DOI: 10.15415/jotitt.2015.32009

Development of Paver Block by Using Foundry Sand Based Geopolymer Concrete

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Received: September 10, 2015| Revised: October 27, 2015| Accepted: November 30, 2015

Published Online: December 17, 2015

Abstract — Foundry sand is high quality silica sand with uniform physical characteristics. It is a byproduct of ferrous and nonferrous metal casting industries, where sand has been used for centuries as a molding material because of its thermal conductivity. Applications of foundry sand in Geopolymer Paver block, which is technically, sound, environmentally safe for sustainable development. In this study, partially replacement of fine aggregate in Geopolymer paver block by used foundry sand for determining the change in the compressive strength of paver blocks and cost of paver block. Partial replacement of fine aggregate in different percentage as like 0%, 20%, 40%, 60%,80% and 100%. The compressive strength has been determined at the end of 7, 14 and 28 days and water absorption test has been determined at 28 days.

Keywords: Foundry sand, Compressive Strength, Water Absorption, Geopolymer paver block.

1. INTRODUCTION

Today precast concrete paver blocks are the most preferred choice for paving of footpaths, parking lots, bus stops, industries, etc. The concept of using interlocking paver block is very old. The first time road using paver block was constructed in 5000 B.C. by the Minoans. Since, this process is continued and culture is followed for constructing pavement roads. Concrete Paving Blocks were first manufactured in the Netherlands in 1924. The general worldwide trend towards beautification of city pavements, the rising cost of bitumen□s as a paving material and the rapid increase in construction and maintenance cost have encouraged designers to alternate paving material such as concrete blocks.

Journal of Today's Ideas – Tomorrow's Technologies, Vol. 3, No. 2, December 2015 pp. 129–144

Geopolymer Paver Blocks is an ecofriendly method of making concrete paver block using foundry sand in Geopolymer concrete. they are gren paver blocks, they have got nothing to do with color, but is an ecofriendly method of making concrete paver block. More advanced interlocking designs have increased the public appeal due to its aesthetic beauty. Due to rapid infrastructure development taking place, today Portland cement concrete is the second most consumed commodity on earth. Manufacture of ordinary Portland cement generates large amounts of carbon dioxide (CO_2) which is then released into the atmosphere.

Today there is a great environmental responsibility, which has initiated research in sustainability and eco-friendly methods for infrastructure development. The other great problem today is disposal of solid waste. This research has combined sustainability with waste management leading to a wonderful product called Geopolymer paver concrete. Geopolymer made of waste materials like fly ash have smaller carbon footprint compared to OPC. In 1978, a French scientist Joseph Davidovits developed a binder called Geopolymer by polymerization of source materials rich in silicon and aluminium with alkaline solutions. Geopolymers are mostly made from low calcium fly ash activated by alkaline solutions (NaOH or KOH) to liberate Si and Al with an additional source of silica (usually sodium silicate or potassium silicate). These are thermally activated along with aggregates to obtain Geopolymer concrete. Water is not involved in chemical reaction of Geopolymer concrete.

2. OBJECTIVE AND SCOPE

The objective of this dissertation is given below-

1) Here Geopolymer Paver Block was manufactured by using design mix M50 and makes ecofriendly paver block more durable and C.
2) Partial replacement of foundry sand is performed by sand in given percentage of (0 to 100) % with increment of 20% and make the Paver Block cheaper.
3) Foundry sand was used by which it becomes cheaper and effectively utilizes the waste material in infrastructure development.
4) Study the Compressive Strength of Geopolymer Paver Block in 7 days, 14 days and 28 days respectively.

3. EXPERIMENTAL WORK

This chapter describes the details of experimental programs for the measurements of strength properties of Paver block in terms of compressive strength, abrasion resistance, water absorbtion. This study was conducted to ensure the suitability of using the waste foundry sand as partial replacement of fine aggeregate in geopolymer concrete paver blocks. In the present work, normal cement concrete Mix design for M 50 grade is used for the construction of Paver Block. IS 10262:2009 (Concrete Mix Proportioning Guideline) was used for design mix and different trials has been performed for decideing the molarity of alkaline solution. Cubes of size 15 × 15 × 15 cm was casted and tested. In this concrete mix fly ash was used instead of cement along with alkaline solution, coarse aggregate and fine aggregate. For NaOH solution 14 molarity decided and the basic test was conducted on manufacturing procedure that is Vibrating table (at NITTTR) and Hydraulic press (at Mohali). Casting of trails of paver blocks was carried out at 2 stages:

By Hydraulic Press Machine: In this stage number of trails were casted on the site but Geopolymer concrete need elevated temperature to gain strength, which was unavailable at the site.Casted blocks were brought to the laboratory NITTTR and than placed them in to the oven. In this task, small cracks were observed on corners.

