Development of Fly Ash & Bottom Ash Based Alkali Activated Paver Blocks

By

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14MCLC06

DEPARTMENT OF CIVIL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

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Development of Fly Ash & Bottom Ash Based Alkali Activated Paver Blocks

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(Computer Aided Structural Analysis And Design)

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Declaration

This is to certify that

a. The thesis comprises my original work towards the Degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) at Nirma University and has not been submitted elsewhere for a degree.

b. Due acknowledgment has been made in the text to all other material used.

Yash P. Khandol

Certificate

This is to certify that Major Project entitled **"Development of Fly Ash & Bottom Ash Based Alkali Activated Paver Blocks"** submitted by **Mr. Yash P. Khandol (14MCLC06)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) of Nirma University, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

Paver blocks made of different materials have been in use since thousands of years. Concrete paver blocks has been extensively used in many countries for quite some time as a specialized problem-solving technique for providing pavement in areas where conventional types of construction are less durable due to many operational and environmental constraints. Today, the demand of paver blocks is increasing day by day as they are the most preferred choice for paving of footpaths, parking plots, bus stops, industries, etc. More advanced interlocking designs of paver blocks have increased the public appeal due to its aesthetic beauty. Ordinary Portland cement (OPC) is used as the primary binder to concrete paver blocks. However, it is well known that the production of OPC not only consumes significant amount of natural resources and energy but also releases substantial quality of carbon dioxide to the atmosphere. The global cement industry contributes around 2.8 billion tons of the greenhouse gas emissions annually, or about 7% of the total man-made greenhouse gas emissions to the earth's atmosphere. It is essential to find alternatives to make environment friendly concrete to produce paver blocks.

One of the alternatives to produce environmentally friendly concrete is the development of inorganic alumina-silicate polymer or alkali activation of aluminosilicate materials and alkaline liquids, called alkali activated concrete, which utilize the polycondensation process to attain the strength. Aluminosilicate materials should be rich in by-product materials such as fly ash, bottom ash, slag, rice-husk ash, red mud, etc. Alkaline liquids are soluble in nature and have sodium and potassium base. By exploring use of the fly ash and bottom ash based alkali activated paver blocks two environment related issues are tackled i.e. the high amount of CO_2 released to the atmosphere during production of OPC and utilization of fly ash and bottom ash.

In this major project, the basic information and design parameters of paver blocks such as materials, size, shape, weight, colour, area, mix proportion, compaction type, mix homogeneity, manufacturing process, cost of production, cost of purchase, type of machine used, cost of machine, etc. are to be collected from the different local manufacturing plant of paver blocks to study the mix proportion and casting procedure of paver blocks. For experimental work Class F fly ash and bottom ash from local suppliers has been used to produce alkali activated paver blocks.

Experimental work comprises investigation on consistency and setting time of alkali activated mortar with different proportion of fly ash and bottom ash. To develop the mix design of paver blocks, the effect of variation in source material and other salient parameters on compressive strength of alkali activated concrete has been investigated. Parameters related to source materials such as ratio of fly ash to bottom ash 70:30, 50:50 and 30:70 and amount of source material in the range of 393 kg/m^3 to 429 kg/m^3 are to

be varied. Other parameters includes alkaline liquid to source material ratio 0.35 and 0.4, alkaline liquid ratio 2 and 2.5, concentration of NaOH solution 8M, 10M, 12M 14M and 16M, addition of super plasticizer 0% and 1%, extra water content 10% and 15%, rest period 1 day and 2 day etc. have been varied throughout investigation. The parameters giving satisfactory and economical results are selected for making fly ash and bottom ash based alkali activated paver blocks. The density of alkali activated paver blocks was found equivalent to that of conventional OPC paver blocks. The zigzag type paver blocks of 60 mm thickness as per IS provisions has been casted for the investigation of the properties of the paver blocks i.e. compressive strength, abrasion resistance and water absorption. Results of properties of alkali activated paver blocks have been compared with the the results of commercially available OPC paver blocks. Specimens have been tested at 7 and 28 days, respectively.

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14MCLC06

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Abbreviation Notation and Nomenclature

OPC .... Ordinary Portland Cement
CO_2 .... Carbon Dioxide
ICBP .... Interlocking Concrete Block Pavement
CBP .... Concrete Block Pavement
GGBS .... Ground Granulated Blast Furnace Slag
SEM .... Scanning Electron Micrograph
NaOH .... Sodium Hydroxide
Na_2SiO_3 .... Sodium Silicate
FA .... Fly Ash
BA .... Bottom Ash

Chapter 1

Introduction

1.1 General

Paver blocks made of different materials have been in use since thousands of years. However, cement concrete paver blocks became an ideal choice because of its easy and faster laying, better looks and finish. The demand of paver blocks is increasing day by day as they are the most preferred choice for paving of footpaths, parking plots, bus stops, industries, etc. More advanced interlocking designs have increased the public appeal due to its aesthetic beauty[1]. Ordinary Portland Cement (OPC) is used as the primary binder to paver blocks. Portland cement production is under critical review due to high amount of carbon dioxide gas released to the atmosphere. De-carbonation of limestone in the kiln during manufacture of cement is responsible for the liberation of one ton of carbon dioxide to the atmosphere for each ton of Portland cement produced[2]. The global cement industry contributes around 2.2 billion tons of the greenhouse gas emissions annually, or about 7% of the total man-made greenhouse gas emissions to the earth's atmosphere. It is essential to find alternatives to make environment friendly concrete[3].

On the other hand, the abundant availability of fly ash and bottom ash worldwide creates opportunities to utilize this by-product of burning coal, as a substitute for OPC to manufacture concrete. In India more than 184 million tons of fly ash and 36 million tons of bottom ash are produced annually. Out of this, only 55% of fly ash and 10% of bottom ash are utilized in concrete or in stabilization of soil. Most of these materials is disposed of as a waste material that covers several hectors of valuable land. So, disposal of these wastes is a major engineering challenge with more stringent environmental laws.

These facts have urged engineers look for development of alternate concretes. One of the alternatives to make more environmentally friendly concrete is the development of inorganic alumina-silicate polymer or alkali activation of aluminosilicate materials and alkaline liquids, called alkali activated concrete, which utilize the polycondensation process to attain the strength. These new concretes utilize industrial wastes in the form of fly ash and bottom ash which are activated by alkaline medium to produce ambient temperature cured inorganic polymeric binder called as alkali activated concrete in the form of aluminosilicates.

According to Davidovits, alkaliactivation is a geosynthesis that chemically integrates materials containing silicon and aluminium. During the process, silicon and aluminium atoms are combined to form the building blocks that are chemically and structurally comparable to those binding the natural rocks[4].

Alkali activated concretes are a new generation of alternative building materials, whose main difference from traditional Portland cement concretes is the use of a relatively alkali-rich, clinker-free binder matrix such as alkali-activated fly ash or bottom ash. Accordingly, efforts to utilize this by-product material in concrete manufacturing are important to make concrete more environmental friendly[2]. By using the fly ash and bottom ash based alkali activated concrete reducing the two environment related issues i.e. the high amount of CO_2 released to the atmosphere during production of OPC and utilization of fly ash and bottom ash.

1.2 Interlocking Concrete Block Pavement

Interlocking Concrete Block Pavement (ICBP) has been extensively used in many countries for quite some time as a specialized problem-solving technique for providing pavement in areas where conventional types of construction are less durable due to many operational and environmental constraints[1]. Concrete Block Pavement (CBP) technology has been introduced in India in construction, a decade ago, for specific requirement namely footpaths, fuel stations, parking areas etc. This technology is now being adopted extensively in different uses where the conventional construction of pavement using bituminous mix or cement concrete technology is not feasible, desirable or economical[1].

Concrete paver blocks were first introduced in Netherlands in the early 1950s as a replacement for baked clay brick roads. The general worldwide trend towards beautification of city pavements, the rising cost of bitumen as a paving material and the rapid increase in construction and maintenance cost have encouraged designers to alternate paving material such as concrete blocks. The strength, durability and aesthetically pleasing surface of pavers have made CBP ideal for many commercial, municipal and industrial applications[1]. Fig 1.1 shows the Concrete Block Pavement at different places.

(a) Pedestrian

(b) Petrol pump

(c) Port

(d) High way

Figure 1.1: Concrete Block Pavement

Paver block is a special dry mix pre-cast piece of concrete commonly used in pavement applications. ICBP consists of a surface layer of small-element, solid un-reinforced concrete paver blocks laid on a thin, compacted bedding material which is constructed over a properly profiled base course and is bounded by edge restraints or kerb stones. A properly designed and constructed ICBP gives excellent performance when applied at locations where conventional systems have lower service life due to a number of geological, traffic, environmental and operational constraints. Many number of such applications for light, medium, heavy and very heavy traffic conditions are currently in practice around the world.

Advantages of ICBP technology:

Some of the advantages of ICBP technology are as mentioned below[1]:

1. No need to deploy heavy construction equipments or machineries

2. Factory production of paving blocks facilitates centralized quality control

3. Labour intensive construction method

4. No need of curing

5. Instant opening of road to traffic

6. No thermal expansion and contraction of concrete
7. Accommodates higher elastic deflections without failure
8. Pavements are not damaged due to fuel and oil spillage
9. High salvage value
10. Least life cycle cost due to low maintenance cost
11. Environment friendly technology
12. Can be used in poor drainage conditions

Applications of ICBP Technology:
Some of the proven areas where ICBP technology is being applied are listed below[1]:

1. Non-traffic Areas: Building Premises, Footpaths, Malls, Pedestrian Plaza, Landscapes, Monuments Premises, Premises, Public Gardens/Parks, Shopping Complexes, Bus Terminus Parking areas and Railway Platform, etc.
2. Light Traffic: Car Parks, Office Driveway, Housing Colony Roads, Office/Commercial Complexes, Rural Roads, Residential Colony Roads, Farm Houses, etc.
3. Medium Traffic: Boulevard, City Streets, Small Market Roads, Intersections/Rotaries on Low Volume Roads, Utility Cuts on Arteries, Service Stations, etc.
4. Heavy and Very Heavy Traffic: Container/Bus Terminals, Ports/Dock Yards, Mining Areas, Roads in Industrial Complexes, Heavy-Duty Roads on Expansive Soils, Bulk Cargo Handling Areas, Factory Floors and Pavements, Airport Pavement, etc.

Shapes and Classifications of Paver Blocks
There are four generic shapes of paver blocks corresponding to the four types of blocks as mentioned below[1]:

1. Group A: Paver blocks with plain vertical faces, which do not key into each other when paved in any pattern.
2. Group B: Paver blocks with alternating plain and curved/corrugated vertical faces, which key into each other along the curve/corrugated faces, when paved in any pattern.
3. Group C: Paver blocks having all faces curved or corrugated, which key into each other along all the vertical faces when paved in any pattern.

4. Group D: 'L' and 'X' shaped paver blocks which have all faces curved or corrugated and which key into each other along all the vertical faces when paved in any pattern.

Fig 1.2 shows the classification of paver blocks according to their typical shapes.

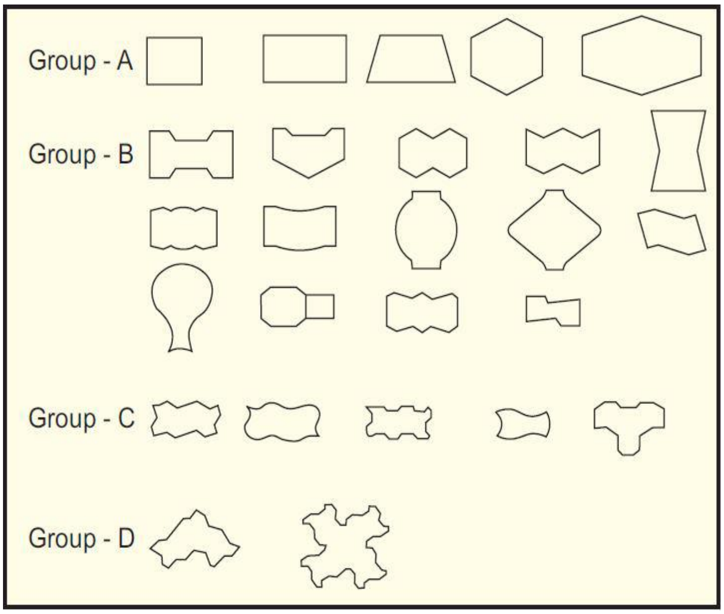


Figure 1.2: Classifications of paver blocks

1.3 Research Significance

Continuous technological upgrading and assimilation of latest technology has been going on in the cement concrete industry. But, the cement production is highly energy intensive and consumes significant amount of nonrenewable natural resources such as lime stone deposits, coal, etc. The production of 1 tonne of ordinary Portland cement directly generates 0.55 tonnes of CO_2 from the calcination of limestone and requires the combustion of carbon-fuel to yield an additional 0.40 tonnes of CO_2. Thus, the Portland cement industry does not quite fit the contemporary desirable picture of a sustainable eco-friendly industry. So, there is a need to find an alternate binder which should be similar or superior to that of Portland cement for use in concretes in respect of parameters such as: processing conditions for production of concrete mixes, mechanical and durability properties, long term chemical stability of the binding system with common filler aggregate systems such as sand, crushed natural stones, etc. Because of unique properties such as high early strength, low shrinkage, sulphate and corrosion resistance alkali activated concrete become a viable alternative to conventional cement and hence substantially reduce CO_2 emission caused by the cement and concrete industries. Now a days, Interlocking Concrete Block Pavement (ICBP) has been extensively used as a specialized problem-solving technique for providing pavement in areas where conventional types of construction are less durable due to many operational and environmental constraints. Therefore, it has been decided to conduct investigations on parametric study and properties of fly ash and bottom ash based alkali activated paver blocks in this project.

1.4 Objectives of Study

The main objective of this study is to develop the alkali activated paver blocks using fly ash and bottom ash. To study various parameters, following objectives are decided for the major project.

- To collect the information on design parameters of paver blocks made of different materials from the local manufacturer such as size, shape, compaction type, manufacturing process, type of machine and equipment used, cost of production, cost of purchase etc.
- To develop a mix design of alkali activated paver blocks using optimum combination of fly ash and bottom ash.
- To study the effect of various parameters such as proportion of fly ash and bottom ash, amount of source material, alkaline liquid to source material ratio, concentration of NaOH solution, alkaline liquid ratio, addition of super plasticizer, curing period, extra water content, rest period etc. on compressive strength of alkali activated paver blocks for selected mixes.
- To compare the properties i.e. compressive strength, abrasion resistance and water absorption of alkali activated paver blocks and commercially available OPC paver blocks.

1.5 Scope of Work

Scope of work of major project includes theoretical work and laboratory work related to comparison of properties of alkali activated paver blocks and OPC paver blocks.

The details of basic information and design parameters of paver blocks are to be collected from the different manufacturing plants to study the mix proportion and casting procedure of paver blocks. Parameters include size, shape, weight, colour and area of paver blocks. It also include type of materials used, mix proportion, compaction type, mix homogeneity, manufacturing process, cost of production, cost of purchase, type of machine used, cost of machine etc.

Investigation on consistency and setting time of alkali activated mortar with different proportion of fly ash and bottom ash is to be worked out. For developing the mix design of alkali activated paver blocks, ratio of fly ash to bottom ash 70:30, 50:50 and 30:70 and amount of source material in the range of 393 kg/m^3 to 429 kg/m^3 are to be varied. Other parameters such as alkaline liquid to source material ratio 0.35 and 0.4, alkaline liquid ratio 2 and 2.5, concentration of NaOH solution in the range of 8M to 16M, addition of super plasticizer 0% and 1%, extra water content 10% and 15%, rest period 1 day and 2 day etc. are to be varied throughout investigation. The parameters giving satisfactory and economical results are to be selected for making fly ash and bottom ash based alkali activated paver blocks. Cubes of size 70.6 mm x 70.6 mm x 70.6 mm are to be used for all the parametric study. Average result of three specimens are to be considered as the main results for all the parameters. The mix design of alkali activated paver blocks are to be developed based on the preliminary investigation.

Properties such as compressive strength, abrasion resistance & water absorption of alkali activated paver blocks are to be measured and compare with the commercially available OPC paver blocks. Four different mixes of alkali activated paver blocks with different concentration of NaOH solution are to be prepared for testing the compressive strength at 7 and 28 days as per IS provisions.

Detailed scope of work is as shown in Figure 1.3.

