Assessment of FlyAsh Based Geopolymer Concrete Paving Blocks for Sri Lankan Roads

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Abstract: *The coal fired thermal power plants generate solid waste in the form of fly ash and pond ash. Disposal of these wastes is a major engineering challenge. Since large amount of raw materials is needed in the production of every tonne of Portland cement and at the same time about one tonne of carbon dioxide (CO_2) is released into the environment during this production, the research attempts to see whether this solid waste Fly ash can be used in geo polymer concrete paving blocks, so that it will mitigate the adverse effects on the environment due to disposal while reducing the carbon footprint.*
In this research geo polymer concrete paving blocks were made from low calcium fly ash activated by alkaline solutions (NaOH or KOH) to liberate silicon and aluminium with an additional source of silica to assess whether these could satisfactorily be used in Sri Lankan roads satisfying the Sri Lanka Standard (SLS) requirements.
Geo polymer concrete blocks with concentration of NaOH of 12M and 16M was prepared for three different strength classes, namely 30MPa,40MPa,50MPa.One set of series was cured in 80°C for 48hrs and the other series was cured in ambient temperature. The compressive strength, slip/skid resistance and water absorption of GPC paving blocks were determined and were compared with SLS 1425 part 1 and 2.
GPC paving blocks for all strength classes which is cured in 80 °C ambient temperature is found to satisfy all SLS specifications while compressive strength of geo polymer concrete paving bocks cured in ambient temperature is found to be less than the design strength.

Keywords: *geo polymer concrete, paving blocks, fly ash.*

1. INTRODUCTION

Paver blocks made of different materials have been in use since thousands of years. Cement concrete paver blocks became an ideal choice because of its easy and faster laying, better look and finish. As the country Sri Lanka continues to develop and urbanize at a rapid rate the need for paving blocks becomes an essential part of town and city development and expansion. Today precast concrete paver blocks are the most preferred choice for paving of foot paths, parking lots, bus stops, industries, etc., (Aaron et. al. 2012).
Due to rapid infrastructure development taking place nowadays, Portland cement concrete is the most popular and widely used building material. However, due to the restriction of the manufacturing process and the raw materials there are two major drawbacks with respect to sustainability. About 1.5 tonnes of raw materials is needed in the production of every tonne of Portland cement, at the same time about one tonne of carbon dioxide (CO_2) is released into the environment during this production (Aaron et. al. 2012).
The coal fired thermal power plants generate solid waste in the form of fly ash and pond ash. Disposal of these wastes is a major engineering challenge. Today research has combined sustainability with waste management leading to a wonderful product called geo polymer concrete. Modern day geo polymers are mostly made from low calcium fly ash activated by alkaline solutions (NaOH or KOH) to liberate silicon and aluminium with an additional source of silica (Vazet. al. 2012).
With the rapid development of the country the generation of waste is also rapidly increased. Under this another new industrial waste which is available in Sri Lanka is fly ash, due to Norochcholai power plant. Approximately 7000 tons of fly ash is generated annually (Diyes et al, 2014). It is therefore pertinent to investigate methods of making use of this solid waste in a manner that will mitigate the adverse effects on the environment due to disposal. Therefore research attempts to seek whether geo polymer concrete

blocks made with fly ash could be satisfactorily used in Sri Lankan conditions satisfying the SLS standard requirements of paver blocks to minimize environmental hazards that occur through disposal of fly ash and to reduce the carbon foot print by reducing the usage of cement.

2. METHODOLOGY

2.1. Materials

2.1.1. Fly Ash

In the present experimental work, low calcium, Class F (American Society for Testing and Materials 2001) dry fly ash obtained from the Collie Power Station, Norochcholai was used as the base material. The chemical compositions and the properties of the fly ash was analysed and the Table 01 presents the properties of the fly ash.

