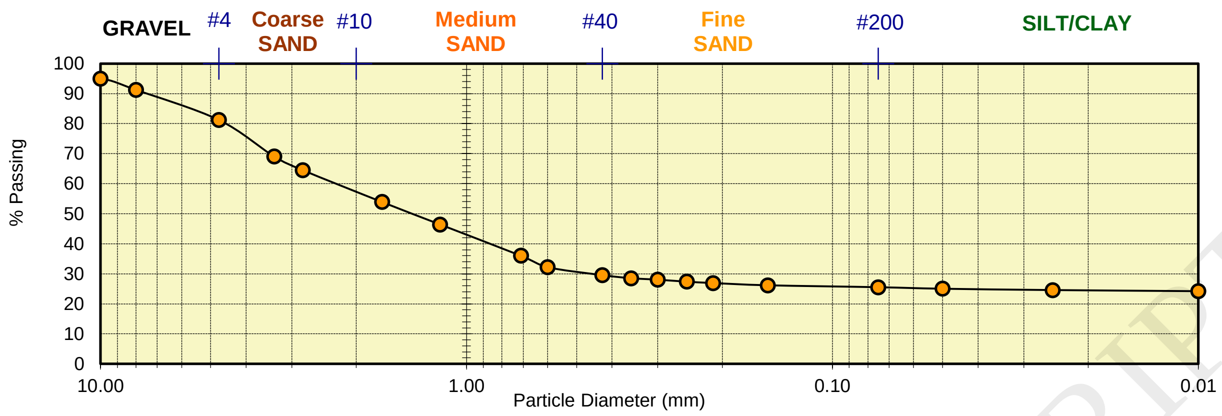


Figure 4: Soil Sieve analysis

Then the soil sample was subjected to mechanical and engineering property analysis. The soil used in this study has 74% water absorption capacity and its density at saturated surface dry (SSD) condition were 2.65 g/cm^3 [50]. Finally, soil mineralogy was studied to understand the chemical composition of the soil shown in the figure 4.The mineralogy of the selected soil sample shown in Figure 5. The results show that the soil contains a high amount of Kaolinite. Kaolinite is a clay mineral with the chemical composition of $Al_2Si_2O_5(OH)_4$ shown in figure 3 and 5.

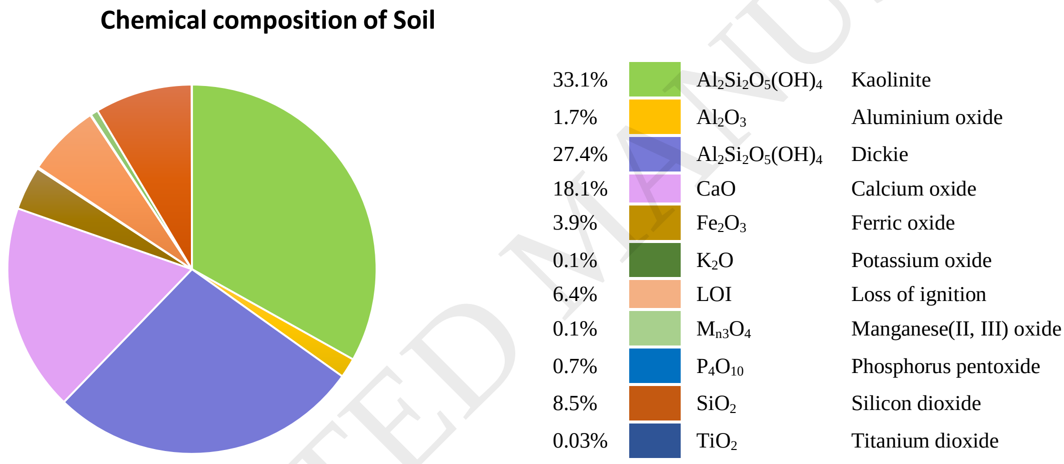


Figure 5: Chemical composition of Soil

2.1.2 Stabilizer

Three different fly ash samples were taken from three different power plants in Sri Lanka. Because chemical composition of the fly ash depends on the source of fly ash. There are two classes of fly ash can be found in Sri Lanka. The properties of those two different fly ash shown in table 2. All the samples were analyzed to understand the use of the full chemical/particle size distribution property of fly ash. Out of the three-power plant, Lakvijaya Power plant which produces the best fly ash (Class C) was chosen as a key stabilizer for this study.