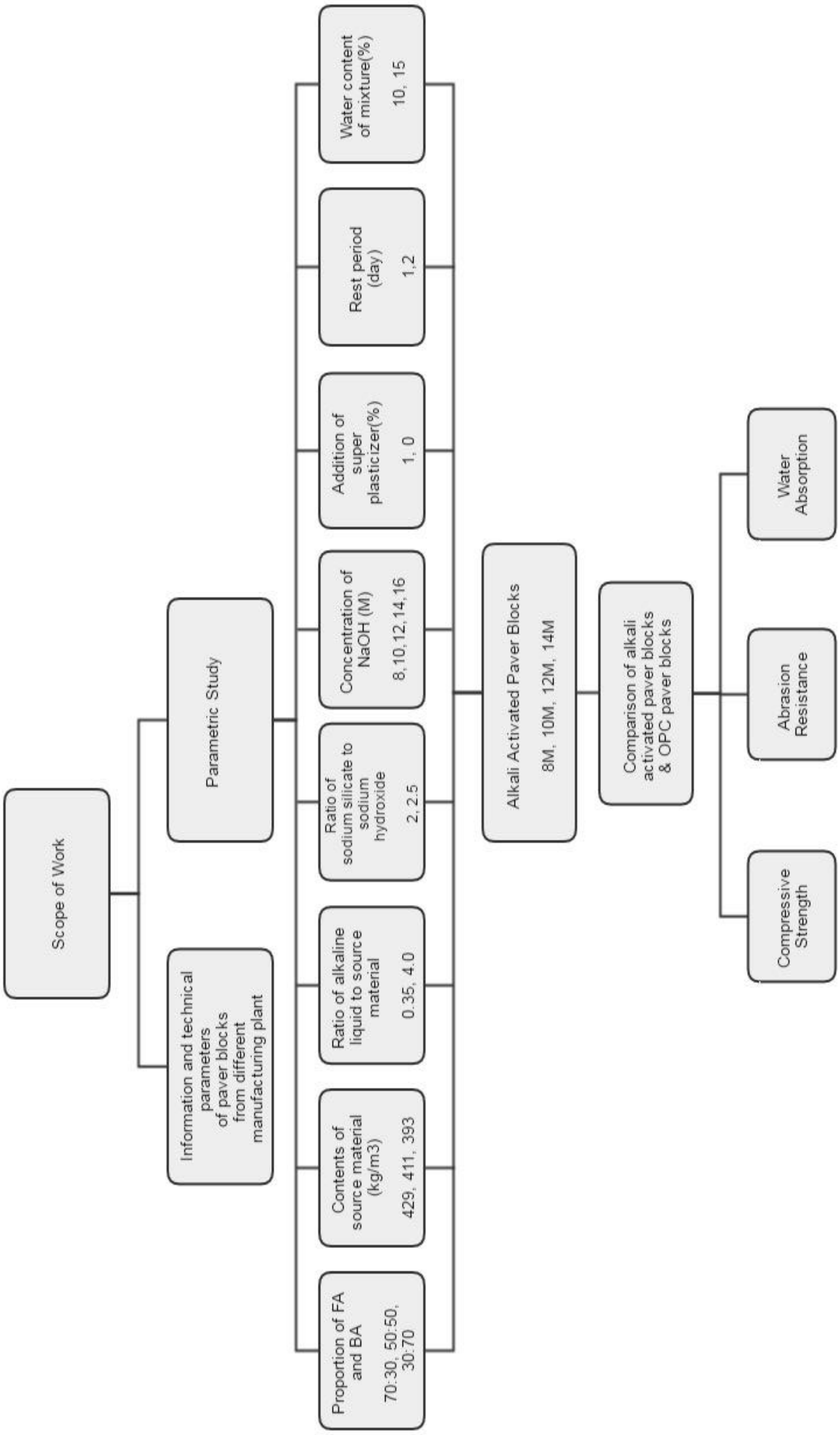


Figure 1.3: Flow Chart of Scope of Work

1.6 Organization of Major Project

The report of major project is divided into seven chapters as given below.

- **Chapter 1** incorporates discussion about introduction and need of study of the alkali activated paver blocks. Objectives of study and scope of work are further included in this chapter.

- **Chapter 2** includes the details of technical parameters of OPC paver blocks from different manufacturing plants and literature review on properties of alkali activated paver blocks based on previous research work related to the major project.

- **Chapter 3** includes the literature review of alkali activated concrete. It includes the chemistry, background, properties and effect of various salient parameters on compressive strength of alkali activated binders.

- **Chapter 4** describes the details of experimental programme. Material used in the investigation, casting of alkali activated specimens and the test procedure used are reported in this chapter.

- **Chapter 5** includes all results and discussion related to investigation on consistency and setting time of alkali activated mortar, effect of salient parameters affecting performance of alkali activated paver blocks and mix design process for alkali activated paver blocks.

- **Chapter 6** describes all results and discussion related to properties including compressive strength, abrasion resistance and water absorption of alkali activated paver blocks and OPC paver blocks at different ages.

- **Chapter 7** consists of summary, conducting remarks and recommendation for future scope of work and cost analysis on basis of work has been conducted in major project.

Chapter 2

Literature Review on Paver Blocks

2.1 General

This chapter presents the literature review of OPC paver blocks and alkali activated paver blocks. Various details of technical parameters of OPC paver blocks from different manufacturing plants and past studies on alkali activated paver blocks has been included in this chapter.

2.2 OPC Paver Blocks

Paver block is a special solid and unreinforced precast piece of concrete commonly used in pavement applications. Ordinary Portland cement (OPC) is used as the primary binder to paver blocks. The demand of paver blocks is increasing day by day as they are the most preferred choice for paving of footpaths, parking plots, bus stops, industries, etc. More advanced interlocking designs, sizes and shapes have increased the public appeal due to its aesthetic beauty.

The basic information and technical parameters of paver blocks such as materials, size, shape, weight, colour, area, mix proportion, compaction type, mix homogeneity, manufacturing process, cost of production, cost of purchase, type of machine used, cost of machine etc. have been collected from the different manufacturing plants of paver blocks. Table 2.1 to Table 2.16 represent the general information of paver blocks and various materials and specifications of paver blocks from different manufacturing plants

Manufacturing Plant - 1

1. General information of paver blocks

Table 2.1: General information of paver blocks

Parameters	Types of Paver Blocks		
	Element 1	Element 2	Element 3
Appearance			
Name	Uni Paver	I Shape	Colorado
Area	100 Sq.Ft / 280 Nos	100 Sq.Ft / 250 Nos	100 Sq.Ft / 220 Nos
Weight	4 to 4.2 kg	4.8 kg	4.8 to 5 kg
Thickness	60/80 mm	60/80 mm	60 mm
Cost per Brass (1 Brass = 100 Sq.Ft)	Rs.2300 to Rs.2500	Rs.2300 to Rs.2500	Rs.2300 to Rs.2500
Cost per piece	Rs.8.2 to Rs.8.9	Rs.9.2 to Rs.10	Rs.10.4 to Rs.11.3

2. Materials and specifications of paver blocks

Table 2.2: Materials and specifications of paver blocks

Materials	Cement, Sand, 6mm Aggregate, 8 mm Aggregate, Water, local Hardener
Colors	Red, Grey, Yellow
Compressive Strength	M20, M25, M30, M40
Packing	Loose

3. Type of compaction: Vibrator, Hydraulic

4. Type of machine use: Concrete Mixer, Color Mixer, Vibrator

5. Quantity produce per day: 600 Sq.Ft/day

6. Cost of production (including labour charge, machine and electricity) : 6Rs./piece

Manufacturing Plant-2

1. General information of paver blocks

Table 2.3: General information of paver blocks

Parameters	Types of Paver Blocks			
	Element 1	Element 2	Element 3	Element 4
Appearance				
Name	Uni Paver	I Shape	Damru paver	8 4Bricks
Area	100 Sq.Ft / 280 Nos	100 Sq.Ft / 250 Nos	100 Sq.Ft / 220 Nos	100 Sq.Ft / 450 Nos
Weight	4 to 4.2 kg	4.8 kg	4.8 to 5 kg	2.5 to 2.8 kg
Thickness	60/80 mm	60/80 mm	60 mm	60 mm
Cost per 100 Sq.Ft	Rs.2400 to Rs.2600	Rs.2400 to Rs.2600	Rs.2400 to Rs.2600	Rs.2400 to Rs.2600
Cost per Piece	Rs.8.5 to Rs.9.2	Rs.9.6 to Rs.10.4	Rs.9.6 to Rs.10.4	Rs.5.3 to Rs.5.7

2. Materials and specifications of paver blocks

Table 2.4: Materials and specifications of paver blocks

Materials	Cement, Sand, 6mm Aggregate, 8 mm Aggregate, 10mm Aggregate, Water, local Hardener
Colors	Red, Grey, Yellow
Compressive Strength	M20, M25, M30, M35, M40, M50
Packing	Loose

3. Type of compaction: Vibrator, Hydraulic

4. Type of machine use: Concrete Mixer, Color Mixer, Vibrator

5. Quantity produce per day: 1400 Sq.Ft/day

6. Cost of production (including labour charge, machine and electricity) : 9Rs./piece

Manufacturing Plant-3

1. General information of paver blocks

Table 2.5: General information of paver blocks

Parameters	Types of Paver Blocks			
	Element 1	Element 2	Element 3	Element 4
Appearance				
Name	Uni Paver	I Shape	Colorado	Damru Paver
Area	100 Sq.Ft / 280 Nos	100 Sq.Ft / 250 Nos	100 Sq.Ft / 220 Nos	100 Sq.Ft / 250 Nos
Weight	4 to 4.2 kg	4.8 kg	4.8 to 5 kg	4.8 to 5 kg
Thickness	60/80 mm	60/80 mm	60 mm	60 mm
Cost per 100 Sq.Ft	Rs.2400 to Rs.2500	Rs.2400 to Rs.2500	Rs.2400 to Rs.2500	Rs.2400 to Rs.2500
Cost per Piece	Rs.8.5 to Rs.8.9	Rs.9.6 to Rs.10	Rs.10.9 to Rs.11.3	Rs.9.6 to Rs.10

2. Materials and specifications of paver blocks

Table 2.6: Materials and specifications of paver blocks

Materials	Cement, Sand, 8 mm Aggregate, 10mm Aggregate, Water, local Hardener
Colors	Red, Grey, Yellow, Black
Compressive Strength	M20, M25, M30, M40, M50
Packing	Loose

3. Type of compaction: Vibrator

4. Type of machine use: Concrete Mixer, Color Mixer, Vibrator

5. Quantity produce per day: 1500 Sq.Ft/day

6. Cost of production (including labour charge, machine and electricity) : 9Rs./piece

Manufacturing Plant-4

1. General information of paver blocks

Table 2.7: General information of paver blocks

Parameters	Types of Paver Blocks		
	Element 1	Element 2	Element 3
Appearance			
Name	Uni Paver	I Shape	Colorado
Area	100 Sq.Ft / 280 Nos	100 Sq.Ft / 250 Nos	100 Sq.Ft / 220 Nos
Weight	4 to 4.2 kg	4.8 kg	4.8 to 5 kg
Thickness	60/80 mm	60/80 mm	60 mm
Cost per Brass (1 Brass = 100 Sq.Ft)	Rs.2500	Rs.2500	Rs.2500
Cost per piece	Rs.8.9	Rs.10	Rs.11.3

2. Materials and specifications of paver blocks

Table 2.8: Materials and specifications of paver blocks

Materials	Cement, Sand, 6mm Aggregate, 10mm Aggregate, Water, local Hardener
Colors	Red, Grey, Yellow
Compressive Strength	M20, M25, M30, M40
Packing	Loose

3. Type of compaction: Vibrator
4. Type of machine use: Concrete Mixer, Color Mixer, Vibrator
5. Quantity produce per day: 900 Sq.Ft/day
6. Cost of production (including labour charge, machine and electricity) : 7Rs./piece

Manufacturing Plant-5

1. General information of paver blocks

Table 2.9: General information of paver blocks

Parameters	Types of Paver Blocks		
	Element 1	Element 2	Element 3
Appearance			
Name	Uni Paver	I Shape	Colorado
Area	100 Sq.Ft / 280 Nos	100 Sq.Ft / 250 Nos	100 Sq.Ft / 225 Nos
Weight	4 to 4.2 kg	4.8 kg	5 to 5.4 kg
Thickness	60/80 mm	60/80 mm	60 mm
Cost per Brass (1 Brass = 100 Sq.Ft)	Rs.2400 to Rs.2500	Rs.2400 to Rs.2500	Rs.2400 to Rs.2500
Cost per piece	Rs.8.5 to Rs. 8.9	Rs.9.6 to Rs.10	Rs.10.6 to Rs.11.1

2. Materials and specifications of paver blocks

Table 2.10: Materials and specifications of paver blocks

Materials	Cement, Sand, 6mm Aggregate, 10 mm Aggregate, Water, local Hardener
Colors	Red, Grey, Yellow
Compressive Strength	M20, M25, M30, M40
Packing	Loose

3. Type of compaction: Vibrator, Hydraulic

4. Type of machine use: Concrete Mixer, Color Mixer, Vibrator

5. Quantity produce per day: 1000 Sq.Ft/day

6. Cost of production (including labour charge, machine and electricity) : 8Rs./piece

Manufacturing Plant-6

1. General information of paver blocks

Table 2.11: General information of paver blocks

Parameters	Types of Paver Blocks			
	Element 1	Element 2	Element 3	Element 4
Appearance				
Name	Uni Paver	I Shape	Colorado	8 4Bricks
Area	100 Sq.Ft / 280 Nos	100 Sq.Ft / 250 Nos	100 Sq.Ft / 225 Nos	100 Sq.Ft / 450 Nos
Weight	4 to 4.2 kg	4.2 kg	4.8 to 5 kg	2.5 to 2.8 kg
Thickness	60/80 mm	60/80 mm	60 mm	60 mm
Cost per 100 Sq.Ft	Rs.2600	Rs.2600	Rs.2600	Rs.2600
Cost per Piece	Rs.9.2	Rs.10	Rs.11.5	Rs.5.7

2. Materials and specifications of paver blocks

Table 2.12: Materials and specifications of paver blocks

Materials	Cement, Sand, 6mm Aggregate, 10 mm Aggregate, Water, local Hardener
Colors	Red, Grey, Yellow
Compressive Strength	M20, M25, M30, M40
Packing	Loose

3. Type of compaction: Vibrator

4. Type of machine use: Concrete Mixer, Color Mixer, Vibrator

5. Quantity produce per day: 500 Sq.Ft/day

6. Cost of production (including labour charge, machine and electricity) : 10Rs./piece

Manufacturing Plant-7

1. General information of paver blocks

Table 2.13: General information of paver blocks

Parameters	Types of Paver Blocks			
	Element 1	Element 2	Element 3	Element 4
Appearance				
Name	Uni Paver	I Shape	Colorado	Damru Paver
Area	100 Sq.Ft / 280 Nos	100 Sq.Ft / 250 Nos	100 Sq.Ft / 220 Nos	100 Sq.Ft / 250 Nos
Weight	4 to 4.2 kg	4.8 kg	5 kg	4.8 to 5 kg
Thickness	60/80 mm	60/80 mm	60 mm	60 mm
Cost per 100 Sq.Ft	Rs.2500	Rs.2500	Rs.2500	Rs.2500
Cost per Piece	Rs.8.9	Rs.10	Rs.11.3	Rs.10

2. Materials and specifications of paver blocks

Table 2.14: Materials and specifications of paver blocks

Materials	Cement, Sand, 8mm Aggregate, 10mm Aggregate, 10mm Aggregate, Water, local Hardener
Colors	Red, Grey, Yellow
Compressive Strength	M20, M25, M30, M40
Packing	Loose

3. Type of compaction: Vibrator, Hydraulic
4. Type of machine use: Concrete Mixer, Color Mixer, Vibrator
5. Quantity produce per day: 700 Sq.Ft/day
6. Cost of production (including labour charge, machine and electricity) : 10Rs./piece

Manufacturing Plant-8

1. General information of paver blocks

Table 2.15: General information of paver blocks

Parameters	Types of Paver Blocks			
	Element 1	Element 2	Element 3	Element 4
Appearance				
Name	Uni Paver	I Shape	Damru Paver	Hexagon
Area	100 Sq.Ft / 280 Nos	100 Sq.Ft / 260 Nos	100 Sq.Ft / 250 Nos	100 Sq.Ft / 225 Nos
Weight	4 to 4.2 kg	4.2 kg	4.8 to 5 kg	5 to 5.4 kg
Thickness	60/80 mm	60/80 mm	60 mm	60 mm
Cost per 100 Sq.Ft	Rs.2600	Rs.2600	Rs.2600	Rs.2600
Cost per Piece	Rs.9.2	Rs.10	Rs.10.4	Rs.11.1