Table 1 Properties of Fly Ash

Parameters	Specifications	Results
Chemical Composition		
Loss on Ignition	<5.0%	3.9%
Free Calcium Oxide(f/CaO)	<1.0%	NT
Reactive Silicon Dioxide	>25.0%	NT
Sulfuric Anhydride (SO_3)	<3.0%	0.05%
(SiO_2 +Al_2O_3 + Fe_2O_3)	>70.0%	84.41%
Total Alkalies (Na_2O eqv)	<5.0%	1.32%
Magnesium Oxide (MgO)	<4.0%	1.53%
Chloride (Cl^-)	<0.10%	NT
Physical Properties		
Fineness (45µm sieve residue)	<35.0%	22.1%
Activity Index at 28days	>75.0%	NT
Activity Index at 90days	>85.0%	NT
Soundness*	<10.0mm	NT

NT – Not Tested

2.1.2. Alkaline Activators

To activate the fly ash, a combination of sodium hydroxide solution and sodium silicate solution was chosen as the alkaline activator. Sodium-based activators were chosen because they were cheaper than potassium-based activators.

2.1.3. Aggregates

Aggregates are inert mineral material used as filler in concrete which occupies 70–85 % volume. Therefore, in the preparation of geo polymer concrete, fine and coarse aggregates are mixed in such a way that it gives least voids in the concrete mass. This was done by grading of fine aggregate and selecting suitable fine-to-total aggregate ratio. Workability of geopolymer concrete is also affected by grading of fine aggregate similar to cement concrete. Coarse aggregates of nominal size 20mm with specific gravity 2.69 were used in the experimental program. The fine aggregate was river sand.

2.2. Test Methods

2.2.1. Mix Design Based on G-Graph, and Specimen Preparation

Based on G-graphs (Talha et al., 2015) which is used for designing of fly ash based Geo Polymer Concrete (GPC), mix was designed and specimens were prepared.Series of mixtures of GPC was prepaired with concentration of NaOH at 12M and 16M.The ratio of Na_2SiO_3 / NaOH was kept at 2.5. GPC paving bloks were cast in dimensions of 200mmx100mmx80mm. Three specimens were cast from each mix. Each cube was cast in three layers and each layer was tamped 25 times. After casting the specimens, they were kept in room temperature for 24 hours.One set of series was cured in 80^0 C and the other in ambient temerature. Curing period was 48 hours. Compressive strength,Slip/Skid Resistance (USRV) and Water absorption (%) were determined for all the specimens and were compared with Specification for concrete paving blocks Part 02: Sri Lanka Standard Institution (2011) given in table 2 and 3. For all the series of samples, Compressive strength,Slip/Skid Resistance (USRV) and Water absorption (%) was determined after 7 days of curing.

2.2.2. Specifications Required for Concrete Paving Blocks according to The Sri Lankan Standard (SLS) 1425 Part 1 :2011

Compressive Strength – refer table 02

Slip/ Skid Resistance (USRV) ≥ 55 Water Absorption (%) ≤ 6

Table 2 Minimum Strength Requirement and Block Thickness

Strength Class	Average Compressive Strength (N/mm^2)	Individual Compressive Strength(N/mm^2)	Block Thickness (mm)
1	50	40	80,100
2	40	32	80,100
3	30	25	80,100
4	15	12	60

3. RESULTS AND DISCUSSION

3.1. Compressive Strength

Figure 1 shows the compressive strength variation for ambient temperature cured samples and the oven cured samples for NaOH 12M concentration. Figure 2 shows the compressive strength variation for ambient temperature cured samples and the oven cured samples for NaOH 16 M concentration.