2.1.3 The activator

The conventional method of alkaline activation by using potassium hydroxide (KOH). For this study commonly, available Sodium hydroxide (NaOH) was used as the activator. This is purely due to the availability of industrial-scale material. To optimize the quick flow of Sodium chloride (NaCl) common salt was used.

Table 2: Properties of different types of fly ash

Class C	Class F
Light Grey	Dark grey
Manufactured from burning lignite	Manufactured from anthracite coal
Has pozzolanic properties	Has pozzolanic properties
Has cementitious properties	Less or no cementitious properties
Active with alkali silicon reaction	More efficient regarding resistance to alkali-silica reaction

3 Results

3.1 Phase One

Eight different fly ash contents were subjected to this study. The results are shown in table 3. Twenty percent of fly ash out of the dry weight of the mix shows the suitable fly ash content.

Table 3: strength variation of different fly ash contents with time

	0% fly Ash (N/mm^2)	**5% Fly Ash** (N/mm^2)	**10% Fly Ash** (N/mm^2)	**15% Fly Ash** (N/mm^2)	**20% Fly Ash** (N/mm^2)	**25% Fly Ash** (N/mm^2)	**30% Fly Ash** (N/mm^2)	**35% Fly Ash** (N/mm^2)
7 days	0.34	0.30	0.32	0.29	0.57	0.38	0.29	0.30
14 days	0.73	0.50	0.46	0.77	0.88	0.58	0.16	0.30
21 days	0.66	0.66	0.81	1.07	1.03	0.58	0.93	0.86
28 days	0.67	0.61	0.74	0.85	1.33	0.79	0.76	0.75

According to results shown in figure 6 and table 2, the optimum fly ash content was confirmed as 20% of the dry weight of the total mixture. The increase of fly ash more than 20% did not perform any strength development.

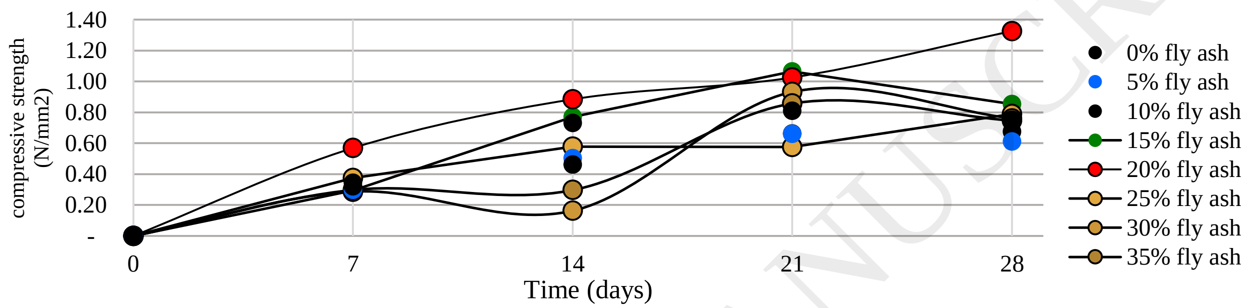


Figure 6: Graph Dry strength variation of different fly ash contents with time

3.1.1 Curing technology

This experiment was conducted to understand the best curing method to build fly ash stabilized self-compacting mud concrete blocks. Following casting schedule is shown in Table 4 was conducted to optimize the suitable curing method. Water curing method was avoided since no sign of water curing. However, heat curing shows an effective method of fast curing and sun drying for a period of 28 days can take the strength 9.6N/mm^2 strength shown in figure 7. Finally, it was confirmed that heat curing for the future experiments and get results within two days. Because, heat curing get the required strength according to the standards (BS-EN-772-1, Method of test for masonry units)[47].