2. Materials and Specifications of Paver Blocks

Table 2.16: Materials and specifications of paver blocks

Materials	Cement, Sand, 6mm Aggregate, 10 mm Aggregate, Water, local Hardener
Colors	Red, Grey, Yellow, Black
Compressive Strength	M20, M25, M30, M35, M40, M50
Packing	Loose

3. Type of compaction: Vibrator, Hydraulic

4. Type of machine use: Concrete Mixer, Color Mixer, Vibrator

5. Quantity produce per day: 500 Sq.Ft/day

6. Cost of production (including labour charge, machine and electricity) : 6Rs./piece

2.2.1 Observation from the Survey of OPC Paver Blocks

It has been observed through survey of various paver block manufacturing plants that Uni paver blocks, I shape paver blocks and Colarado paver blocks are commonly available. Density of paver blocks is ranging between 2250 kg/m^3 to 2450 kg/m^3. Paver blocks having 60mm and 80mm thickness is commonly available. Cost of the paver blocks are ranging between Rs.2300 to Rs.2600 per 100 Sq.Ft. Ingredient materials for the manufacturing of paver blocks are Ordinary Portland Cement, sand, 10mm passing aggregates, water and hardener. Paver blocks are commonly available in red, gray and yellow colors. Production of paver blocks require concrete mixer, colour mixer and vibration table. Paver blocks are commonly available in M20, M25, M30 and M40 grades. From the survey of OPC paver blocks parameters of paver blocks which commonly avilavle are shown in Figure 2.17

Table 2.17: Commonly available parameters of paver blocks

Parameters	Types of Paver Blocks		
	Element 1	Element 2	Element 3
Appearance			
Name	Uni Paver	I Shape	Colorado
Area	100 Sq.Ft / 280 Nos	100 Sq.Ft / 250 Nos	100 Sq.Ft / 220 Nos
Weight	4 to 4.2 kg	4.8 kg	4.8 to 5 kg
Thickness	60/80 mm	60/80 mm	60 mm
Cost per Brass (1 Brass = 100 Sq.Ft)	Rs.2300 to Rs.2600	Rs.2300 to Rs.2600	Rs.2300 to Rs.2600
Cost per piece	Rs.8.2 to Rs.9.2	Rs.9.2 to Rs.10.4	Rs.10.4 to Rs.11.8
Commonly use materials and specification of paver blocks			
Materials	Ordinary Portland Cement, Sand, 10mm passing aggregate, Water, Hardener		
Colours	Red, Gray and Yellow		
Compressive Strength	M20, M25, M30, M40		

2.3 Alkali Activated Paver Blocks

2.3.1 Compressive Strength

Janardhanan and Ramasamy[12] studied the mechanical properties of alkali activated paver blocks using verious proportion of botttom ash and GGBS under ambient conditions. The density range was taken as 1800 kg/m^3, 2000 kg/m^3, 2200 kg/m^3 and 2400 kg/m^3. Compressive strength of M30 grade for density 2200 kg/m^3 and 2400 kg/m^3 at 28 days shown in Fig 2.1 and 2.2. They conclude that as the density of the alkali activated concrete increases, the strength also increases variably. But the difference in compressive strength for various densities is very nominal. The maximum strength being achieved for the highest density of 2400 kg/m^3 and 50:50 proportion of botttom ash and GGBS.

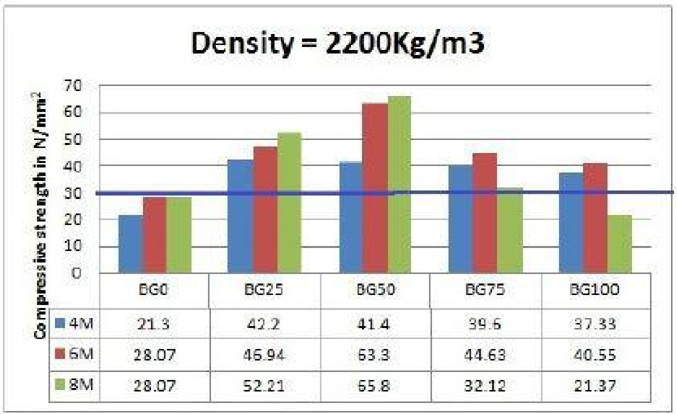


Figure 2.1: Compressive strength of paver blocks for density 2200 kg/m^3

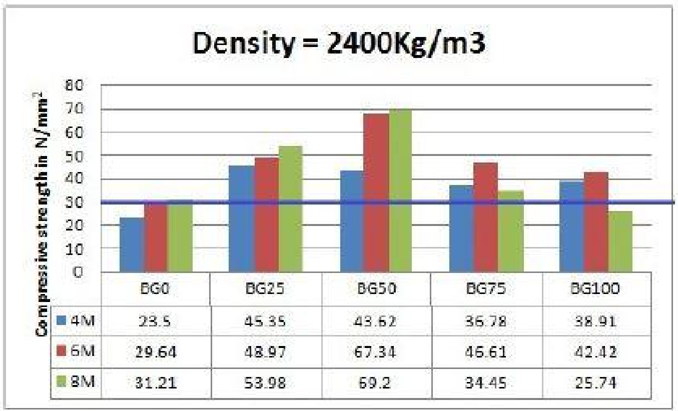


Figure 2.2: Compressive strength of paver blocks for density 2400 kg/m^3

Vaz et al.[13] investigated the properties of alkali activated precast concrete paver blocks and compare the performance with the commercially available OPC paver blocks. Fig 2.3 shows the compressive strength of paver blocks with respact to ages. The concentration of sodium hydroxide was varied from 8M to 12M. They find that the alkali activated paver block have high compressive strength for the same mix proportion as compare to OPC paver blocks and also high strength to gain that can save lot of curing time and space at manufacturing units.

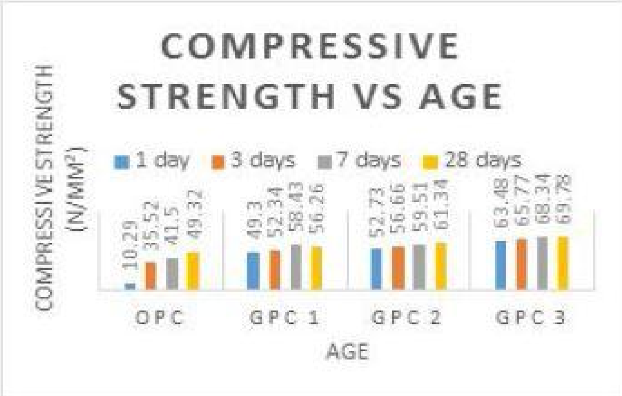


Figure 2.3: Compressive strength of paver blocks with respect to ages

Revathi et al.[14] investigated the mechanical properties of alkali activated paver blocks using various proportion of bottom ash and GGBS. Two curing mode such as ambient and steam curing at 60° for 24 hours were selected for the test. Fig 2.4 shows the compressive strength of alkali activated paver blocks with different ages. Mix with 75:25 proportion of bottom ash and GGBS was observed with the highest compressive strength of 44.29 MPa and 59.58 at 7 days and 28 days; respectively.

COMPRESSIVE STRENGTH OF BA-GGBS-GP PAVER BLOCK

Mix Identity	Grade	Compressive Strength, MPa		
		3 days	7 days	28 days
BG_{75}	M30	36.22	42.49	57.34
$1BG_{25}$	M35	37.65	44.29	59.58

Figure 2.4: Compressive strength of paver blocks

2.3.2 Abrasion Resistance

Vaz et al.[13] investigated abrasion resistance of alkali activated paver blocks and OPC paver blocks. Ratio of sodium silicate to sodium hydroxide was taken as 2.5. The concentration of sodium hydroxide was varied from 8M to 12M. They found that alkali activated paver blocks have higher abrasion resistance than OPC paver blocks. 28 day average abrasion value of alkali activated paver block and OPC paver block were 1.75 mm and 2.10 mm, respectively.

2.3.3 Water Absorption

Vaz et al.[13] compare the water absorption of alkali activated paver blocks and OPC paver blocks. Alkali activated paver blocks had very less water absorption as compare to OPC paver blocks. 24 hours water absorption of alkali activated paver block and OPC paver block were 2.1% and 2.6%, respectively.

Revathi et al.[14] studied the water absorption of alkali activated paver blocks. Fig 2.5 shows the results of water absorption of paver blocks with different mix. The water absorption of mix with 25:75 proportion of BA and GGBS was obtained as 0.76% and mix with 75:25 proportion of BA and GGBS was obtained as 0.28% . As per IS: 15658:2006[20], the water absorption shall not be more than 6% by mass and in individual samples and it should be restricted to 7 percent.

WATER ABSORPTION OF BA-GGBS-GP PAVER BLOCK

Mix Identity	Grade	Water Absorption %
$1BG_{75}$	M30	0.76
$1BG_{25}$	M35	0.28

Figure 2.5: Water absorption of paver blocks

2.3.4 Finding from Literature Review of Alkali Activated Paver Blocks

It has been observed through various litterateurs that as the density of the alkali activated paver blocks increases, the strength also increases. But the difference in compressive strength for various densities is very nominal. Also it has been found that higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of alkali activated paver blocks. It was found that alkali activated paver blocks have higher abrasion resistance than OPC paver blocks. It has been also observed that alkali activated paver blocks has very less water absorption as compared to OPC paver blocks.

Chapter 3

Literature Review on Alkali Activated Concrete

3.1 General

This chapter presents a brief review of the needs of the development of alternate binding material for the present construction industry, background of alkali-activated aluminosilicate concrete and fly ash and bottom ash based alkli activated concrete. The terminology, chemistry and properties of aluminosilicate concrete and past studies on alkali activated concrete has been included in this chapter.

3.2 Requirement of Alkali Activated Concrete

Concrete is a most commonly used construction material in the world due to its properties such as strength, mouldability and availability of its ingredients. Customarily, concrete is produced by using Portland cement as the binder. Portland cement production is under critical review due to high amount of carbon dioxide gas released to the atmosphere. The global cement industry contributes around 2.2 billion tons of the greenhouse gas emissions annually, or about 7% of the total man-made greenhouse gas emissions to the earth's atmosphere. Activation of alumino-silicate materials such as fly ash, bottom ash, and metakaolin using alkaline solutions to produce binders free of Portland cement is a major advancement towards increasing the beneficial use of industrial waste products and reducing the adverse impacts of cement production.

3.3 Alkali Activated Alumino Silicate binders

3.3.1 Terminology and Chemistry

Davidovits[4] proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice-husk ash to produce binders. Alkali-activated alumino silicate binders are the members of the family of inorganic polymers. The chemical composition of the alkali activated material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline conditions on silicon aluminum minerals that results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

Poly(sialates) are chain and ring polymers with Si^{4+} and Al^{3+} in IV-fold coordination with oxygen and range from amorphous to semi-crystalline with the empirical formula[10]:

$$M_n\Big(-(SiO_2)_z \ - \ AlO_2\Big)_n.\omega H_2O \tag{3.1}$$

where M is a monovalent cation such as potassium or sodium, the symbol '-' indicates the presence of a bond, "z" is 1, 2 or 3 or higher up to 32; and "n" is a degree of polycondensation or polymerisation.

Polycondensation has also distinguished 3 types of polysialates, namely the Poly(sialate) type (-Si-O-Al-O), the Poly(sialate-siloxo) type (-Si-O-Al-O-Si-O) and the Poly(sialate-disiloxo) type (-Si-O-Al-O-Si-O). The structures of these polysialates can be schematized as given in Figure 3.1 and 3.2, respectively.

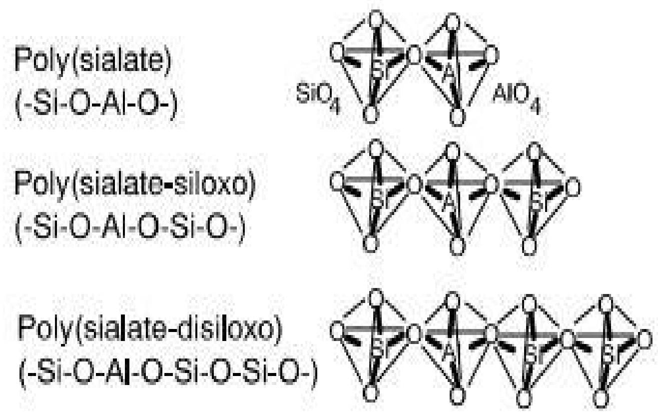


Figure 3.1: Three basic forms of alkali activated binders

Figure 3.2: Polymeric structures from polymerisation of monomers

Alkali activation involves the chemical reaction of alumino-silicate oxides (Si_2O_5, Al_2O_2) with alkali polysilicates yielding polymeric Si - O - Al bonds. Polysilicates are generally sodium or potassium silicate supplied by chemical industry or manufactured fine silica powder as a by-product of ferro-silicon metallurgy. Figure 3.3 shows an example of poly-condensation by alkali into poly (sialate-siloxo).

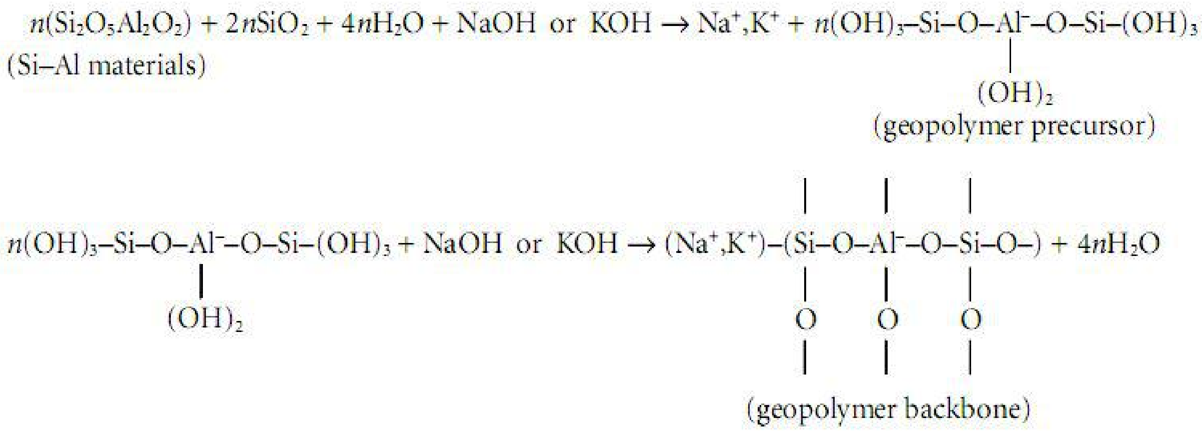


Figure 3.3: The formation of alkali activated material

The last term in Figure 3.3 reveals that water is released during the chemical reaction that occurs during the formation of alkali activated material. This water, expelled from the alkali activated matrix during the curing and further drying periods, leaves behind discontinuous nanopores in the matrix which provide benefits to the performance of alkali activated binders. The water in a alkali activated mix, therefore, plays no role in the chemical reaction that takes place; it merely provides workability to the mix during handling. This is in contrast to the chemical reaction of water in a Portland cement concrete mix during the hydration process[10].

Unlike ordinary Portland/pozzolanic cements, alkali activated binders do not form calcium-silicate-hydrates (CSHs) for matrix formation and strength, but utilise the polycondensation of silica and alumina precursors and a high alkali content to attain structural strength.

3.3.2 Constituents of Alkali Activated Binders

There are two main constituents of alkali activated binders, namely the source materials for binders based on alumina-silicate should be rich in silicon (Si) and aluminum (Al) and alkaline liquids. Coarse and fine aggregates used by the concrete industry are suitable to manufacture alkali activated concrete.

Source materials
Any material that contains mostly Si and Al in amorphous form is a possible source material for the manufacture of alkali activated binders. Several minerals and industrial by-product materials have been investigated in the past. Metakaolin or calcined kaolinite, low-calcium ASTM Class F fly ash, natural Al-Si minerals, combination of calcined mineral and non-calcined materials, combination of fly ash and metakaolin, and combination of granulated blast furnace slag and metakaolin have been studied as source materials[5].