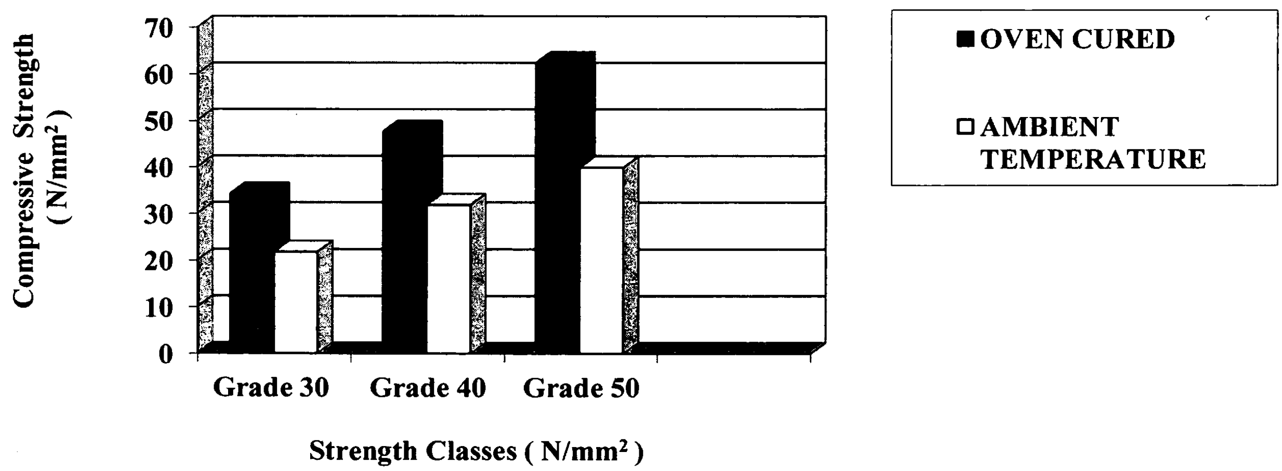

Figure 1 Compressive Strength of ambient temperature versus oven cured - 12M

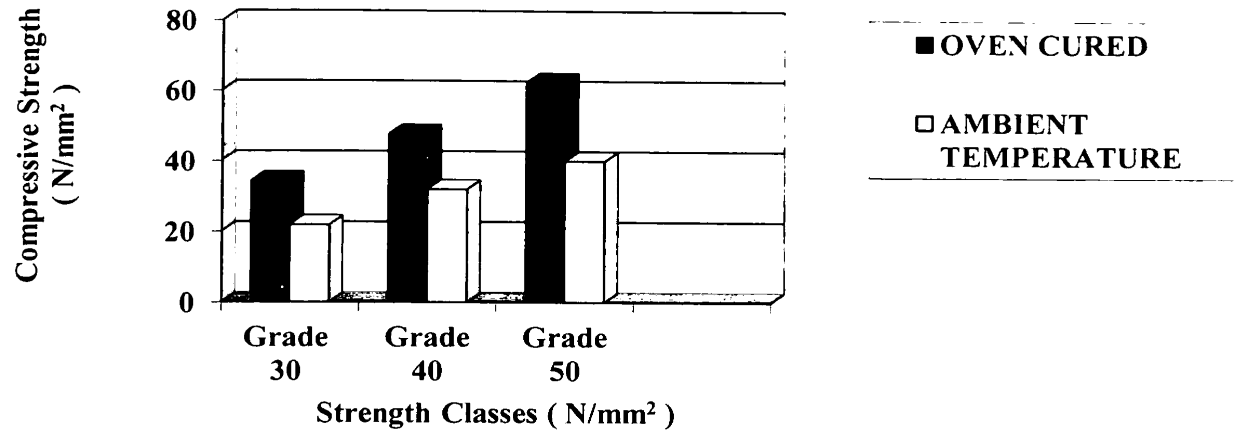

Figure 2 Compressive Strength for ambient temperature versus oven cured - 16 M

Influence of temperature was found to be a key factor for the development of the compressive strength of geo polymer paving blocks. It shows that in elevated temperature (80°C) 7 day compressive strength was found to be higher than the ambient temperature cured samples of NaOH concentrations 12M and 16M. However both the series satisfied the strength requirement of SLS for all the strength classes.

3.2. Slip/ Skid Resistance (USRV)

Figure 3 shows the Slip / Skid resistance of oven cured and ambient temperature cured samples for 12M NaOH concentration. Figure 4 shows the Slip / Skid resistance of Oven cured and ambient temperature cured samples for 16M NaOH concentration.