By Table Vibrating Machine: In this stage number of trails were casted on vibrating table and left for 2 days to take its shape because we cannot place these blocks into oven with plastic mould. So after 2 days rest period specimens were demoulded and placed into oven at 60°C temperature.

Compressive strength	**14 days (MPA)**	**28 days (MPA)**
Hydarullic press machine	41	52
Table vibrating machine	70	78

After following these procedures it has been observed that the tails casted on vibrating table method easy to cast and gain more strength then the hydraulic press. Casting of Geopolymer concrete block in unavailability of oven is not recommended as per my own experience. For this experimental work black foundry or waste foundry sand was used as replacement of the sand in the mix. The replacement was done in six different percentages. The engineering properties of paver block were tested according to the Indian Standards. For testing the compressive strength of paver block of I shape of size 200 × 160 × 60 mm were casted and tested. The compressive strength of paver block was measured at 7, 14 and 28 days. Water absorption and Abrasion test was carried on 7, 28 days. IS: 15658-2006 code specifications were followed for testing the strength of Paver block. This study aims at determining the suitability of using the waste foundry sand with replacement of fine aggregate in Geopolymer concrete blocks and make eco friendly Paver block.

4. MATERIAL USED

4.1 Fly Ash

In this experimental work, Class F Low calcium fly ash (ASTM Class F) conforming to IS: 3812-1987 specifications, collected from Ramagundam Super Thermal Power Station, India has been utilized. The chemical composition of the fly ash determined by X-Ray Fluorescence (XRF) analysis is shown in Table below

Chemical composition of fly ash

SiO_2	Al_2O_3	Fe_2O_3	CaO	TiO_2	K_2O	MgO
387.7 KCps	194.0 KCps	433.1KCps	47.3 KCps	32.2 KCps	28.3 KCps	8.2 KCps
61.73 %	26.97 %	3.74 %	2.60 %	1.56 %	1.49 %	0.93 %

Sieve analysis of fly ash reveals that 65% of particles are smaller than 45 micron. The specific gravity of fly ash using the density bottle test was found to be the 2.06.

4.2 Alkaline Liquids

In this research Analytical Grade Sodium Hydroxide pellets were used with 98% to 100% purity dissolved in distilled water and Sodium Silicate Solution (Na_2O = 7.5-8.5% and SiO_2 = 25-28%.) were used as alkaline activator liquids. The sodium hydroxide is in pellet form and sodium silicate was in solution form. The alkaline solution is prepared by mixing both the sodium hydroxide and sodium silicate solution together. Sodium hydroxide pellets were dissolved in distilled water. Thereafter, some amount of heat is released due to the mixing. After cooling sodium hydroxide, sodium silicate mixed in it.

The quantity of NaOH solids in a solution varies depending on the concentration of the solution is expressed in terms of molar, we have used 14M. The NaOH solution with a 14M contain $14 \times 40 = 560$ grams of NaOH solids pellet per litre of the solution, where 40 is the molecular weight of NaOH.

The Sodium hydroxide was obtained from Lomb Chemie Pvt. Ltd. The sodium hydroxide (NaOH) AR solution was prepared by dissolving pellets in water. Sodium silicate solution (A53 grade) AR obtained from Lomb Chemie Pvt. Ltd was used.

4.3 Aggregates

The aggregates account for 75-80% by mass in concrete. Locally available aggregate was used in this experimental work. The SSD (saturated surface dry) coarse and fine aggregates were used. The coarse aggregate was graded and sand was well graded so that coarse aggregate interlocks and fine aggregate fill the voids.

5. FINE AGGREGATES

Fine aggregate (sand): are those that pass through No.4 (4.75 mm) sieve and were retained on the No. 200 (75 µm) sieve. Sieve analysis helps to find out the zoning, size of aggregate and to determine the particle size distribution of fine aggregates. The fine aggregates were tested as per IS: 383-1970.