On the nature of the source material, it was stated that the calcined source materials, such as fly ash, slag, calcined kaolin, demonstrated a higher final compressive strength when compared to those made using non-calcined materials, for instance kaolin clay and naturally occurring minerals. However, it was found that using a combination of calcined (e.g. fly ash) and non-calcined material (e.g. kaolinite or kaolin clay) resulted in significant improvement in compressive strength and reduction in reaction time[6].

Alkaline Liquids
Palomo et al.[7] concluded that the type of alkaline liquid plays an important role in the polymerisation process. Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides. **Xu & Van Deventer**[6] confirmed that the addition of sodium silicate solution to the sodium hydroxide solution as the alkaline liquid enhanced the reaction between the source material and the solution.

3.3.3 Reaction Mechanism of Alkali Activated Binders

The hardening of fly ash based alkali activated binders achieved by dissolving the Al and Si components of fly ash by alkaline activators is known as polymerization. Duxson has proposed the several stage for the reaction mechanism of the alkali activated matrix : (1) Dissolution (2) Speciation Equilibrium (3) Galazion (4) Reorganiztion (5) Polymeriztion and Hardening (Fig 3.4). Dissolution of the solid alumino-silicate source by alkaline hydrolysis (consuming water) produces aluminate and silicate and further dissolution of amorphous alumino-silicates creates a supersaturated alumino-silicate solution. In concentrated solutions this results in the formation of a gel. After gelation the system continues to rearrange and reorganize, as the connectivity of the gel network increases, that resulting in the three-dimensional alumino-silicate network commonly attributed to alkali activated binders[17].

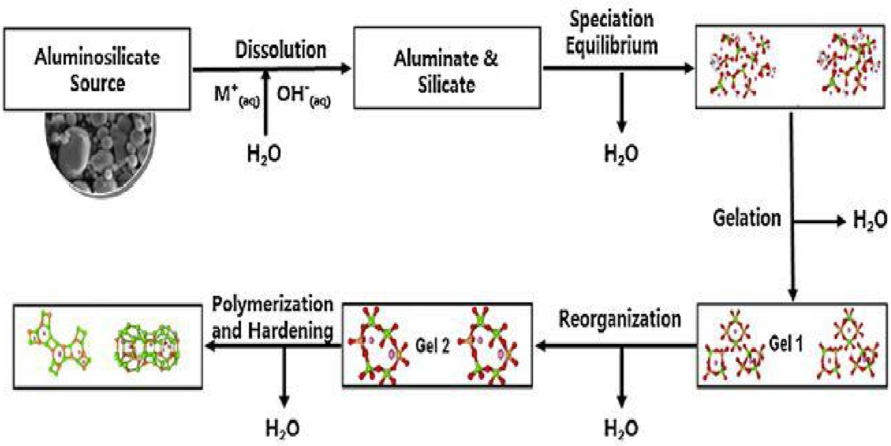
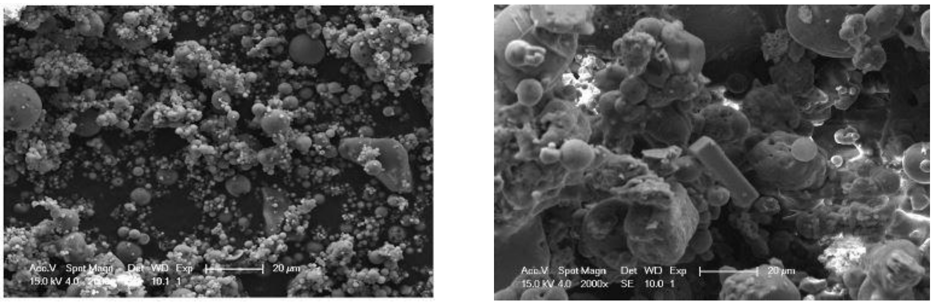


Figure 3.4: Polymeric structures from polymerisation of monomers[17]

3.3.4 Microstructure Analysis of Fly Ash and Bottom ash Based Alkali Activated Concrete

Xie and Ozbakkaloglu[15] investigate the microstructure analysis of fly ash and bottom ash. The scanning electron micrographs (SEM) of fly ash and bottom ash were evaluated as shown in Fig 3.5a and Fig 3.5b. It can be seen that the particles of the fly ash appear to be spherical and with varying sizes. In addition, the micrograph of the fly ash also shows that there are no evidently visible pores in the microstructure of the fly ash particles. The micrograph of the bottom ash illustrates that the particles of the bottom ash were significantly larger and angular, with plenty of irregular fragments and only a small amount of semi-spheres. These observations clearly indicate that the bottom ash contains more impurities compared to the fly ash, and this can be explained by the fact that the bottom ash is extracted from the base of the furnace, where larger and foreign objects can fall.



(a) Fly ash (b) Bottom ash

Figure 3.5: SEM images (2000eX magnificantion)[15]

They also investigate the microstructure analysis of alkali activated concrete with different fly ash and bottom ash contents. Fig 3.6 present the SEM micrograph of alkali activated concrete with 50:50 proportion of fly ash and bottom ash. SEM micrographs show that the density and homogeneity of the concrete increase with an increase in the mass ratio of fly ash-to-bottom ash. This indicates that fly ash undergoes a higher degree of polymerization compared to that seen in bottom ash. SEM micrographs also show that a large amount of coal ash remains in the hardened concrete structures, which suggests that at the ambient temperature coal ash based alkali activated concrete undergo a lower degree of polymerization.

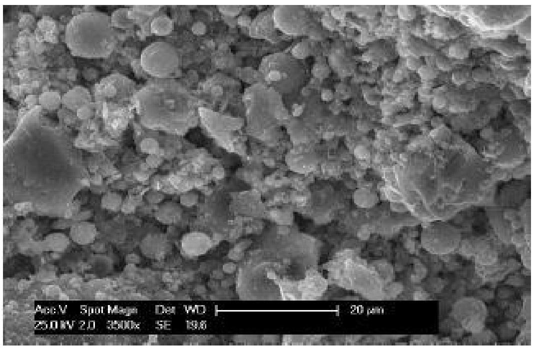


Figure 3.6: SEM micrograph of alkali activated concrete (200X magnificantion)

3.4 Effect of Salient Parameters on Compressive Strength

3.4.1 Curing Time

Ahmed & Nuruddin[8], explained that longer curing time improves the polymerisation process resulting in higher compressive strength. It was observed that the compressive strength was highest when the specimens were cured for a period of 96 hours. However, the increase in strength after 48 hours was not significant as shown in Figure 3.7.

The rate of increase in strength was rapid up to 24 hours of curing time as shown in

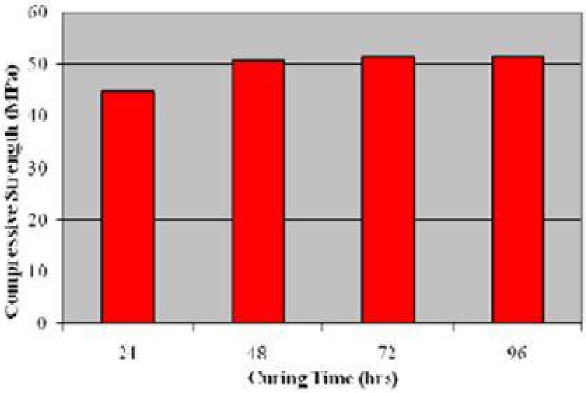


Figure 3.7: Effect of curing time on compressive strength

Figure 3.8. **Hardjito & Rangan**[9] also noted that, longer curing time improves the polymerisation process and that gives higher compressive strength.

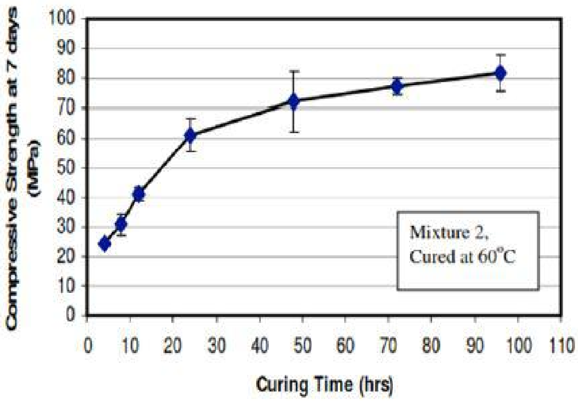


Figure 3.8: Effect of curing time on compressive strength

3.4.2 Addition of Super Plasticizer

Hardjito & Rangan[9] explained that, the addition of naphthalene-based super plasticizer improved the workability of fresh concrete, but did not affect the compressive strength of the hardened concrete, except when the content of super plasticizer was 4% a slight reduction in compressive strength was observed as shown in Figure 3.9.

Based on these test results, it is recommended that naphthalene sulphonate based super plasticizer may be used to improve the workability of fresh low-calcium fly ash based alkali activated concrete. However, the content of the super plasticizer need not be more than 2% of the mass of fly ash. Beyond this amount, the addition of super plasticizer can cause a slight reduction in the compressive strength of hardened concrete; moreover, amounts greater than 2% may be uneconomical in practice.

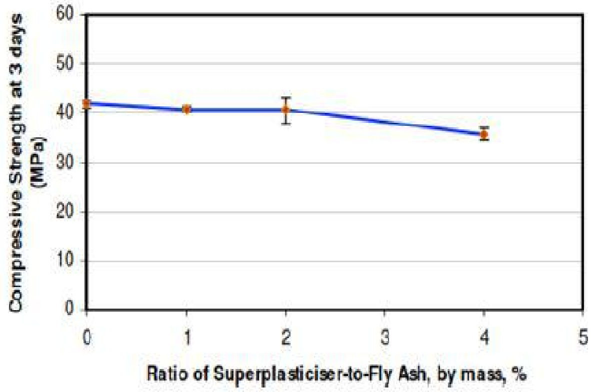


Figure 3.9: Effect of Superplasticizer content on compressive strength

3.4.3 Extra Water Content

Ahmed & Nuruddin[8] explained that the addition of water improved the workability characteristics of freshly prepared concrete mixtures; However, the addition of water beyond certain limit resulted in bleeding and segregation of fresh concrete and decreased the compressive strength of the concrete significantly. The compressive strength of alkali activated concrete significantly decreased as the amount of extra water increased shown in Figure 3.10.

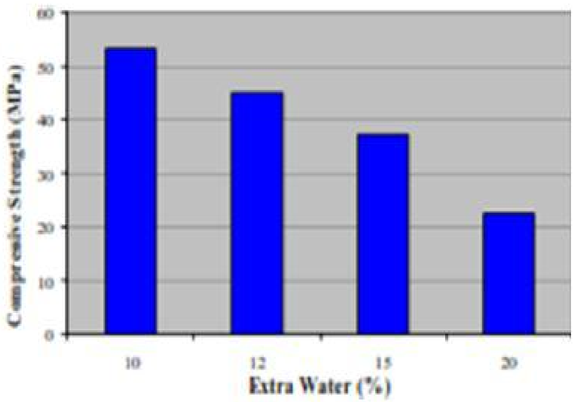


Figure 3.10: Effect of Extra Water on Compressive Strength

3.4.4 Rest Period Prior to Curing

Hardjito & Rangan[9] explained that, the term Rest Period was coined to indicate the time taken from the completion of casting of test specimens to the start of curing at an elevated temperature. This may be important in certain practical applications. For instance, when fly ash-based alkali activated concrete is used in precast concrete industry, there must be sufficient time available between casting of products and sending them to the curing chamber. The strength gain was a maximum when the rest period was three days; beyond that very little further strength gain was attained as shown in Figure 3.11.

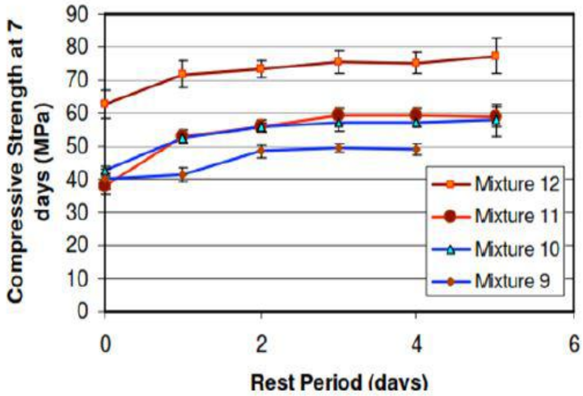


Figure 3.11: Effect of Rest period on compressive strength

3.4.5 Finding from Literature Review of Alkali Activated Concrete

It has been observed that fly ash undergoes a higher degree of polymerization as compared to that of bottom ash. It has been found out through various literatures that longer curing time alkali activated concrete improves the polymerisation process and gives higher compressive strength of concrete. Also, it is observed that naphthalene sulphonate based superplasticiser can improve the workability of fresh low-calcium fly ash based alkali activated concrete. It has been found that compressive strength of alkali activated concrete significantly decreased as the amount of extra water increased. It has been observed that the strength gain was maximum when the rest period was three days; beyond that very little further strength gain was observed.

Chapter 4

Experimental Programme

4.1 General

This chapter describes the experimental work. Materials, mixture design, method of casting, and curing of the specimens adopted during the investigation are discussed in the chapter. Materials and mix design includes physical and chemical properties of the materials and mix proportion of the concrete mix. This is followed by description of types of specimens used, test parameters and test procedures adopted during the investigation.

4.2 Material

The materials used during the present investigation are fly ash and bottom ash as the source material, aggregates, alkaline liquids, water, and superplasticizer.

4.2.1 Fly Ash

Fly ash used in this study is low calcium class F fly ash from Suyog suppliers limited, Ahmedabad. Fig 4.1 shows the pictorial view of fly ash.

Figure 4.1: Fly ash

Physical properties and chemical compositions of the fly ash used along with the specifications are given in Table 4.1.

Wet Sieve Analysis

Wet sieving test is conducted for evaluating the percentage of material passing 45-micron sieve. In this test, 100 gm of fly ash is taken in 45-micron sieve. The material is washed with a jet of water and keep it well agitated. The washing is continued till it appear no more turbid. After washing of sieve, the sieve is allow to dry in an oven with residue. The residue from the sieve after drying, is weighed on a balance sensitive to 0.1 percent of the weight of the test sample. The percentage of material passing sieve on wet sieving is reported to the nearest 0.1 percent by weight of the test sample. Allowable percentage retained on 45-micron sieve is 34 percent as per IS: 3812 (Part-1)[21]. Results of wet sieve analysis is mentioned in Table 4.1.

Pozzolanic Activity Index

The main purpose of this test is to check the effect of fly ash as pozzolon when 20% of cement is replaced with fly ash. When cement mortar with fly ash is compared with control mortar, minimum achievable strength of cement mortar with fly ash on 28-day is required to be 80%. It means addition of fly ash is not interfering with the hydration chemistry of OPC. Pozzolanic activity index is a ratio of strength of fly ash blended mortar and strength of control mortar. In control mortar, materials i.e. cement and ennore sand are taken as 225 gms and 675 gms, respectively and are mixed thoroughly well. Water is added to this mix till thixotropic point. 50 mm cubes are cast with this mix in two layers thoroughly pressing with the thumb. Mould is tamped for minimum 5 times for better consolidation of the matrix. In this fly ash blended mortar, 20% OPC is replaced with fly ash. Three cubes are made of both type of mortar. Cubes are tested at the age of 28 days to evaluate compressive strength of both types of mortar. Pozzolonic activity index is determined by following equation.

$$\text{Pozzolanic Activity Index (PAI)} : \frac{\text{Strength of FA blended mortar}}{\text{Strength of control mortar}} \times 100 \tag{4.1}$$

Results of PAI is derived below:

Pozzolanic Activity Index (PAI) $= \frac{49.09}{55.64} \times 100 = 88.23\%$

4.2.2 Bottom Ash

Bottom ash used in this study is pulverized fuel ash collected from the bottom of boilers from Suyog suppliers limited, Ahmedabad. Fig 4.2 shows the pictorial view of bottom ash.

Figure 4.2: Bottom ash

Physical properties and chemical compositions of the bottom ash used along with the specifications are given in Table 4.1.