Table 4: Optimizing activator contents

Soil	Fly Ash	Sodium hydroxide	Sodium chloride	Water
78%	20%	0%	2%	20%
76%	20%	2%	2%	20%
74%	20%	4%	2%	20%
72%	20%	6%	2%	20%
70%	20%	8%	2%	20%
68%	20%	10%	2%	20%

Soil	Fly Ash	Sodium hydroxide	Sodium chloride	Water
80%	20%	0%	0.0%	20%
78%	20%	2%	0.5%	20%
75%	20%	4%	1.0%	20%
73%	20%	6%	1.5%	20%
70%	20%	8%	2.0%	20%
68%	20%	10%	2.5%	20%

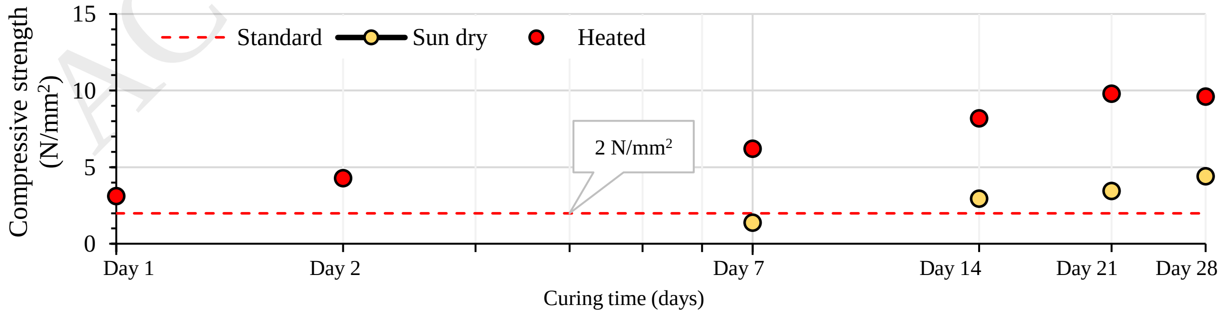


Figure 7: Compressive strength results of curing method optimization

3.2 Phase two – Optimizing Sodium hydroxide and Sodium chloride content

The activators content was optimized by changing Sodium hydroxide content from 0% to 10% by the weight of the total mix shown in table 4. The other component such as soil content; fly ash content was comparatively changed according to the Sodium hydroxide content. The experiment results are shown in figure 8. Similarly, the Sodium chloride content was optimized. The results are shown in figure 9. According to results shown in figure 8; the suitable strength was achieved when the NaOH at 4..2% of the dry weight. And it comes to strength 4.51N/mm^2 when the NaOH percentage of 5%. And figure 9 shows the suitable mix design of NaCl content is more than 1.8% of the total dry weight and it comes to the strength of 2.88N/mm^2 when the NACL at the composition of 2% of the dry weight of the mix.