Properties of normal sand

Characteristics	Value
Fineness modulus	3.32
Specific Gravity	2.6
Grading zone of fine aggregates	Zone III

6. FOUNDRY SAND

In this experimental work, foundry sand was used as a partial replacement of normal sand Zone III is used. A foundry is a manufacturing facility that produces metal castings by pouring molten metal into a preformed mould to yield the resulting hardened cast. Foundry sand is high quality silica sand that is a by-product from the production of both ferrous and nonferrous metal castings. The physical and chemical characteristics of foundry sand will depend in great part on the type of casting process and the industry sector from which it originates. Metal foundries use large amounts of sand as part of the metal casting process. Foundries successfully recycle and reuse the sand many times in a foundry. When sand can no longer be reused in the foundry, it is removed from the foundry and is termed foundry sand. The properties of foundry sand shown in table

Table 1: Properties of foundry sand.

Characteristics	Value
Fineness modulus	2.45
Specific Gravity	2.65
Zone of sand	4

6.1 Coarse Aggregate

Coarse aggregate are those, retained on the No. 4 (4.75 mm) sieve. Sieve analysis helps to find out size of aggregate and to determine the particle size distribution of coarse aggregates. The aggregates were tested as per IS: 383-1970 Specific gravity of coarse aggregates is given in Table no.10. The sieve analysis of coarse aggregate was done. Nominal maximum size of aggregate used in production of aggregate shall be 12mm as per IS 15658-2006 so that 10mm and 12mm sizes were used.

Properties of coarse aggregates

Characteristics	Value
Shape	Angular
Maximum Size	12 mm
Specific Gravity	2.65

7. MIX DESIGN FOR M 50 GRADE

The compressive strength of concrete is considered as the index of its quality. Therefore the mix design is generally carried out for a particular compressive strength. The proportions for the mix were calculated adopting the requirements of water as specified in BIS: 10262-2009. In the present study, Mix design for M 50 grade for the construction of Paver Block were calculated as per IS 10262:2009 Concrete Mix Proportioning guideline (First Revision).

Data:

Characteristic strength at 28 days	=	50 N/mm^2
Degree of quality control expected at site	=	Good
Maximum size of aggregate	=	12mm
Type of exposure	=	Mild
Concrete use	=	Paver Blocks

Target strength for mix proportioning

f'ck= f'ck + 1.65s
From Table 1 standard deviation, s = 5 N/mm^2
Therefore target strength = 50 + 1.65 × 5 = 58.25 N/mm^2

Selection of w/ c ratio

From Table 5 of IS 456:2000, maximum water cement ratio = 0.45
Adopting water cement ratio as 0.35
0.35 < 0.45, hence ok

Selection of water content

From Table 2, maximum water content = 208 liters (for 10 mm aggregates)
No super plasticizer is used.
Based on trails water content reduction to 11% has been achieved.
Hence the arrived content= 208 × 87 = 185.12 liters say 185.5 liters

Calculation of cement content

Water cement ratio = 0.35
Cement content = 185.5/0.35 = 530 kg/m^3 > 320 kg/m^3
From Table 5 of IS 456, minimum cement content = 320 kg/m^3, Hence OK

Proportion of volume of coarse aggregate and fine aggregate content

From Table 3, volume of coarse aggregate corresponding to 10 mm size aggregate and fine aggregate (Zone III) = .48
Based on trails, therefore volume of course aggregate = .63, volume of fine aggregate = .37

Mix calculations: The mix calculations per unit volume of concrete shall be as follows:

a) Volume of concrete = 1 m^3
b) Volume of cement = mass of cement/specific gravity of cement × 1/1000
= [530/3.15] × [1/1000] = 0.168 m^3

c) Volume of water = [185.5/1] × [1/1000] = 0.185 m^3
d) Volume of all in aggregates = a – (b + c)
= 1 – (0.168 + 0.185) = 0.647 m^3
e) Volume and weight of coarse aggregates Volume = 0.647 × 0.63 × [2.65/1000] = 1088 kg
f) Volume and weight of fine aggregates= 0.647 × 0.37 × [2.6/1000] = 622 kg

Mix proportions:

Cement = 530 kg/m^3 replaced by fly ash
Water = 185.5 liters/m^3 replaced by alkali solution.
Ratio of sodium silicate/sodium hydroxide = 2.5
[53(sodium hydroxide) +132.5(sodium silicate) = 185.5 liters(alkali solution)]
Fine aggregate = 622kg/m^3
Coarse aggregates = 1088 kg/m^3
Water cement ratio = 0.35