Table 4.1: Properties of fly ash and bottom ash

Sr. No.	Chemical Properties	Unit	Test Results of Fly ash	Test Results of Bottom ash	Specification as per IS : 3812 (Part-1)[21] - 2013
1	Colour	-	Light Grey	Grey	-
2	Specic surface Area	m^2/kg	332.94	416.36	Min 320
3	Pozzolanic Activity Index	%	88.23	85.08	Min 80% by mass
4	Retaining on 45 micron sieve (wet sieving)	%	17.63	22	Max 34%
5	Loss of Ignition	N/mm^2	1.05	1.17	Max 5%
6	SiO_2	%	61.4	66.15	Min 35% by mass
7	AL_2O_3	%	-	30.76	-
8	Fe_2O_3	%	-	0.5	-
9	$SiO_2 + AL_2O_3 + Fe_2O_3$	%	93.02	97.41	Min 70% by mass
10	CaO	%	-	0.9	-
11	Reactive Silica	%	34.36	-	Min 20% by mass
12	MgO	%	1.42	0.44	Max 5% by mass
13	SO_3	%	0.56	0.03	Max 3% by mass
14	Alkalies	%	0.62	-	Max 1.5% by mass
15	Chloride	%	0.03	-	Max 0.05% by mass

4.2.3 Alkaline Liquid

The alkaline liquid used was a combination of sodium hydroxide and sodium silicate solution.

Sodium Hydroxide (NaOH)

Sodium hydroxide is commonly available in flakes or pellets form. Sodium hydroxide in flakes form with 98% purity is purchased from local chemical supplier has been used. Fig 4.3 shows the sodium hydroxide in flakes form. The sodium hydroxide solution is prepared by dissolving the flakes in water. Tap water available in laboratory is used to prepare NaOH solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. Properties of the sodium hydroxide are given in the Table 4.2.

Figure 4.3: Sodium Hydroxide in Flakes

Table 4.2: Properties of the Sodium Hydroxide

Properties	Value
Sodium hydroxide(purity)	98.0
Chloride (%)	1.0
Silicate (%)	0.01
Na_2Co_3	0.01
Nitrate(No_3)	0.005

Sodium Silicate (Na_2Sio_3)

Many types of sodium silicate solution depends on application are available in market. The sodium silicate solution obtained from local supplier has been used as shown in Fig 4.4. Properties of the sodium silicate solution are given in Table 4.3.

Figure 4.4: Sodium Silicate

Table 4.3: Properties of the Sodium Silicate

Properties	Value
Colour	Colourless
Bulk density	1.656 gm/cm
Na_2O	16.73%
SiO_2	36.63%
Total solid content	53.36%
Matter insoluble in water	0.10%

4.2.4 Aggregate

Locally available 10 mm down size crushed aggregates have been used as coarse aggregates. Locally available river sand is used as fine aggregate in the mixes. Tests for coarse and fine aggregates were conducted as per IS: 2386-1963[23] and IS: 383-1970[24]. Physical properties and sieve analysis results of 10 mm aggregates and fine aggregate are presented in Table 4.4, 4.5 and 4.6, respectively.

Table 4.4: Physical Properties of Aggregates

Material	Loose Bulk Density (kg/cu.mt.)	Compact Density (kg/cu.mt.)	Specific Gravity
Sand	1532	1671	2.57
Aggregate (10 mm)	1348	1509	2.73

Table 4.5: Gradation of Coarse Aggregate (10 mm)

Sieve Size	Mass Retained (gms)	% of Mass Retained	Cumulative % of Mass Retained	Cumulative % of Passing
80 mm	0	0	0	100
40 mm	0	0	0	100
20 mm	0	0	0	100
10 mm	63	6.3	6.3	93.7
4.75 mm	902	90.2	96.5	3.5
2.36 mm	35	3.5	100	0
1.18 mm	0	0	100	0
600	0	0	100	0
300	0	0	100	0
150	0	0	100	0
Total	1000	100	602.8	
Fineness modulus = 602.8/100 =6.028				

Table 4.6: Gradation of Fine Aggregate

Sieve Size	Mass Retained (Grams)	% of Mass Retained	Cumulative % of Mass Retained	Cumulative % of Passing
80 mm	0.00	0.00	0.00	100.00
40 mm	0.00	0.00	0.00	100.00
20 mm	0.00	0.00	0.00	100.00
10 mm	3.50	0.35	0.35	99.65
4.75 mm	14.30	1.43	1.78	98.23
2.36 mm	31.30	3.13	4.90	95.10
1.18 mm	313.50	31.35	36.25	63.75
600 micron	207.00	20.70	56.95	43.05
300 micron	272.20	27.22	84.16	15.84
150 micron	110.5	11.05	95.22	4.78
Lower than 150	0.00	2.17	-	2.62
Total	1000	100	279.61	
Fineness Modulus = 279.61/100 = 2.79				

With reference to table 4.6 and IS 383-1970[24] Table-4 sand is under Zone-II category.

4.2.5 Superplasticizer

To improve the workability of the fresh alkali activated concrete, Polycarboxylic ether based superplasticiser, supplied by Samrock Chemicals, has been used for selected alkali activated concrete mixes. Initially superplasticizer used is 1% of source material as per literature review. Properties of superplasticizer are shown below in Table 4.7.

Table 4.7: Properties of Superplasticizer

Sr. No.	Parameter	Observation
1	Appearance Colour	Pale yellow
2	Specific Gravity	1.02 at 25° C
3	Chemical name of the active ingredient	Polycarboxylic Ether (12.03%)
4	Air Entrainment	2% additional air
5	Chloride Content	Nil

4.3 Casting of Alkali Activated Specimens

4.3.1 Preparation of Alkaline Solution

The sodium hydroxide (NaOH) solids have been dissolved in water to make the alkaline solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, NaOH solution with a concentration of 14M consisted of 14x40 = 560 grams of NaOH solids (in flake form) per liter of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids is measured as 400 grams per kg of NaOH solution of 14M concentration[16]. Note that the mass of NaOH solids is only a fraction of the mass of the NaOH solution, and water has been the major component.

4.3.2 Manufacturing of Alkali Activated Specimens

For primary investigation alkali activated mixes is manufactured using steel moulds of size 70.6 mm $\times$ 70.6 mm $\times$ 70.6 mm. The moulds and base plates to be used are cleaned, fitted and internal faces of moulds are coated with thin layer of oil as shown in Figure 4.5.

Figure 4.5: Preparation of steel moulds

Alkali activated paver blocks is manufactured using rubber moulds of 60mm thickness. The shape of the moulds are zigzag as shown in Figure 4.6.

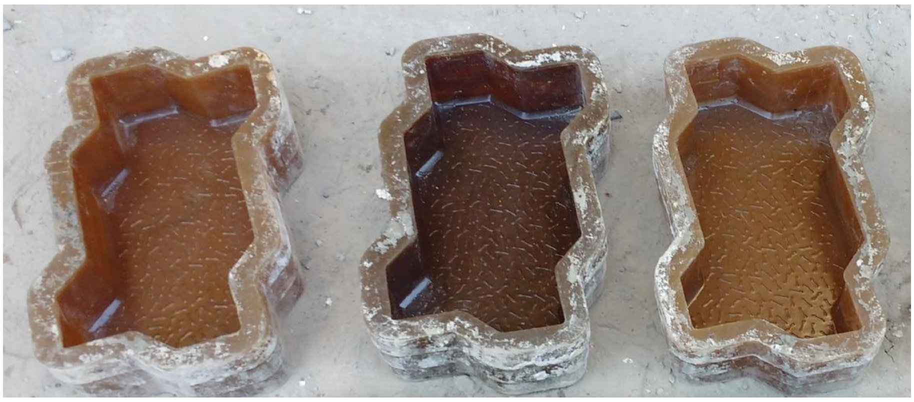


Figure 4.6: Preparation of rubber moulds

The mixing procedure for alkali activated paver blocks is similar to that of conventional OPC paver blocks. Mixing of all the materials have been done in the laboratory at room temperature. The fly ash, bottom ash and the aggregate has been mixed together in pan mixture as shown in Fig 4.7 and Fig 4.8. The mixing is allowed to continue for about 3 to 4 minutes. The alkaline solution which is prepared one day before is added with additional water in the mix. Then liquid component and superplasticiser has been added to the dry material and mixing is continued for another 3 to 4 minutes.

Figure 4.7: Pan mixture for casting of paver blocks

Figure 4.8: View of alkali activated binders

The fresh alkali activated binders is cast into the moulds immediately after mixing in three layers. For compaction of the specimens, each layer is given 25 to 35 manual strokes using 20 mm rod. Specimens are vibrated using vibration table for another 10 to 15 seconds as shown in Figure 4.9.

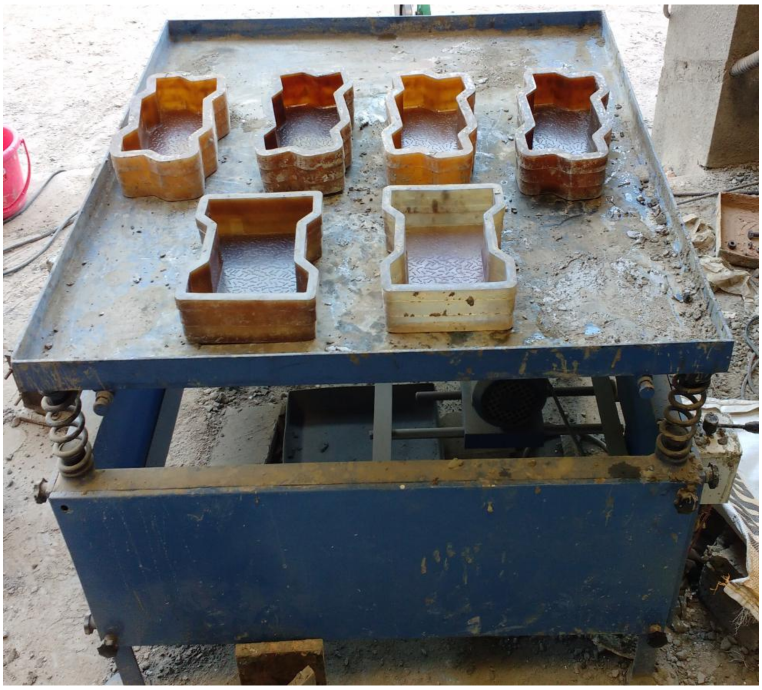


Figure 4.9: Table vibrator for compaction of specimen

After compaction of the specimen, the top surface is leveled by using trowel and also the sides of mould are struck by using hammer in order to expel air if any present inside the concrete and to make the sides smoothened. After the casting, the specimens have been kept at room temperature as per the designated rest period. Setting of fresh alkali activated cubes and paver blocks is as shown in Fig 4.10 and Fig 4.11.

Figure 4.10: Setting of fresh alkali activated cubes

Figure 4.11: Setting of fresh alkali activated paver blocks

4.4 Curing of Alkali Activated Specimens

Generally two types of curing i.e ambient curing and oven curing have been used for preparing the alkali activated binders by various researchers. Ambient curing has been used for all the specimen in the present study. In ambient curing, the specimens are left in open atmosphere till curing time. Ambient curing of paver blocks and cubes are shown in Fig 4.12 and Fig 4.13, respectively.

Figure 4.12: Ambient curing of alkali activated paver block

Figure 4.13: Ambient curing of alkali activated cubes

4.5 Properties of Paver Blocks

4.5.1 Compressive Strength

The compression testing machine of 2000 kN is used to evaluate compressive strength of both type of concrete mixes. For the compressive strength test, paver blocks of 60 mm thickness are tested in compression as per IS 15658:2006[20]. Equation of finding out compressive strength of the paver block specimens is given below. Figure 4.14 shows test set up for finding compressive strength of paver blocks.

$$\text{Compressive Strength (N/mm}^2) = (\text{P} \times 10^3) \div \text{A} \tag{4.2}$$

Where,
P = Failure load of paver blocks (kN)
A = Surface area of paver block (mm^2)

Figure 4.14: Paver block in Compression Testing Machine

4.5.2 Abrasion Resistance

The abrasion test has been performed as per IS 15658:2006[20] on abrasion testing machine as shown in Figure 4.15. It decides the suitability of rock as road material. The abrasion machine consists of a flat circular cast-iron or steel disc of not less than 60 cm diameter which revolves in horizontal plane about a vertical shaft. The arrangement for holding two test specimens in diametrically opposite direction is made and the specimens are so placed in vertical direction that their lower ends are pressed with a prescribed pressure against the surface of disc. A convenient funnel is also attached for continuously feeding a standard sand upon the disc. The test procedure is described below.

1. Square-shaped specimens measuring 71.0 ± 0.5 mm shall be cut from the paver block specimens.

2. The den-sity of the specimen, PR shall be determined nearest to 0.1 g. The weight of the specimen shall be noted to nearest 0.1 g both prior to the abrasion test and after every four cycles.

3. The grinding path of the disc of the abrasion testing machine shall be evenly strewn with 20 g of the standard abrasive powder as per IS 1237.

4. The grinding disc shall be run at a speed of 30 rpm. The disc shall be stopped after one cycle of 22 revolutions.

5. The specimen shall be turned 90 in the clockwise direction and 20 g of abrasive powder shall be evenly strewn on the testing track before starting the next cycle.

6. The test cycle shall be repeated 16 times.

7. The abrasive wear of the specimen after 16 cycles of testing shall be calculated as the mean loss in specimen volume(V) from the equation:

$$\Delta V = \frac{\Delta m}{PR} \tag{4.3}$$

Where,
Δ V = Loss in volume after 16 cycles in mm^3
Δ m = Loss in mass after 16 cycles in gm and
PR = Density of the specimen in gm/mm^3.

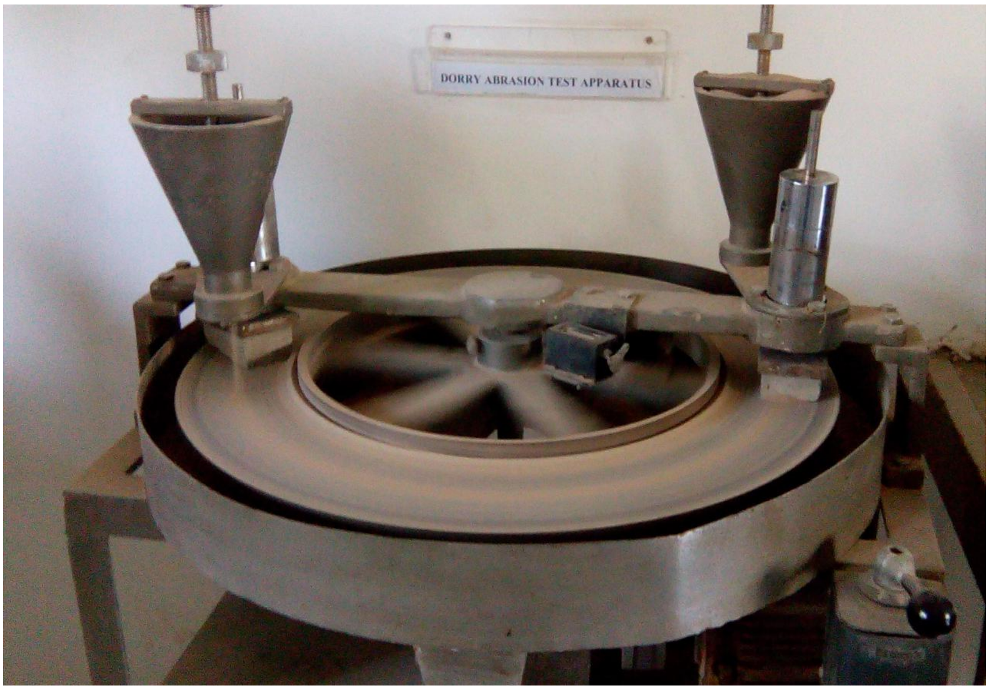


Figure 4.15: Dorry Abrasion Machine

4.5.3 Water Absorption

Water absorption characteristic of paver blocks plays an important role for the durability. The test has been performed to evaluate the water absorption characteristics of alkali activated paver blocks as per IS 15658:2006[20]. Water absorption shall not be more than 6% by mass in individual samples and it should be restricted to 7% according to IS 15658:2006[20].

Test specimens used for change in mass test were zigzag type alkali activated unipaver blocks. 3 specimens for each test were prepared for the change in mass to take average result of the specimen.

The test specimen shall be completely immersed in water at room temperature for 24 hours. Then the specimen shall be immediately weighed and the weight for each specimen noted in N (W_w). After that specimens shall be dried in a ventilated oven at 107 ± 7°C for not less than 24 hours. The dry weight of each specimen (W_d) shall be recorded in N.