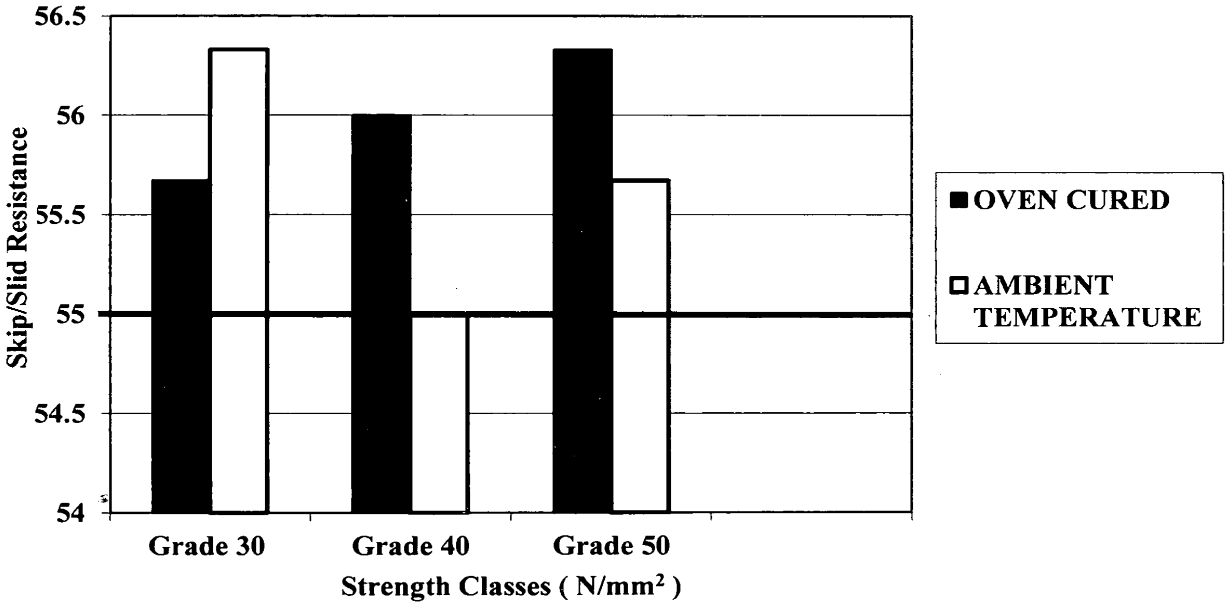

Figure 3 Skid /Slip Resistance for oven cured versus ambient temperature -12 M

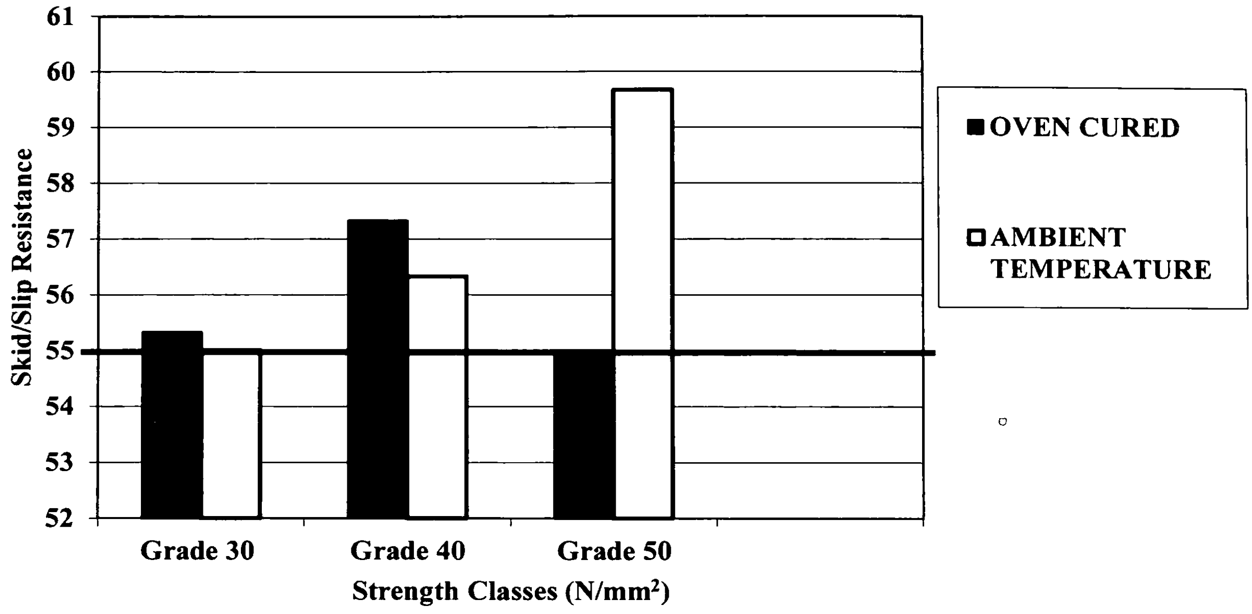

Figure 4 Skid /Slip Resistance for oven cured versus ambient temperature -16 m

It can be seen from figures 3 and 4 that the Slip/Skid resistance for the GPC blocks cured at 80°C and ambient temperature satisfies the SLS requirement for all the strength classes.