Mixture proportion

		Geopolymer concrete for M 50					
	Replacement by foundry Sand	**0%**	**20%**	**40%**	**60%**	**80%**	**100%**
1	Fly ash	530	530	530	530	530	530
2	Normal Sand	622	497.6	373.2	248.8	373.2	00
3	Foundry sand	00	124.4	248.8	373.2	497.6	622
5	Coarse agg.	1088	1088	1088	1088	1088	1088
6	NaOH	53	53	53	53	53	53
7	Na_2SiO_3	132.5	132.5	132.5	132.5	132.5	132.5
8	Molarity	14	14	14	14	14	14
	Liquid/binder Ratio	.35	.35	.35	.35	.35	.35

8. EXPERIMENTAL PROCESS

1) The moulds are used for making of concrete Paver Block as per IS: 15658-2006 methods of tests for Strength of concrete.
2) Paver back mould of 200 × 160 × 60 mm size.

3) Firstly decide the number of sample to be taken during concreting.
4) Before casting of materials shuttering oils should be used inside the mould properly.
5) Collect the all material in the pan before the mixing properly.
6) Mix the all material in the pan.
7) Use of vibrating machine/table in compacting concrete to a voids formation of air voids in concrete.
8) After casting the specimen was placed in oven at a temperature of 27° C for 7 days, 14 days and 28 days respectively.
9) Finally check its compressive strength and water absorption as per as IS: 15658-2006.

9. RESULTS AND DISCUSSION

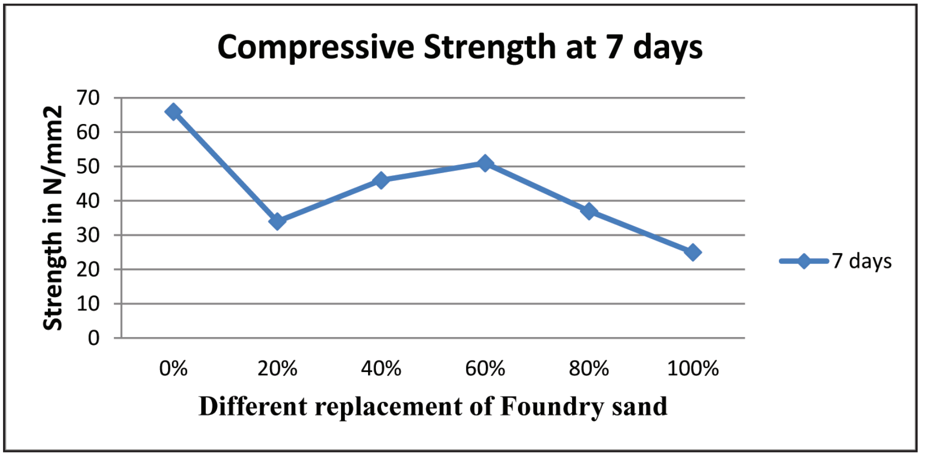
The Paver Block is designed on the basis of IS: 15658–2006 as per M-50 Grade Designation of-Paver Blocks. The results which are comes out from testing is given below

9.1. Compressive strength of paver block

These results show Compressive Strength of Paver Block with partial replacement of fine sand with foundry sand at 7, 14 and 28 days and there is also comparison of Compressive Strength is also shown below

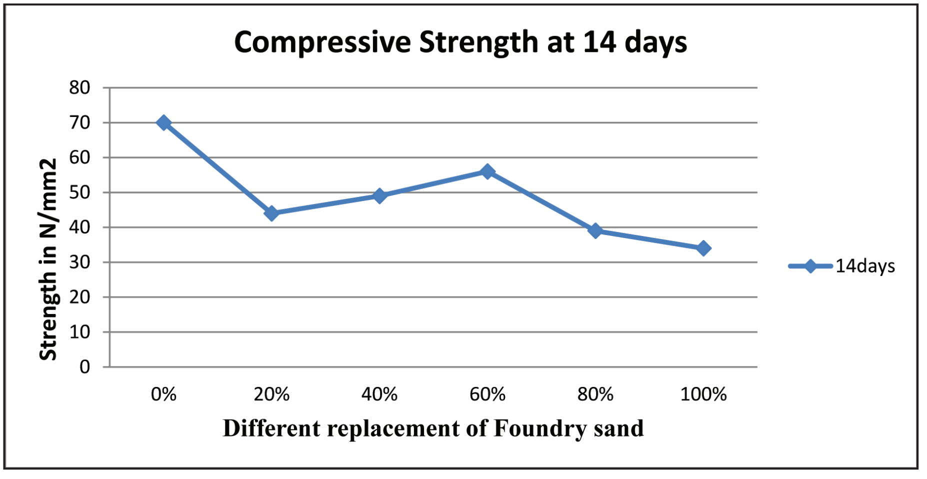
Compressive strength of M 50 Ggeopolymer Paver Blocks