The percent water absorption shall be calculated as follows:

$$Wpercent = \frac{W_w - W_d}{W_d} \times 100 \tag{4.4}$$

Where,
W = Percent water absorption
W_w = Weight of specimen after curing
W_d = Weight of specimen after over dry

Chapter 5

Development of Mix Design

5.1 General

The results of investigation on consistency and setting time of alkali activated mortar are presented in this chapter. To develop the mix design of paver blocks, the effect of variation in source material and other salient parameters on compressive strength of alkali activated concrete are also presented and discussed by means of tables and plots in this chapter. Mix design process developed for alkali activated paver blocks is also presented in this chapter.

5.2 Parameters varied for Development of Mix Design of Paver Blocks

Salient parameters affecting the performance of fly ash and bottom ash based alkali activated paver blocks are as follows:

1. Proportion of fly ash and bottom ash
2. Amount of source material
3. Ratio of alkaline liquid to source material
4. Ratio of sodium silicate solution to sodium hydroxide solution, by mass
5. Concentration of sodium hydroxide solution, in Molar.
6. Addition of superplasticiser
7. Water content of mix
8. Curing temperature
9. Rest period prior to curing

Total fifteen alkali activated concrete mixes have been cast to study the effect of above parameters on compressive strength of mixes.

5.3 Consistency and Setting Time of Alkali Activated Mortar

The setting time of the alkali activated fly ash and bottom ash based mortar was measured using a Vicat needle according to IS: 40311988(Part-4)[26] and IS: 40311988(Part-5)[27]. Five proportion of fly ash and bottom ash 100:0, 75:25, 50:50, 25:75, 0:100, respectively were evaluated. Setting time tests were conducted under two type of concentration of NaOH, 8M & 12M at ambient temperature. Proportion of materials for normal consistency for different combinations of fly ash and bottom ash with different molarity are given in Table 5.1.

Table 5.1: Proportion for consistency of alkali activated mortar

Mix Constituents		Proportion				
Fly ash:Bottom ash		100:0	75:25	50:50	25:75	0:100
NaOH (% of source material)	8M	13.9	14.5	17.5	20.8	26.6
	12M	9.5	10.4	11.25	12.1	15.8
Na_2SiO_3 (% of source material)	8M	27.8	29	35	41.6	53.3
	12M	19.2	20.8	22.5	24.2	31.7

Table 5.1 shows amount of NaOH and Na_2SiO_3 used for consistency of alkali activated mortar with different proportion of fly ash and bottom ash. 8M and 12M NaOH solution was used in alkaline solution. It was observed requirement of alkaline solution is increased when amount of bottom increases and concentration of NaOH solution decreases.

Figure 5.1 shows the consistency of alkali activated mortar for different combinations of fly ash and bottom ash content with 8M & 12M NaOH solution.

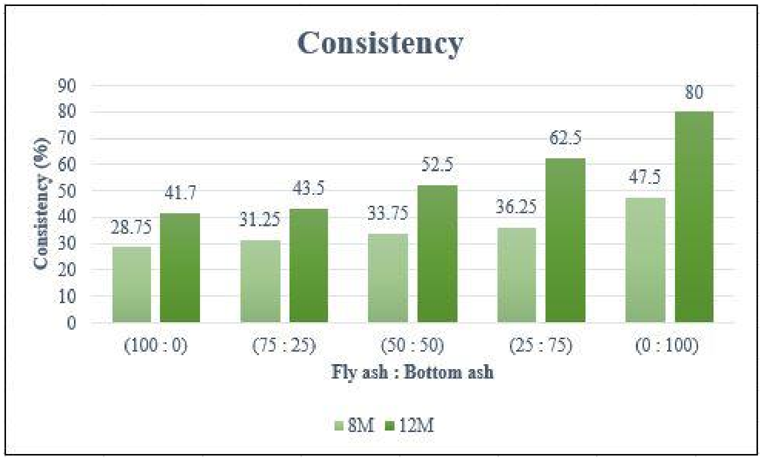


Figure 5.1: Consistency of alkali activated mortar

It has been observed from the Fig 5.1 that consistency of alkali activated mortar increases with increase in the concentration of sodium hydroxide solution.

Fig 5.2 and Fig 5.3 shows the initial and final setting time for different proportion of fly ash and bottom ash with 8M and 12M NaOH solution, respectively. The initial setting time and final setting time of different mixes considered in this investigation varied from 3 to 48 min & 10 to 210 min, respectively.

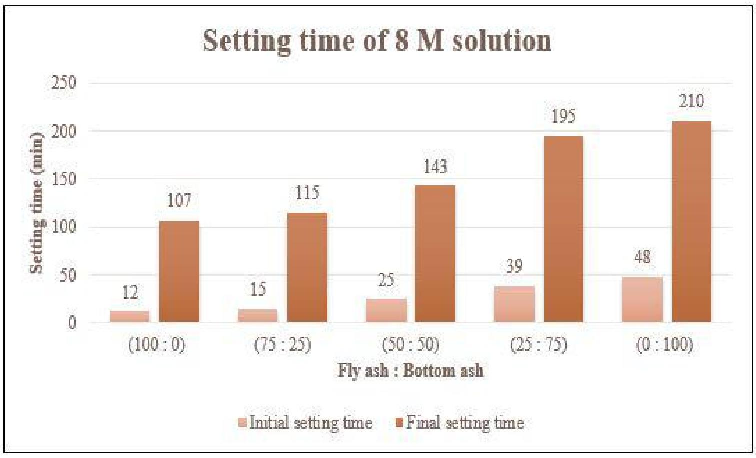


Figure 5.2: Setting time with 8M solution

It has been found that increase in the concentration of NaOH solution resulted in reduction in initial and final setting time for all the mixes. It was also observed that initial and final setting time of alkali activated mortar increases as the amount of bottom ash is increased in all the mixes.

It has been observed from the investigation that alkali activated mortar with higher amount of fly ash require less alkaline solution. The reason for this behavior can be attributed to the fact that fly ash particles are spherical and exhibit less internal friction,

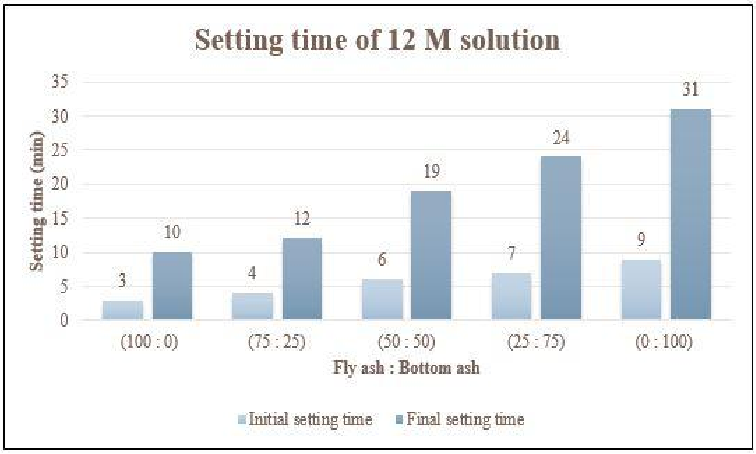


Figure 5.3: Setting time with 12M solution

allowing free movement of Vicats plunger for lower alkaline activator content. On the other hand, bottom ash particles are straight, flaky-elongated shape with sharp-edged angularity, possessing high internal friction compared to fly ash particles and hence need more alkaline solution[15]. The setting aspects of fly ash with the alkaline solution are faster than bottom ash. Mortar with higher amount fly ash has fast setting behavior that is not convenient for alkali activated concrete in conventional construction. Thus, 50:50 and 70:30 are the recommended dosage for further investigation.

5.4 Variation in Source Materials

For achieve the target strength of 25MPa to 30MPa, proportion of fly ash and bottom ash and amount of source material is decided from the few trial mixes.
Proportion of fly ash and bottom ash is decided from the following trial mixes:

1. (70:30) proportion of fly ash and bottom ash (T-1)

2. (50:50) proportion of fly ash and bottom ash (T-2)

3. (30:70) proportion of fly ash and bottom ash (T-3)

For deciding above proportion initially following salient parameters are considered as per the literature review:

1. Ratio of alkaline liquid to source material - 0.4

2. Ratio of sodium silicate solution to sodium hydroxide solution - 2

3. Concentration of sodium hydroxide solution- 12 M

4. Addition of superplasticiser- 1%

5. Water content of mix - 10%
6. Curing temperature - Ambient
7. Rest period prior to curing - 1 day

Among above three mixes, Mix T-2 fulfil the required strength and utilize more amount of bottom ash as shown in Figure 5.4. Therefore, (50:50) proportion of fly ash and bottom ash has been selected for further investigation. The details of mixes used for deciding fly ash and bottom ash proportion are shown in Table 5.2.

For deciding amount of source material following trial mixes are investigated.

1. Source material = 429 kg/m^3 (T-2)
2. Source material = 411 kg/m^3 (T-4)
3. Source material = 393 kg/m^3 (T-5)

The details of all the trial mixes are shown in Table 5.2.

Table 5.2: Details of mix proportion of trial mixes

Alakli activated concrete mix	Fly ash (kg)	Bottom ash (kg)	Aggegates		Sodium Hydroxide (kg)	Sodium Silicate (kg)	Extra water (kg)	Super-plasticiser (kg)
			10 mm down (kg)	Fine Sand (kg)				
T-1	300	129	1170	630	57.14	114.28	43	4.3
T-2	215	215	1170	630	57.14	114.28	43	4.3
T-3	129	300	1170	630	57.14	114.28	43	4.3
T-4	206	206	1121	604	54.76	109.52	41	4.1
T-5	197	197	1073	576	52.38	104.76	40	4.0

Figure 5.4 shows the compressive strength of all trial mixes.

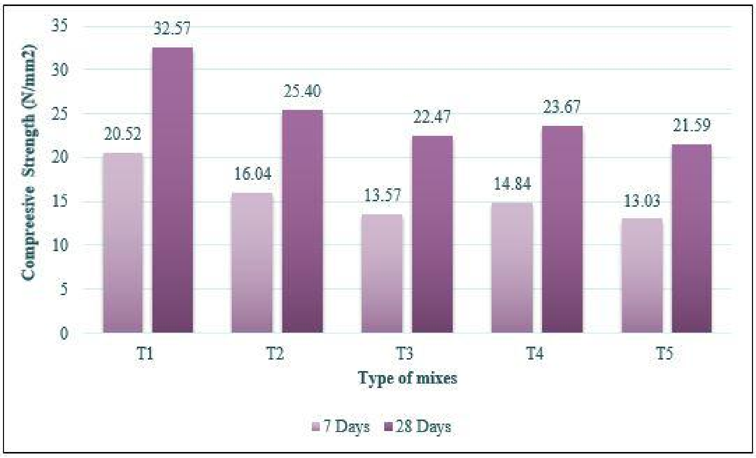


Figure 5.4: Compressive Strength of trial mixes

From the mixes T-2, T-4 and T-5, mix T-2 gives the highest compressive strength as shown in Figure 5.4. Therefore, 429 kg/m^3 amount of source material with (50:50) proportion of fly ash and bottom ash has been selected for further investigation of alkali activated paver blocks.

5.5 Variation in other Salient Parameters

For development of mix design of paver blocks, effect of various salient parameter on compressive strength of alkali activated concrete mixes has been investigated. The details mixes with different parameters are presented in Table 5.3 and Table 5.4, respectively.

Table 5.3: Details and proportion of different mixes

Alakli activated concrete mix	Fly ash (kg)	Bottom ash (kg)	Aggegates		Sodium Hydroxide (kg)	Sodium Silicate (kg)	Extra water (kg)	Super-plasticiser (kg)
			10 mm down (kg)	Fine Sand (kg)				
T-6	215	215	1170	630	57.14	114.28	43	4.3
T-7	223	223	1170	630	51.85	103.70	43	4..5
T-8	215	215	1170	630	48.98	122.44	43	4.3
T-9	215	215	1170	630	48.98	122.44	43	4.3
T-10	215	215	1170	630	48.98	122.44	43	4.3
T-11	215	215	1170	630	48.98	122.44	43	4.3
T-12	215	215	1170	630	48.98	122.44	43	4.3
T-13	215	215	1170	630	48.98	122.44	43	0.00
T-14	215	215	1170	630	48.98	122.44	43	0.00
T-15	215	215	1170	630	48.98	122.44	65	0.00

Table 5.4: Varying parameters of different mixes

Alkali activated concrete mix	NaOH Molarity	Curing	Rest Period (days)	Alkaline liquid ratio	Super-plasticiser (%)	Extra water content (%)	Alkaline solution to source material ratio	Varying Parameters
T-6	12	Ambient	1	2	1.0	10	0.4	Alkaline solution/source material = 0.4
T-7	12	Ambient	1	2	1.0	10	0.35	Alkaline solution/source material = 0.35
T-8	12	Ambient	1	2.5	1.0	10	0.4	Alkaline ratio = 2.5
T-9	8	Ambient	1	2.5	1.0	10	0.4	Molarity = 8 M
T-10	10	Ambient	1	2.5	1.0	10	0.4	Molarity = 10 M
T-11	14	Ambient	1	2.5	1.0	10	0.4	Molarity = 14 M
T-12	16	Ambient	1	2.5	1.0	10	0.4	Molarity = 16 M
T-13	14	Ambient	1	2.5	0.0	10	0.4	Superplasticiser = 0.0%
T-14	14	Ambient	2	2.5	0.0	15	0.4	Rest period = 2 day
T-15	14	Ambient	1	2.5	0.0	15	0.4	Water content = 15%

Effect of various salient parameters on compressive strength of alkali activated concrete is discussed by means of plots in the following section.

5.5.1 Ratio of Alkaline Solution to Source Material

Mix T-6 and T-7 as given in Table 5.3 and Table 5.4 with the alkaline liquid to source material ratio 0.35 and 0.4 have been cast for this study. The effect of ratio of alkaline liquid to source material on compressive strength of concrete mix at the age of 7 and 28 days has been observed by comparing results of both mixes. The results are shown in Figure 5.5.

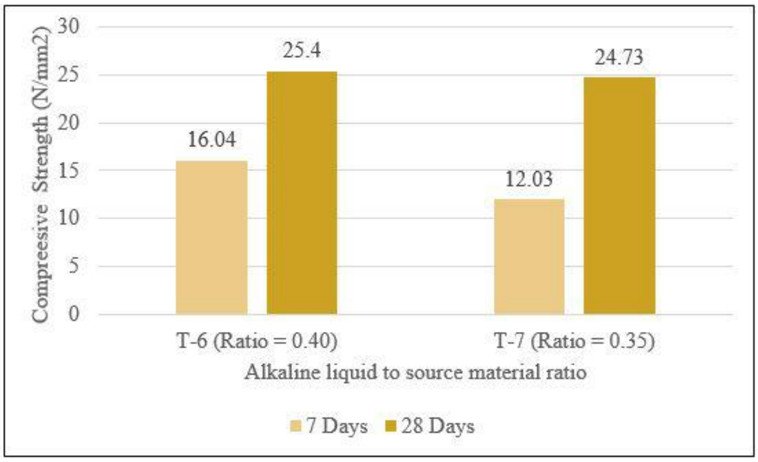


Figure 5.5: Effect of Alkaline Liquid to Source Material Ratio on Compressive Strength

Percentage increment in compressive strength for mix T-6 at 28 days is 36.85% as compared to compressive strength achieved at 7 days. Percentage increment in compressive strength for mix T-7 at 28 days is 51.35% as compared to compressive strength achieved at 7 days. By comparing the results of compressive strength of T-6 and T-7, T-6 gives 25% and 2.63% higher compressive strength as compared to T-7 at 7 days and 28 days, respectively. Results show that higher compressive strength achieved with ratio 0.4 as compared to ratio 0.35. Therefore mix T-6 with ratio 0.4 has been selected for further investigation.

5.5.2 Ratio of Sodium Silicate Solution to Sodium Hydroxide Solution

The effect of ratio of sodium silicate solution to sodium hydroxide solution by mass on compressive strength of concrete has been observed by comparing results of mixes T-6 and T-8 as given in Table 5.3 and Table 5.4. The results of compressive strength are shown in Figure 5.5.