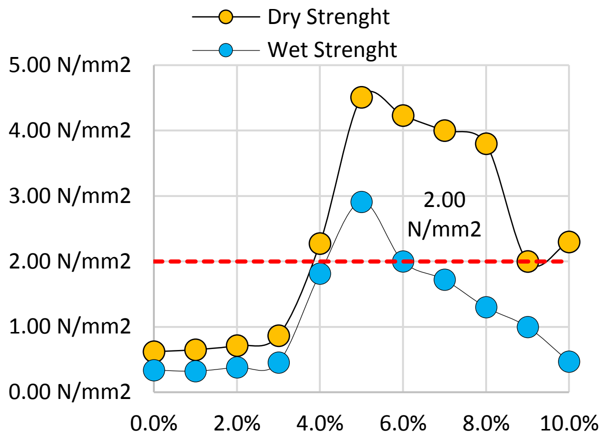


Figure 8: Optimize sodium hydroxide content

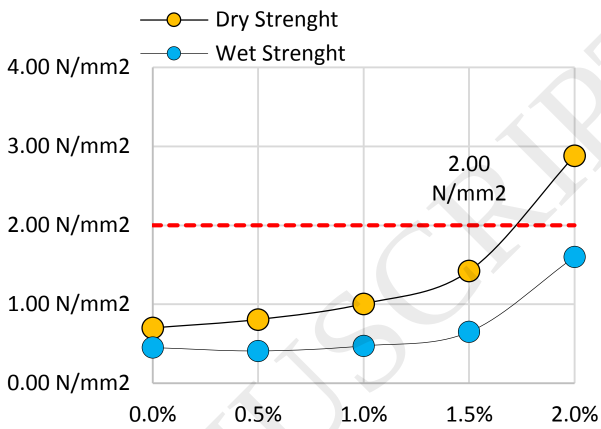


Figure 9: Optimizing sodium chloride content

3.3 Phase three – Soil Mix development

The soil comes in different particle compositions such as Gravel 10 - 20% (sieve size 4.25mm ≤ gravel≤ 20mm) Sand 70 - 80% (sieve size 0.425mm ≤ sand ≤4.25 mm) Fine ≤ 10% (≤ sieve size 0.425mm). Therefore, the best particle size composition should be tested in order to find the best soil mix design. The study was conducted according to mix design shown in table 4. The mix proportion test was started by varying gravel, sand and fine combinations shown in table 5. The cube casting was started from FS70G25F5 sample (25% gravel, 70% sand and 5% fine). Then FS60G35F5 mix proportion (35% gravel, 60% sand and 5% fine) and FS50G45F5 sample (45% gravel, 50% sand and 5% fine) were casted. For each mix experimented the green water content of the mix was measured after oven drying at 100C constant temperature. These experimental results are shown in Table 5. The discovered optimum mix proportion is sand between 50% and 60%, gravel content is 30% and 40% and fine content is 5% (*see the Figure 10*)

Table 5: Experimental criteria to find the best soil mix proportion

		Existing Proportio			Proposed Proporti							Added		
	Mix N.	Gravel	Sand	Fine	Sand	Gravel	Fine	Fly Ash	Sodium hydroxide	Sodium chloride	Water	Gravel	Sand	Fine
FS70G25F5	FC1	54%	41%	5%	70%	25%	5%	20%	5%	2%	20%	-29%	29%	0%
FS60G35F5	FC2	54%	41%	5%	60%	35%	5%	20%	5%	2%	20%	-19%	19%	0%
FS50G45F5	FC3	54%	41%	5%	50%	45%	5%	20%	5%	2%	20%	-9%	9%	0%
FS40G55F5	FC4	54%	41%	5%	40%	55%	5%	20%	5%	2%	20%	1%	-1%	0%
FS30G65F5	FC5	54%	41%	5%	30%	65%	5%	20%	5%	2%	20%	11%	-11%	0%

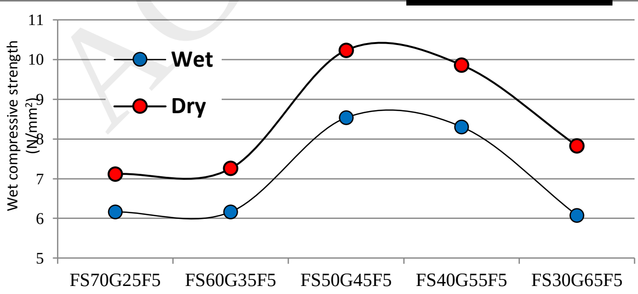


Figure 10: Optimized soil mix proportion results

Table 5: Summary of best mix proportions

Average compressive strength (N/mm²)		
Mix name	**Wet**	**Dry**
FS70G25F5	**6.16**	**7.12**
FS60G35F5	**6.16**	**7.26**
FS50G45F5	**8.53**	**10.23**
FS40G55F5	**8.31**	**9.86**
FS30G65F5	**6.08**	**7.83**

3.4 Phase Four

3.4.1 Moisture content

Even thou the literature shows the required water mole content to produce the reaction is 20%. The required moisture content to produce the fly ash block should be optimized. Because the moisture content is very important to develop the workability of the experimental mixture. The quick flow mixture shall help to improve the self-compacting nature of the soil fly ash mixture. Therefore, the liquid limit, as well as the compaction level, was subjected to this study.