Curing Temp. 60°C	7 days		14 days		28 days	
	Comp. strength	Density Kg/m³	Comp. strength	Density Kg/m³	Comp. strength	Density Kg/m³
0% replacement	66	2358	70	23661	78	2370
20% replacement	34	2196	44	2258	48	2293
40% replacement	46	2280	49	2274	53	2266
60% replacement	41	2174	56	2289	62	2311
80% replacement	37	2078	39	2162	45	2283
100% replacement	25	2031	34	2066	41	2168



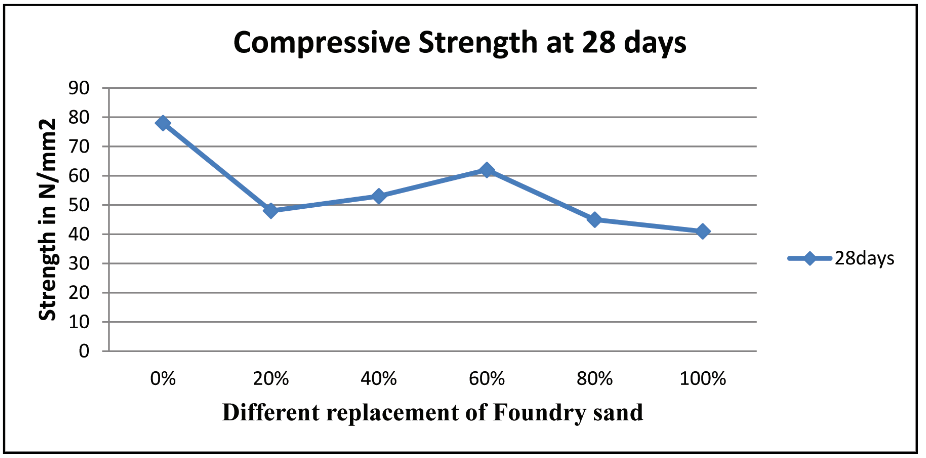
Compressive strength at 7 days of Geopolymer Paver Block with different replacement of foundry sand

It has been clearly shown by the above-mentioned results that after 7 days of casting Geopolymer paver blocks achieved very high early strength upto 70% of total strength i.e. 66 N/mm^2. But with the replacement by foundry sand with normal sand strength is achieving very low strength 34 N/mm2. And up to 60% replacement by foundry sand of normal sand slight increase in strength after that decrease in strength up to 100% replacement.



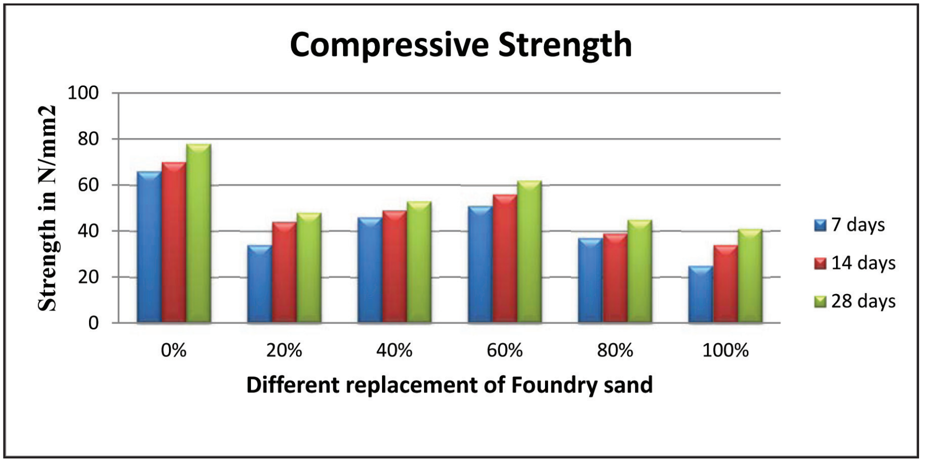
Compressive strength at 14 days of geopolymer Paver Block with different replacements

It has been clearly shown by the above graph that after 14 days of casting Geopolymer paver blocks achieved 70 N/mm^2 but at first replacement by foundry sand with normal sand gain 44 N/mm^2 and then up to 60% replacement slight increment was observed ,same like figure 11 and after that decrease in strength up to 100% replacement.