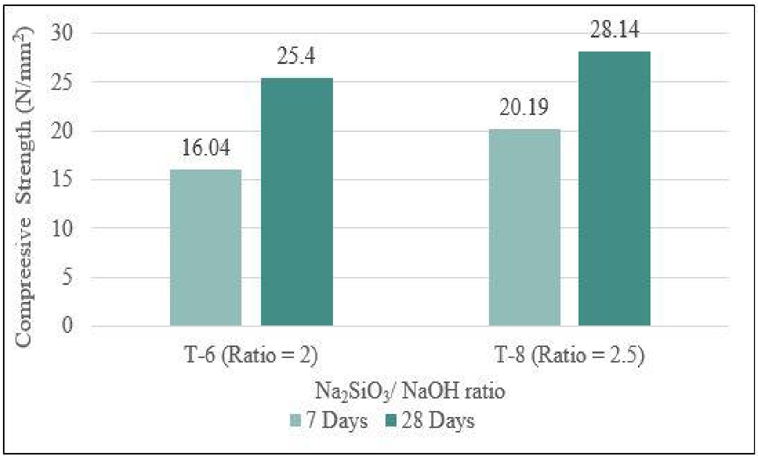


Figure 5.6: Effect of Na_2SiO_3 Solution to NaOH Solution Ratio on Compressive Strength

Percentage increment in compressive strength for mix T-6 at 28 days is 36.85% as compared to compressive strength achieved at 7 days. Percentage increment in compressive strength for mix T-8 at 28 days is 28.25% as compared to compressive strength achieved at 7 days. By comparing the results of compressive strength of T-6 and T-8, T-8 gives 20.55% and 9.73% higher compressive strength as compared to T-6 at 7 days and 28 days, respectively. Results show that higher compressive strength achieved with ratio 2.5 as compared to ratio 2. Therefore mix T-8 with ratio 2.5 has been selected for further investigation.

5.5.3 Concentration of Sodium Hydroxide Solution

The effect of concentration of sodium hydroxide solution on compressive strength of concrete at the age of 7 and 28 days has been observed by comparing results of mixes T-8 to T-12 as given in Table 5.3 and Table 5.4. The compressive strength results measured at 7 and 28 days are given in Figure 5.7.

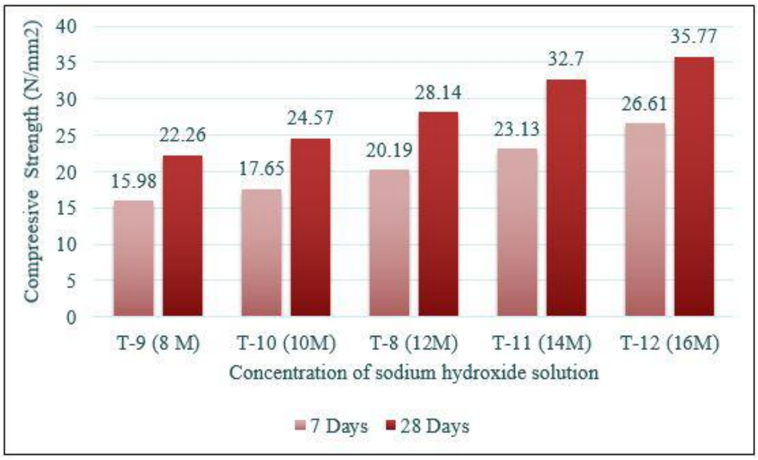


Figure 5.7: Effect of Concentration of NaOH Solution on Compressive Strength

Mix T-12 with 16M concentration of sodium hydroxide solution resulted into 66.52% and 60.69% higher compressive strength as compared to mix T-9 with 8M solution at the age of 7 and 28 days, respectively. It has been observed for all mixes that, higher concentration of sodium hydroxide solution gives better results in terms of compressive strength of alkali activated concrete. As the mix T-11 with 14M solution satisfied the require the compressive strength of 25MPa to 30MPa, mix T-11 is selected for further investigation.

5.5.4 Addition of Superplasticiser

The effect of addition of superplasticizer on compressive strength of concrete has been observed by comparing results of of mixes T-11 with T-13 as given in Table 5.3 and Table 5.4. The compressive strength results measured at 7 and 28 days are given in Figure 5.8.

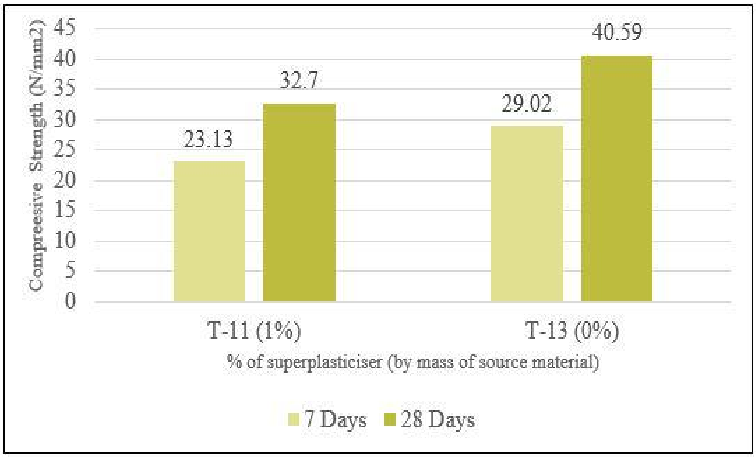


Figure 5.8: Effect of Addition of Superplasticiser on Compressive Strength

Percentage increment in compressive strength for mix T-11 at 28 days is 29.26% as compared to compressive strength achieved at 7 days. Percentage increment in compressive strength for mix T-13 at 28 days is 28.50% as compared to compressive strength achieved at 7 days. By comparing the results of compressive strength of T-11 and T-13, T-13 gives 20.29% and 19.43% higher compressive strength as compared to T-11 at 7 days and 28 days, respectively. Results shows that addition of superplasticizer only helps to achieve good workability but it shows significant amount of reduction in compressive strength. Hence mix T-13 with 0% superplasticizer has been selected for further investigation.

5.5.5 Rest Period Prior to Curing

The term 'Rest Period' is defined by the time taken from the completion of casting of paver block specimens to the start of curing at an elevated temperature. This is very important in contex to many practical applications. For instance, when the fly ash based alkali activated concrete is used in precast concrete industry, there must be sufficient time available between casting of products and sending them to the curing chamber[10].

For studying the effect of rest period on compressive strength of concrete mix T-13 and T-14 as given in Table 5.3 and Table 5.4 has been cast. The compressive strength results at 7 and 28 days of mix T-13 and T-14 are presented in Figure 5.9.

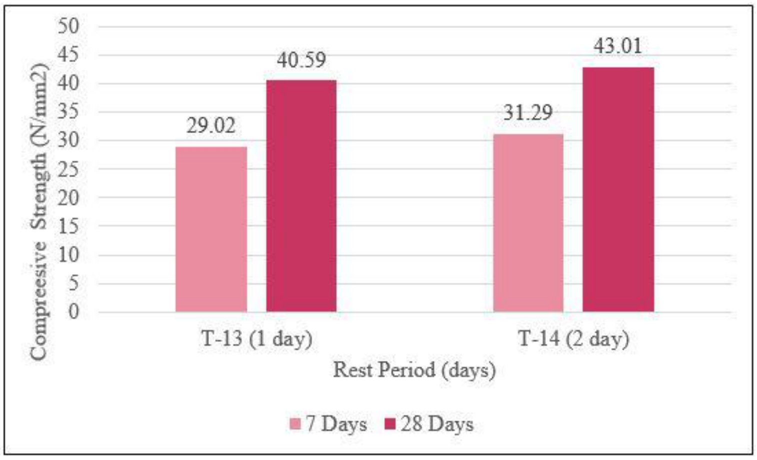


Figure 5.9: Effect of Rest Period on Compressive Strength

It has been observed from the Fig 5.9 that mix T-14 with 2 day rest period has resulted into minor increment in compressive strength as compared to mix T-13 with 1 day rest period. Rest period of 1 day is commercially beneficial as compare to rest period of 2 day hence mix T-13 with 1 day rest period is selected for further investigation.

5.5.6 Water Content of Mix

Water in alkali activated paver block does not take any part in the chemical reaction. In OPC paver block, water in the mix chemically reacts with the cement to produce a paste that binds the aggregates. The chemical reaction that occurs in alkali activated paver block produces water that is eventually expelled from the binder. It has been observed that additional water content in the alkali activated concrete mixture affected the properties of concrete in the fresh state as well as in the hardened state[10].

The effect of water content of mix on compressive strength of alkali activated concrete has been observed by comparing results of mix T-13 and T-15 as shown in Table 5.3 and Table 5.4. The compressive strength results at 7 and 28 days are presented in Figure 5.10.

Percentage increment in compressive strength for mix T-13 at 28 days is 28.50% as compared to compressive strength achieved at 7 days. Percentage increment in compressive strength for mix T-15 at 28 days is 26.08% as compared to compressive strength achieved at 7 days. By comparing the results of compressive strength of T-13 and T-15, T-13 gives 5.30% and 8.40% higher compressive strength as compared to T-15 at 7 days and

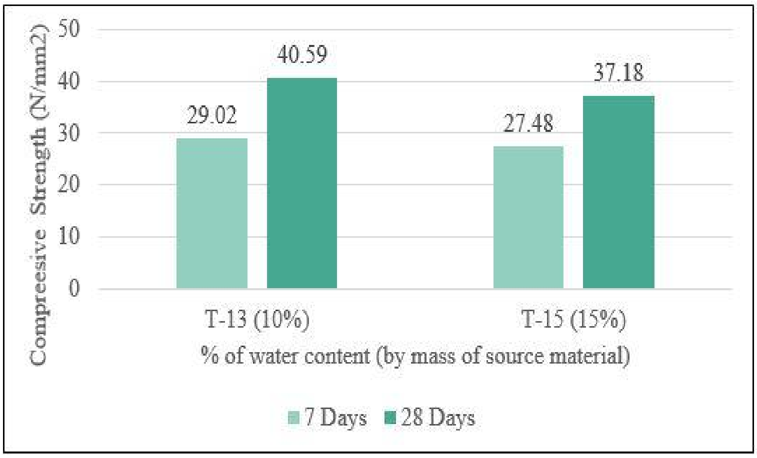


Figure 5.10: Effect of Water content on Compressive Strength

28 days, respectively. Results show that higher compressive strength achieved with 10% water content as compared to 15% water content. Therefore mix T-13 with 10% water content has been selected for the mix design of paver blocks.

5.6 Mix Design of Alkali Activated Paver Blocks

Basic difference between alkali activated paver blocks and OPC paver blocks is the binding material. In alkali activated paver blocks, the silicon and aluminum oxides in the fly ash reacts with alkaline liquid to form the geopolymeric bond between the coarse aggregates, fine aggregates, and other unreacted materials together to form the alkali activated paver blocks.

In the mix design of alkali activated paver block, coarse and fine aggregates has been taken as 75% to 78% of entire mix by mass. This value is similar to that used in OPC paver blocks in which aggregate have been in the range of 75% to 80% of the paver block mix by mass. Fine aggregate has been taken as 35% of the total aggregate. The average density of fly ash and bottom ash based alkali activated paver blocks has been considered similar to that of OPC paver blocks of 2400 kg/m^3

Knowing the density of paver block, the combined mass of alkaline liquid and source material has been calculated. The ratio of alkaline liquid to source material has been taken as 0.4, mass of source material and mass of alkaline liquid has been evaluated. By taking the ratio of sodium silicate to sodium hydroxide of 2.5, the mass of sodium silicate solution and sodium hydroxide solution have been calculated.

Following constituents for mix design have been decided based on the results of parametric study :

- Proportion of fly ash and bottom ash : 50:50
- Amount of source material : 429 kg/m^3
- Ratio of alkaline liquid to source material by mass : 0.4
- Ratio of sodium silicate to sodium hydroxide : 2.5
- Admixture dosage : 0%
- Additional water content : 10%
- Rest period : 1 day

Design of alkali activated paver blocks:

a. Density:
From literature survey it has been observed that the density of the paver blocks varies between 2300 to 2500 kg/m^3
Therefore, the density of the alkali activated concrete is assumed as 2400 kg/m^3

b. Aggregates:
Mass of combined aggregates is selected as 75% of the mass of concrete.
Total aggregate = 0.75 x 2400 = 1800 kg/m^3
Assuming 35% of fine aggregate to the total mass of aggregate.
Fine aggregate = 0.35 x 1800 = 630 kg/m^3
Coarse aggregate (10 mm down) = 1800 - 630 = 1170 kg/m^3

c. Fly ash:
Mass of cementitious material and alkaline liquid = 2400 - 1800 = 600 kg/m^3
Ratio of alkaline solution to source material is taken as 0.4.
Mass of cementitious material = 600/(0.4+1) = 428.57 kg/m^3
Initially for alkali activated paver blocks fly ash and bottom ash proportion (50:50) is used.
Mass of fly ash = 428.57/2 = 214.29 kg/m^3

d. Bottom ash:
Mass of bottom ash = 428.57/2 = 214.29 kg/m^3

e. Alkaline Liquid:
   Mass of alkaline liquid = 600 - 428.57 = 171.43 kg/m^3
   Ratio of Na_2SiO_3 solution to NaOH solution is taken as = 2.5
   Mass of NaOH = 171.43/(2.5+1) = 48.98 kg/m^3
   Mass of Na_2SiO_3 solution = 171.43 - 48.98 = 122.45 kg/m^3

f. Extra water:
   It has been observed that 10% of extra water is required for workability of the alkali activated concrete.
   Extra water = 428.57 x 0.10 = 43 kg/m^3

The details of all alkali activated paver block mixes are summariesd in Table 5.5.

Table 5.5: Proportion of alkali activated paver block mixes

Constituents	Unit	Type of mixes			
		Mix-1	Mix-2	Mix-3	Mix-4
Fly ash	kg/m^3	215	215	215	215
Bottom ash	kg/m^3	215	215	215	215
Fine Aggregate	kg/m^3	630	630	630	630
Coarse Aggregate	kg/m^3	1170	1170	1170	1170
NaOH Solution	kg/m^3	48.98	48.98	48.98	48.98
Na_2SiO_3	kg/m^3	122.44	122.44	122.44	122.44
Water	kg/m^3	43	43	43	43
Molarity	Molar	8	10	12	14

Chapter 6

Testing of Paver Blocks

6.1 General

Results related to properties including compressive strength, abrasion resistance and water absorption for alkali activated paver blocks and commercially available OPC paver blocks at different ages are presented and discussed by means of tables and plots in this chapter.

6.2 Fresh Alkali Activated Paver Block Properties

The workability of the fresh alkali activated paver block is measured by means of the conventional slump test. Comparison of slump values of paver block Mix-1 to Mix-4 are shown in Figure 6.1.

Figure 6.1: Slump values of paver block mixes

Figure 6.1 shows that the workability of Mix-1 is higher as compared to the all mixes. It has been observed from the results that workability of paver block mixes increases with reduction in the concentration of sodium hydroxide solution.

6.3 Compressive Strength

The compressive strength at an age of 7 and 28 days has been evaluated for all alkali activated paver block mixes and OPC paver blocks according to IS 15658:2006[20] and are presented in Table 6.1. Average compressive strength of 3 cubes for all paver block mixes are presented in Table 6.1. The corrected compressive strength shall be calculated by multiplying the apparent compressive strength by the appropriate correction factor for thickness and chamfer curved edge from Table 5 of IS 15658:2006[20]. Corrected strength of average compressive strength for all paver block mixes are presented in Table 6.1.

Table 6.1: Compressive strength of paver blocks

Days	Alkali Activated Paver Blocks												OPC Paver Blocks		
	Mix-1			Mix-2			Mix-3			Mix-4					
	Comp. Stren. (MPa)	Avg. Comp. Stren. (MPa)	Corr. Comp. Stren. (MPa)	Comp. Stren. (MPa)	Avg. Comp. Stren. (MPa)	Corr. Comp. Stren. (MPa)	Comp. Stren. (MPa)	Avg. Comp. Stren. (MPa)	Corr. Comp. Stren. (MPa)	Comp. Stren. (MPa)	Avg. Comp. Stren. (MPa)	Corr. Comp. Stren. (MPa)	Comp. Stren. (MPa)	Avg. Comp. Stren. (MPa)	Corr. Comp. Stren. (MPa)
7 Days	34.78	35.10	37.20	40.53	39.88	42.27	47.87	46.06	48.82	49.78	50.63	53.66	24.57	26.27	27.84
	36.70			37.65			45.95			50.74			26.80		
	33.82			41.48			44.36			51.38			27.44		
28 Days	48.51	48.08	50.96	52.65	54.14	57.38	60.63	60.63	64.26	70.85	72.02	76.34	37.02	36.91	39.12
	45.31			55.21			58.72			74.04			38.61		
	50.42			54.57			62.55			71.17			35.10		

Test results shows that Mix-4 with 14M NaOH solution achieved the highest compressive strength of 53.66 MPa and 76.34 MPa at 7 days and 28 days, respectively.