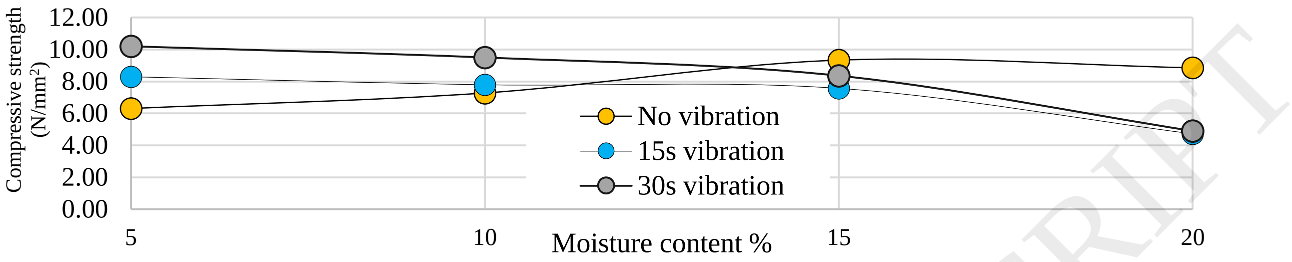
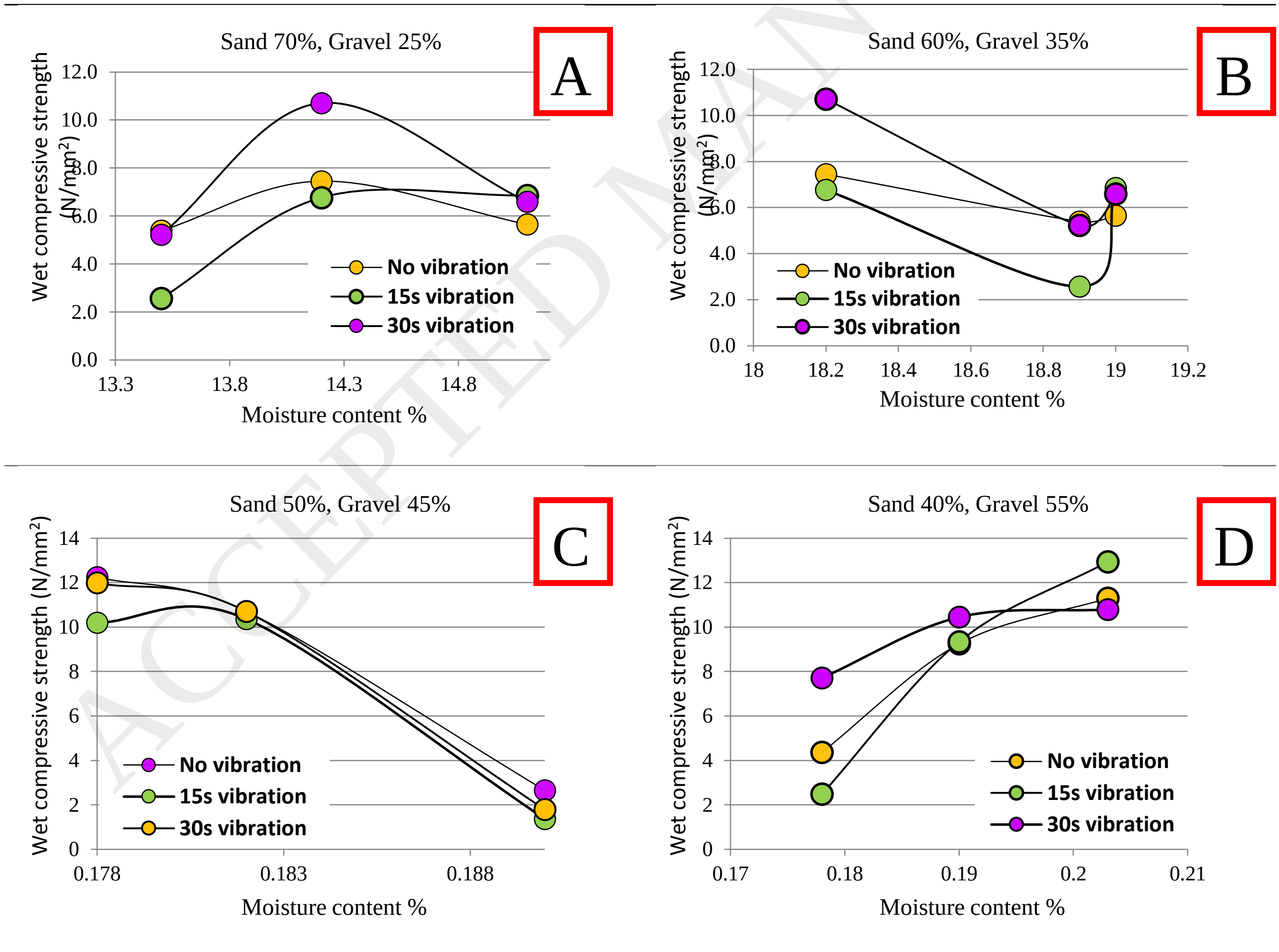


Figure 11: Finding optimum moisture content.