3.3. Water Absorption

Figure 5 shows the water absorption of oven cured and ambient temperature cured samples for 12M NaOH concentration. Figure 6 shows the water absorption of oven cured and ambient temperature cured samples for 16M NaOH concentration.

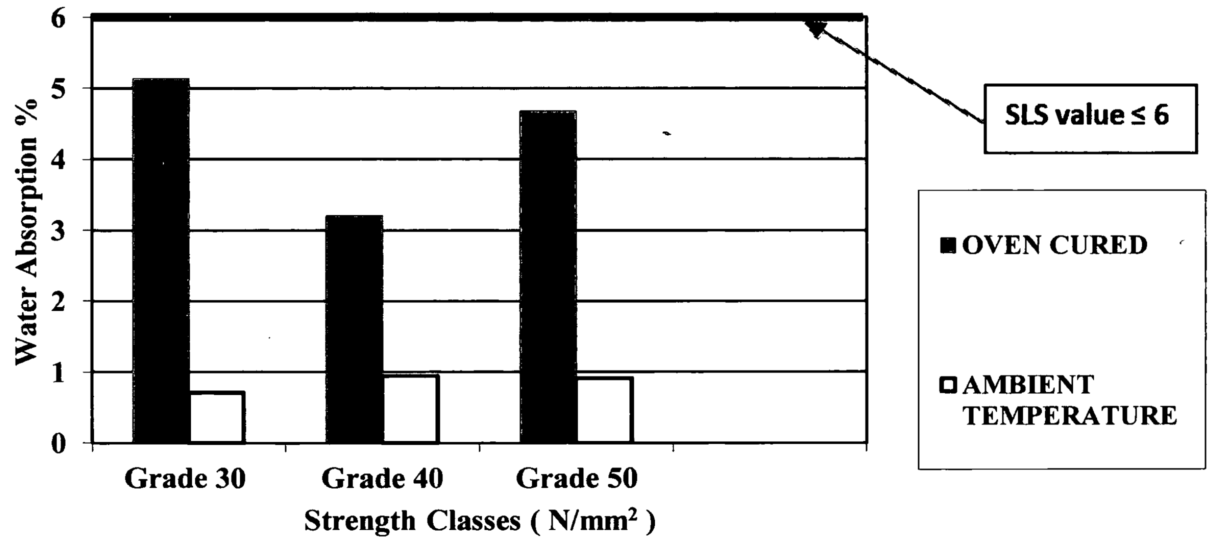

Figure 5 Water Absorption of oven cured versus ambient temperature -12M

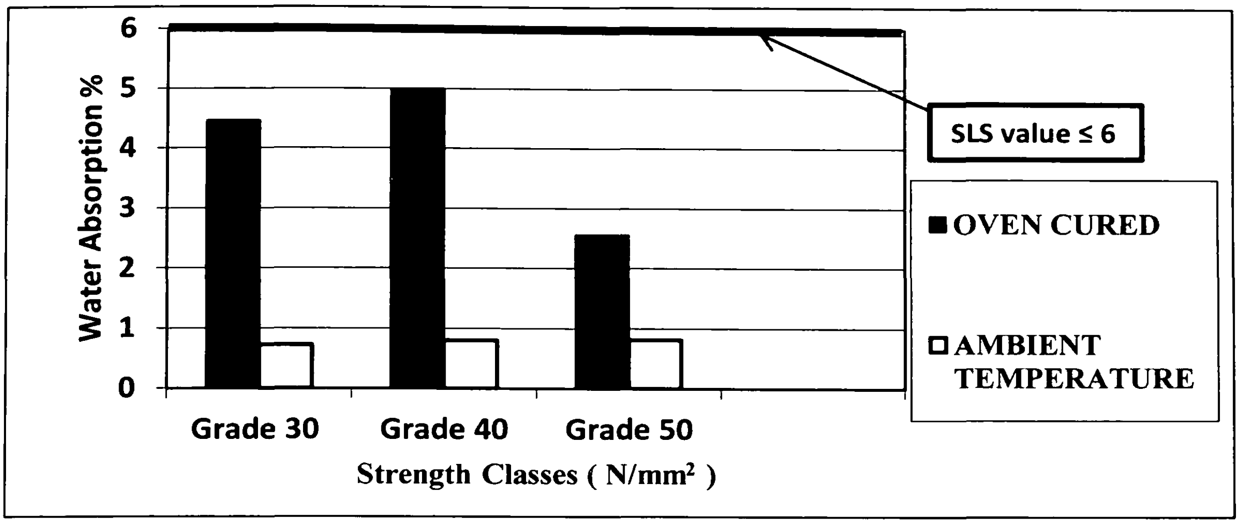

Figure 6 Water Absorption of oven cured versus ambient temperature -16M

Water absorption of GPC blocks cured at 80°C and ambient temperature satisfies the SLS requirement for all the strength classes. However water absorption of ambient temperature cured samples are significantly less than that of elevated temperature cured blocks.

4. CONCLUSIONS

GPC paving blocks for all strength classes which is cured in 80°C ambient temperature is found to satisfy all SLS specifications while compressive strength of geo polymer concrete paving bocks cured in ambient temperature is found to be less than the design strength. Geopolymers made out of waste materials like fly ash not only have smaller footprints but help reduce the footprint of other industries namely, coal fired power plants. By considering the compressive strength results of the paving blocks, cured at elevated temperature and ambient temperature the applicability road classes are given in Table: 03.

Table 3 Selection of the Concrete Blocks Strength Classes for the Appropriate Road Classes

Strength Class	Average compressive strength required according SLS:1425 (MPa)	Usage	Traffic Class (10^6 esa)	Applicable GPC paving block series	Average individual compressive strength of a block (MPa)
1	50	Vehicle usage	T8 = 17-30	G-80-12-48-50	62.33
				G-80-16-48-40	52.83
				G-80-16-48-50	68.5