Compressive strength of Geopolymer Paver Block at 28 days with different replacement of foundry sand

It has been clearly shown by the above graph that after 28 days of casting Geopolymer paver blocks achieved 78 N/mm^2 but at first replacement by foundry sand with normal sand gain 48 N/mm^2 and then up to 60% replacement slight increment was observed ,same like figure 11, figure 12 (page- 59,60) and after that decrease in strength up to 100% replacement.



Compressive strength of geopolymer Paver Block at 28 days with different replacement by foundry sand

28 days of casting achieved more than the designed compressive strength under heat curing 60°C that is 78 N/mm^2. Also it has been observed that compressive strength by replacement of foundry sand achieving very low strength, but Further increase in replacement by foundry sand upto 60%. It is clearly indicated by the test results that the behavior of Geopolymer concrete is similar for both 7, 14 and 28 days with respect to replacement of foundry sand. It also observed that 60% replacement is achieving more than designed strength 62 N/mm^2 and we can replace up to 100% also, because 41 N/mm^2 strength of paver block can be used for medium traffic.

9.2 Water Absorption Test of Paver Block

The ability of a material to absorb and retain water is known as its water absorption. It mainly depends on the volume, size and shape of pores, present in the material. The completely dried pavement blocks were weighed and immersed in clean water for 24 hours at (Ww).The block is then removed from water and then weighed (Wd).

Water absorption test of M50 Geopolymer Paver Block at 28 days

S. No.	Foundry sand %age	Wet Weight (Ww) in kg	Dry Weight (Wd) in kg	% Water Absorption (W %)	Mean
		3.836	3.778	1.53	
1.	0%	3.949	3.812	3.59	2.27
		3.629	3.568	1.70	
		3.718	3.640	2.14	
2.	20%	3.423	3.319	3.13	2.87
		3.589	3.472	3.36	
		3.638	3.572	1.84	
3.	40%	3.571	3.432	4.05	3.52
		3.248	3.103	4.67	
		3.752	3.646	2.90	
4.	60%	3.359	3.219	4.34	3.61
		3.691	3.563	3.59	

		3.506	3.388	3.48	
5.	80%	4.030	3.826	5.33	4.85
		3.740	3.536	5.76	
		3.768	3.692	2.05	
6.	100%	4.006	3.872	3.46	2.79
		3.946	3.836	2.86	

It has been clearly shown by the above mentioned results that maximum water absorption of Geopolymer Paver Block at 28 days, among all groups was found to be 4.96 % and individual was 5.80that as per IS: 15658:2006 water absorption of concrete Paving Block should be less than 6% by mass and in individual sample water absorption is restricted to 7% But this is much less than the requirement.

CONCLUSIONS

Based on the results of the experimental investigation, following conclusions are drawn:

1. Geopolymer Paver Block achieved very early high compressive strength of 66 MPa.
2 The Compressive strength of Geopolymer Paver Block was found to be dcreasing with replacement of foundry sand. Upto 60% replacement of fine sand by foundry sand gives slightly high compressive strength was found tobe optimum.
3 Complete replacement by foundry sand decreasing slight compressive strength, lesser value is 41 MPa which can be used for manufacturing of paver blocks for 40 MPa.
4. Maximum strength of Paver block was found at 78 MPa at 0% replacement, which is very high, can be used for very heavy traffic.
5. Water absorbption of Geopolymer paver blocks 4-5%, which is satisfing permissible limits of IS :15658-2006.

RECOMMENDATIONS FOR FUTURE STUDIES:

- The properties of geopolymer concrete using foundry sand with varing sodium hydroxide to sodium silicate ratio can be studied.
- In addition to foundry sand chemicals variations in GPC concrete due to sodium hydroxide or potassium hydroxide can study.

- Different mix strength can be explored.
- Us of foundry sand based Geopolymer concrete in manufacturing of Bricks.
- The fine sand can be replaced with waste foundry slag. As slag is a waste utilized in high performance concrete.
- The effect on foundry sand based Geopolymer concrete due to use of slag instead of fly ash along with replacement of slag by sand can be investigated.

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LIST OF CODES

- Code used in the present studies: -
- Code for fly ash - ASTM C 618
- Code for foundry cand - IS: 1918-1966
- Code for ggregate testing - IS: 383-1970
- Code for testing of concrete Paver Block - IS:15658-2006, IS 13801:2013