Results are shown in figure 11. According to results the required moisture content for the mix is between 20%-30% to activate all the molecules in the mixture. For, the effect of vibration was taken into account shown in Figure11. According to results, when the moisture content is below 15%. When the moisture content is in the range of 15%, the introduction of vibration (compaction) reduces the strength. Therefore, it was confirmed that block can be produced without compaction when the moisture content is in the range of 15% to 20%.

Table 6: Self-Compaction improvement by changing moisture content



3.5 Workability Variation

Workability of each mix was measured with the above-mentioned method which is same to slump cone test. Results are shown in figure 11. According to results, there is a very low impact on the increase of fly ash content and the workability. The slum test results clearly show that the addition of fly ash increases the workability. This is because of the mixing ability of fly ash with soil. To investigate this more an SEM study was conducted. The SEM images are shown in figure 13.

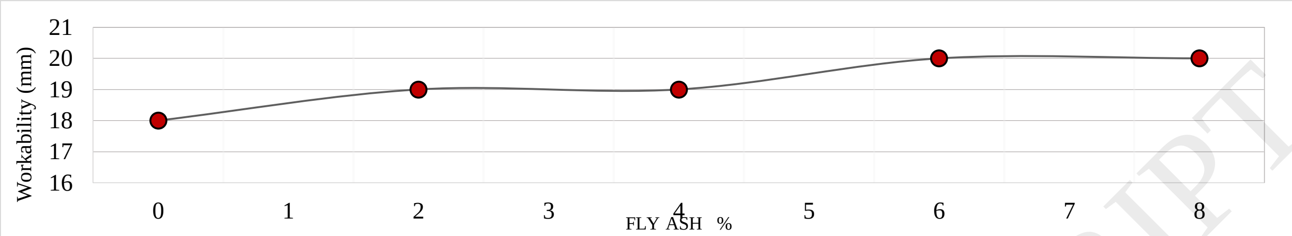


Figure 12: Graph Variation of workability

The Figure13 shows the SEM (scanning electronic microscope) image taken in the sample mix of FS50G45F5 *(see the table 5)*. The image (a) in Figure 13 was taken at 100µm magnifier in local scale to understand how the geopolymer stabilizer work. The image (b) in Figure 13 shows how the geopolymer links work in the mix. The image (c) in Figure 13 was taken at 2µm shows the fibre kind mix developed within the mix and how the bonding has occurred. The last image (c) in Figure 13 taken at a high resolution of 0.2 µm detail view of the geopolymer synthesis. Fly ash bubbles are mixed with total mix and the melting effect of fibre type of geopolymer. However, there are leftover fly ash bubbles as well. Even thou the mix was optimized to create the optimum compressive strength, there is some leftover portion of fly ash bubbles.