Figure 6.2 shows the percentage increment in compressive strength of alkali activated paver blocks w.r.t OPC paver blocks. Test results clearly shows that all alkali activated paver blocks have higher compressive strength as compared to OPC paver blocks in all the mixes.

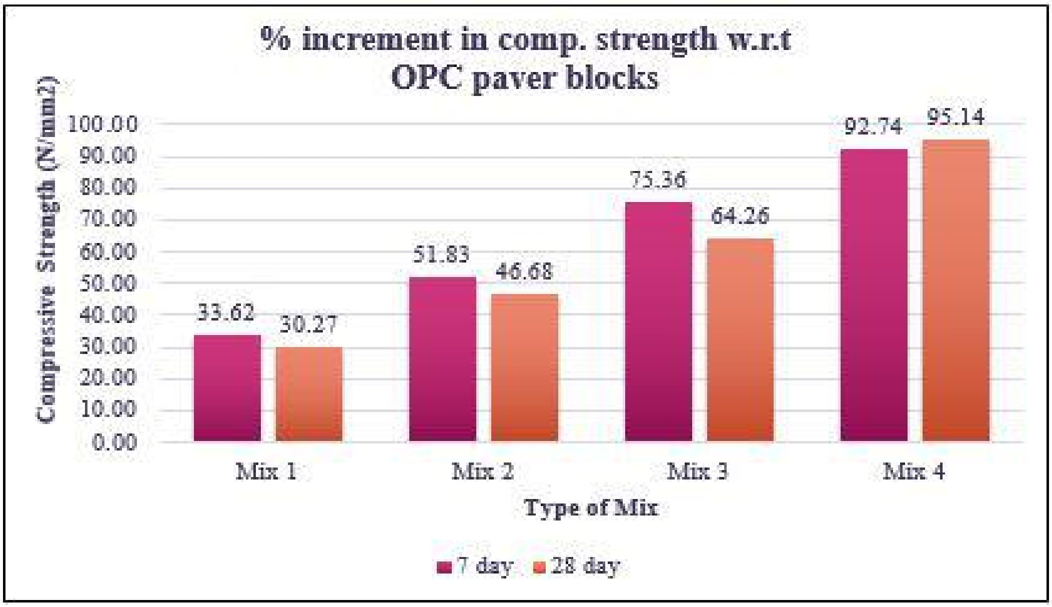


Figure 6.2: % increment in Compressive Strength of alkali activated paver blocks w.r.t OPC paver blocks

Percentage increment in compressive strength for Mix-1, Mix-2, Mix-3 and Mix-4 at 7 days is 33.62%, 51.83%, 75.36% and 92.74%, respectively as compared to compressive strength of OPC paver blocks at 7 days. Percentage increment in compressive strength for Mix-1, Mix-2, Mix-3 and Mix-4 at 28 days is 30.27%, 46.68%, 64.26% and 95.14%, respectively as compared to compressive strength of OPC paver blocks at 28 days. Test results shows that compressive strength increases with increase in concentration of NaOH solution in all the alkali activated paver block mixes. As Mix-1 with 8M NaOH solution achieved higher results as compare to OPC paver blocks, Mix-1 is further investigated for abrasion resistance and water absorption test.

6.4 Abrasion Resistance

The abrasion resistance test for Mix-1 of alkali activated paver blocks and commercially available OPC paver blocks is conducted at the age of 28 days and test results are presented in Table 6.2. Initial weight before testing of specimen and final weight after testing of specimen are calculated. Average results of four specimens are taken for the final result. According to IS 15658:2006[20], specimens dimensions should be square-shaped of 71.0 $\pm$ 0.5 mm dimension. Due to limitation of abrasion machine, final dimensions of the specimens have been kept as 86 mm $\times$ 50 mm $\times$ 32 mm.

Table 6.2: Weight Losses of Mix 1 at 28 days in Abrasion Test

Specimen	Alkali Activated Paver Blocks (Mix-1)			OPC Paver Blocks		
	Initial Weight (gram)	Final Weight (gram)	% Weight Loss	Initial Weight (gram)	Final Weight (gram)	% Weight Loss
1	294.26	260.54	11.45	282.35	240.45	14.83
2	298.63	264.24	11.51	273.19	233.29	14.60
3	302.42	259.76	14.10	276.53	230.18	16.76
4	295.89	257.35	13.02	272.84	231.68	15.08
Average	297.80	260.47	12.53	276.22	233.90	15.32

Sample calculation of weight loss of paver block specimen due to 500 r.p.m. revolution is derived below:

A = Weight of specimen before testing = 294.26
B = Weight of specimen after testing = 260.54

Percentage loss in weight = $\frac{100\times(A-B)}{A} = \frac{100\times(294.26-260.54)}{294.26} = 11.45\%$

Figure 6.3 represent the variation of average abrasion resistance of OPC paver blocks and alkali activated paver blocks (Mix-1).

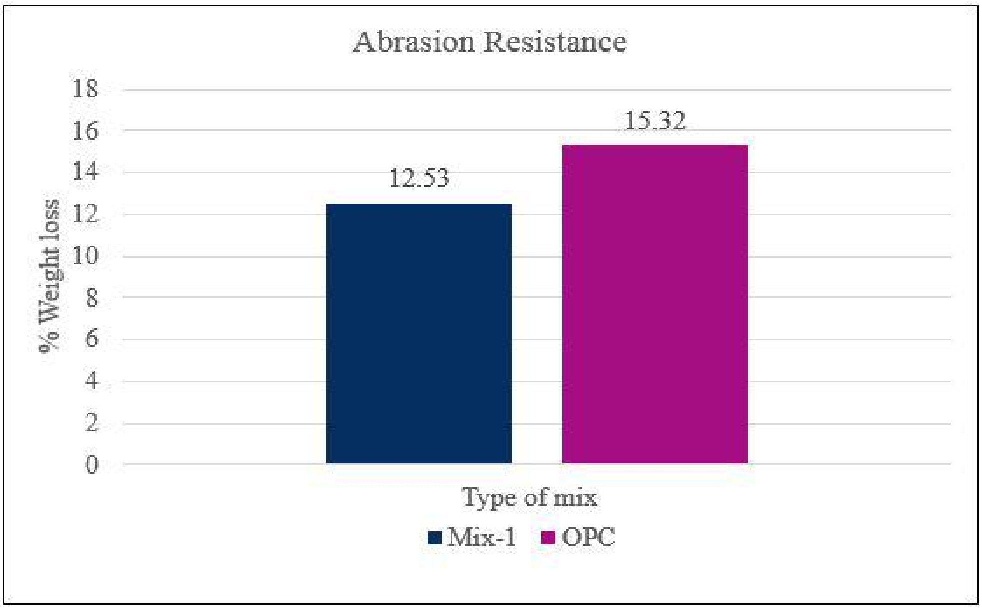


Figure 6.3: Comparison of Abrasion Resistance

Average weight loss of alkali activated paver blocks and OPC pave blocks is 12.53% and 15.32%, respectively. It shows that alkali activated paver blocks have good abrasion resistance as compared to OPC paver blocks.

Figure 6.4 shows the abrasion test specimens of alkali activated paver blocks and OPC paver blocks after testing.

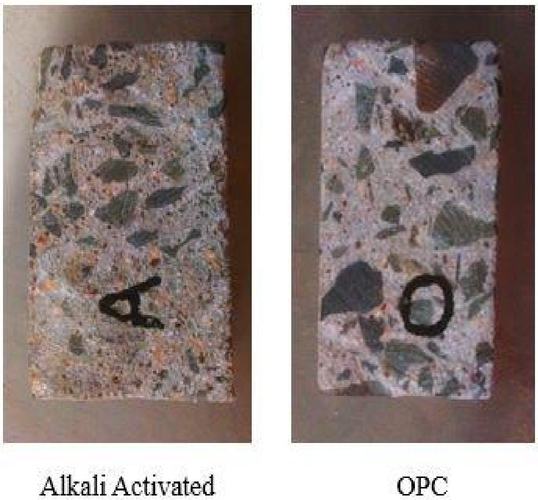


Figure 6.4: Abrasion test specimens after testing

It has been observed that depth of alkali activated paver block specimens are more compared to OPC which indicates that wear due to abrasion is high for OPC specimens.

6.5 Water Absorption

The water absorption test for Mix-1 of alkali activated paver blocks and commercially available OPC paver blocks is conducted at the age of 28 days according to IS 15658:2006[20]. Test results are presented in Table 6.3.

Table 6.3: Percentage gain in weight of paver blocks in water absorption test

Type of paver blocks	No. of Specimen	Dry weight	Weight after water curing	Oven dry weight	% Gain
Alkali Activated Paver Blocks (Mix-1)	1	4.54	4.60	4.52	1.76
	2	4.57	4.64	4.54	2.20
	3	4.62	4.67	4.60	1.52
OPC Paver Blocks	1	4.15	4.35	4.13	5.32
	2	4.18	4.36	4.13	5.56
	3	4.01	4.20	3.98	5.52

Weight difference of specimen after 24 hours of water curing and after 24 hours of oven curing have been calculated and % gain in weight of specimen is evaluated. Average weight of three specimens have been taken as final results.

Figure 6.5 represents the comparison of average % gain in weight of specimen of OPC paver blocks and alkali activated paver blocks.

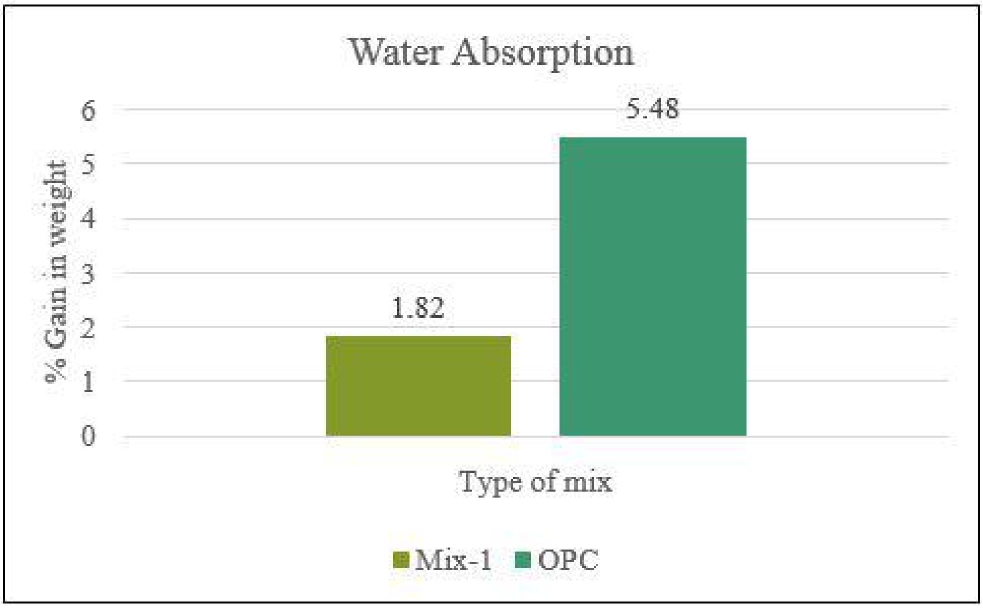


Figure 6.5: Comparison of Water Absorption

Average % gain in weight of specimens of alkali activated paver blocks and OPC paver blocks is 1.82% and 5.46%, respectively. It shows that alkali activated paver blocks have very less water absorption as compared to OPC paver blocks.

6.6 Cost Analysis of Alkali Activated Paver Blocks and OPC Paver Blocks

The basic difference between OPC paver blocks and alkali activated paver blocks is the binder system only, otherwise all other ingredients including fine aggregates and course aggregates are more or less same, so an attempt has been made to compare only variable ingredients. Table 6.4 shows the cost analysis of alkali activated paver blocks and OPC paver blocks.

Table 6.4: Cost analysis

Type of paver blocks	Ingredients	Quantity (kg)	Cost per unit quantity (Rs./kg)	Total cost (Rs./m^3)
Alkali Activated paver blocks	Fly ash	215	1	215
	Bottom ash	215	0.5	108
	NaOH	12.5	40	500
	Na_2SiO_3	123	10	1230
	Total			2053
OPC paver blocks	Cement	350	6	2100
	Total			2100

Table 6.4 presents the cost of binder ingredient of alkali activated paver blocks and OPC paver blocks per m^3 are Rs.2050 and Rs. 2100, respectively.

From this analysis, it is clear that production cost of alkali activated paver blocks and OPC paver blocks are at par. As per as strength criteria is concerned, alkali activated paver blocks are superior to OPC paver blocks such as higher compressive strength, higher abrasion resistance and lesser water absorption.

Chapter 7

Concluding Remarks and Future Scope of Work

7.1 Summary

The present work incorporates investigation of properties of paver blocks including compressive strength, abrasion resistance and water absorption of fly ash and bottom ash based alkali activated paver blocks and their comparison with commercially available OPC paver blocks at different ages. For understanding about terminology, chemistry, mix proportioning process of alkali activated concrete, effect of various parameter on properties of alkali activated concrete etc. & information available in literature has been studied.

The design parameters of paver blocks such as materials, size, shape, weight, colour, area, mix proportion, compaction type, manufacturing process, cost of production etc. have been collected from the different local manufacturing plants to study basic information regarding paver blocks. Investigation on consistency and setting time of fly ash and bottom ash based alkali activated mortar has been conducted to find to the proper proportion of fly ash and bottom ash. To develop the mix design of paver blocks, the effect of variation in source material and other salient parameters on compressive strength of alkali activated concrete has been investigated. Properties such as compressive strength, abrasion resistance & water absorption of alkali activated paver blocks have been measured as per IS provisions and compared with the results of commercially available OPC paver blocks. Four diiferent mixes of alkali activated paver blocks with different concentration of NaOH solution i.e. 8M, 10M, 12M & 14M, respectively have been prepared for testing the compressive strength at 7 and 28 days as per IS provisions. For abrasion resistance and water absorption test alkali activated paver block mix with 8M of NaOH solution has been compare with OPC paver blocks at 28 days as per IS provisions.

7.2 Concluding Remarks

Following concluding remarks have been made on basis of the work conducted in the major project:

- Consistency of alkali activated mortar with different proportion of fly ash and bottom ash increases with increase in the concentration of sodium hydroxide solution in all the mixes. Increase in the concentration of NaOH solution resulted in reduction in initial and final setting time for all the mixes. It was also observed that initial and final setting time of alkali activated mortar increases as the amount of bottom ash is increased in all the mixes.

- By evaluating the effect of various salient parameters on compressive strength of alkali activated concrete, it was found out that compressive strength of concrete increases as the ratio of fly ash to bottom ash by mass is increased for selected mixes. Higher the ratio of sodium silicate to sodium hydroxide by mass, higher is the compressive strength of alkali activated concrete. Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of alkali activated concrete. Minor improvement in compressive strength of alkali activated concrete is observed with 2 day rest period as compare to 1 day rest period. Compressive strength of alkali activated concrete decreases as the water content is increased.

- Workability of paver block mixes increases with reduction in the concentration of NaOH solution in all the mixes.

- There was marginal increase in compressive strength of alkali activated paver blocks as compared to OPC paver blocks at the age of 7 and 28 days for all the mixes.

- Alkali activated paver blocks have high abrasion resistance as compared to OPC paver blocks at the age of 28 days.

- Water absorption in the alkali activated paver blocks is less as compared to OPC paver blocks due to lesser porosity of alkali activated paver blocks.

- With approximately the same cost as that compared to OPC paver blocks, the alkali activated paver blocks have a significantly higher compressive strength, higher abrasion resistance and a lower water absorption.

7.3 Future Scope of Work

- Fly ash or bottom ash can be replace by other source material i.e. rice husk ash, silica fume, metakaolin etc. to produce alkali activated paver blocks.
- Investigation can be carried out with different alkaline activators such as potassium hydroxide and potassium silicate for making alkali activated paver blocks.
- Study can be conducted by employing lesser concentration of NaOH solution in terms of molarity.
- Investigation can be carried out by employing different types of curing methods i.e. oven curing, steam curing etc. on strength of alkali activated paver blocks.
- Other mechanical properties of paver blocks i.e. flexure strength, split tensile strength etc. can also be studied in detail.
- The investigations can be further extended to study the durability properties of fly ash and bottom ash based alkali activated paver blocks.
- Different type of environmental tests including leachate test can be performed on alkali activated paver blocks.
- Retarders can be used to delay the setting time of alkali activated paver blocks.

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