2	40	Vehicle usage	T5 = 3.0-6.0 T6 = 6.0-10 T7 = 10-17	G-80-12-48-40	47.58
				G-80-16-48-30	41.66
3	30	Vehicle usage	T1(a) <0.1 T1(b) <0.1-0.3 T2 = 0.3-0.7 T3 = 0.7-1.5 T4 = 1.5-3.0	G-80-12-48-40-a	31.83
				G-80-12-48-50-a	39.83
				G-80-16-48-40-a	30.25
				G-80-12-48-30	34.25
				G-80-16-48-50-a	39.83
4	15		Not applicable	G-80-12-48-30-a	21.75

		Pedestrian usage, Strictly excluding any vehicle access		G-80-16-48-30-a	20.01

Source: SLS 1425 part I :2011.
Note:

- Traffic Classes – The cumulative number of standard axles for the design life of the pavement
- Equivalent Standard axle (esa) – The hypothetical axle considered to be having a load of 80kN
- G- 80-12-48- 30- Geo polymer Concrete blocks designed for 80^0C temperature curing, NaOH consecration -12 M, curing period-48 hrs., target 7day strength- 30MPa
- G- 80-12-48- 30-a - Geo polymer Concrete blocks designed for 80^0C temperature curing, NaOH consecration -12 M, curing period-48 hrs., target 7day strength- 30MPa, ambient temperature curing.

All the above geopolymer concrete paving blocks can be used in Sri Lankan roads.

5. ACKNOWLEDGEMENT

Authors wish to express their sincere appreciation to all the staff members of the research laboratory of the department of Civil Engineering of the Open University of Sri Lanka. Thanks are also extended to Dr.(Ms.) H.L.D.M.A Judith (Director, Road Development Authority Research and Development Division,Rathmalana) and the staff members of the division. The assistance given by Mr. P.W Bamunusinghe (Chief Engineer, Electrical Maintenance, Norochcholai coal power plant), Mr. Janaka Ariyadasa and Mr. D.C.S Fernando of Siam City Cement Lanka Pvt. Ltd. are greatly acknowledged.

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