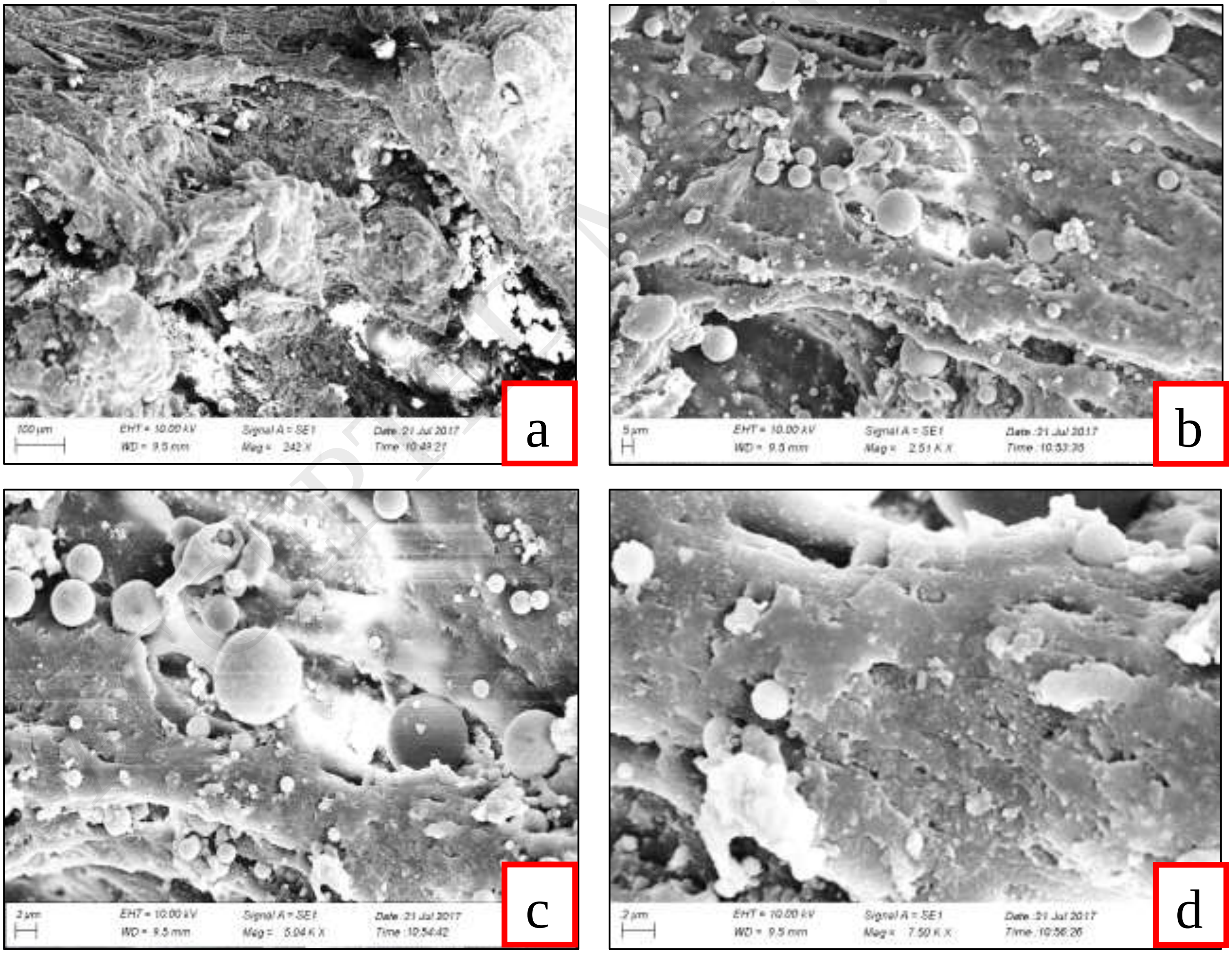


Figure 13: SEM images of fly ash stabilized geo polymers mix after oven curing of 7 days

4 Conclusion

This study was conducted to alter cement in mud concrete block aspires at developing self-compacting Geopolymerized materials stabilized with fly ash to use as affordable masonry units. The concept of employing fly ash and soil can be a win-win situation whereas fly ash is waste and soil is the most abandoned construction materials on earth. Therefore, a waste fly ash from Sri Lankan electricity production plant used as the key stabilizer and it was activated by using Sodium hydroxide and Sodium chloride combination to alkaline activated the mixture. After finalizing the suitable mix for the development of alkaline activated fly ash mixture, the suitable soil combination was explored.

In the first phase of the study, fly ash content was optimized as 20% of the dry weight of the mixture. The most suitable combination of Sodium hydroxide and Sodium chloride to alkaline activate fly ash is Sodium hydroxide 5% of the dry weight and Sodium chloride 2% of the dry weight. The curing technology was an experiment to understand the best method of curing after conducting following studies such as sun drying, heat curing and water curing. This study found that the heating is the suitable curing method, curing at 100^0C for a period of one day. In the third phase, the soil mix was developed. It was found that gravel (aggregates) acts as an immense role in the strong growth in alkaline activated fly ash stabilized mud concrete block. The most suitable mix proportion range between 60% and 35% gravel and 5% fine and 70% and 25% gravel and 5% fine. The optimum water content is in the range of (15%-20%) of the total dry weight. The experiment was conducted with several water ratios taken to optimize the self-compacting nature. The self-compacting nature was studied and found that, at the range of (15%-20%) water content, it can gain the suitable strength without compaction. Thus it can be achieved with 15 seconds vibration at the moisture range below 10%. Further study should be conducted to understand how the heat curing helped to accelerate the curing speed and what is the optimum curing needed for total stabilization.

5Acknowledgment

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