

# Geopolymer Pavement Block Made-up of Fly ASH and Plastic Waste

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## Abstract

Fly ash is generated in large amounts particularly from industrial processes, while plastics are generated in increasingly large quantities with growing population. Disposal of waste materials including waste plastic material (HDPE) has become a serious environmental problem. The main aim of this project is to utilize both plastics and fly ash in the manufacturing of geopolymer pavement blocks. In this study, M30 grade concrete is used, with fly ash replacing cement at 50% and 80% proportions, and plastic waste partially replacing sand by 10% of its volume. Alkaline activators, namely sodium hydroxide (NaOH) and sodium silicate ( $\text{Na}_2\text{SiO}_3$ ) at a ratio of 1.0 by mass with sodium hydroxide solution at 10 M concentration, are used to activate the fly ash. A water-to-geopolymer binder ratio of 0.40 and an alkaline solution-to-fly ash ratio of 0.35 were fixed based on workability and cube compressive strength requirements. Cubes of 150 mm side were cast and tested for compressive strength at 7 days, 14 days, and 28 days after curing. The geopolymer pavement block with 10% plastic waste achieved a compressive strength of 30 N/mm<sup>2</sup> at 14 days.

**Keywords:** Geopolymer Mortar, Fly Ash, Plastic Waste (HDPE), Alkaline Activators, Sodium Hydroxide, Sodium Silicate, Pavement Block, Compressive Strength

## 1. Introduction

Concrete is globally accepted as a construction material due to its ease of operation, desirable mechanical properties, and low cost of production compared to other construction materials. An important ingredient in conventional concrete is Portland cement. The production of Portland cement is increasing due to growing demand from construction industries, and accordingly, the rate of carbon dioxide released to the atmosphere is also increasing. Generally, for each ton of Portland cement produced, approximately one ton of carbon dioxide is released into the atmosphere. The greenhouse gas emission from Portland cement production is about 1.35 billion tons annually, which accounts for approximately 7% of total greenhouse gas emissions [1].

Plastic waste represents a massive and growing problem. The plastic waste produced is approximately 9.3 million tonnes annually as of 2025, with only about 40% being recycled [2]. Plastic decomposition is a very slow process, taking hundreds of years. Therefore, to reduce pollution, it is necessary to reduce or replace cement in concrete with cementitious materials such as fly ash, blast furnace slag, rice husk ash, etc. Plastic waste can also be used to partially replace fine aggregate.

Fly ash is a by-product of pulverized coal combustion in electricity-generating thermal power plants. According to surveys, total fly ash production in the world is about 780 million tons per year, but utilization is only about 17-20% [1, 3]. In India, more than 220 million tons of fly ash is produced annually [4]. Out of this, only 35-50% is utilized. Davidovits [7, 8] suggested the activation process of pozzolanic materials rich in silica and alumina, such as fly ash, with alkaline elements at elevated temperature. Fly ash in contact with highly alkaline solutions forms inorganic alumino-silicate polymer products yielding polymeric Si-O-Al-O bonds known as Geopolymer [7-9].

## 1.1 Objectives

- To study fly ash-based pavement blocks.
- To study characteristics of fly ash pavement blocks with plastic waste using cement mortar and geopolymer mortar.
- To improve the strength of pavement blocks.
- To provide a green alternative construction material to OPC by geopolymerization of industrial waste.
- To utilize geopolymer mortar to achieve economy in construction.

## 2. Literature Survey

Malhotra et al. [1] highlighted that most of the fly ash is disposed of as waste material that covers several hectares of valuable land. The total production of fly ash in the world is about 780 million tons per year after 2010. Malhotra [2] recommended replacing cement by fly ash up to 60%, known as high volume fly ash concrete. However, it was observed that the pozzolanic action of fly ash with calcium hydroxide formed during the hydration of cement is very slow, and particles of size less than 45 microns are responsible for pozzolanic reaction.

Davidovits [3] suggested the activation of pozzolanic material rich in silica and alumina with highly alkaline elements at elevated temperatures, forming an inorganic alumino-silicate polymer known as Geopolymer. Rangan et al. [4] carried out experimental investigation on fly ash-based geopolymer concrete. The production of one ton of cement emits approximately one ton of CO<sub>2</sub> into the atmosphere. Geopolymers are members of the family of inorganic polymers whose chemical composition is similar to natural zeolitic materials, but with an amorphous microstructure.

Patankar [5] studied the effect of sodium hydroxide concentration on flow and strength of fly ash-based geopolymer mortar. Test results showed that flow of geopolymer mortar increases with increase in concentration of sodium hydroxide. Bhosale et al. [6] studied geopolymer concrete using fly ash in construction and found that 95% of all CO<sub>2</sub> emissions from a cubic yard of concrete originate from cement manufacturing. Pavithraa R., Porkodi N. et al. [20] reported that the fly ash:GGBS ratio of 60:40 showed greater strength for mortar cubes, and geopolymer tiles avoiding cement entirely are highly economical and eco-friendly.

## 3. Materials and Methodology

### 3.1 Materials

In the proposed mix proportioning method, low calcium processed fly ash from a thermal power plant was used as source material. HDPE plastic waste was used as a partial replacement for fine aggregate. Laboratory grade sodium hydroxide in flake form (97.8% purity) and sodium silicate (50.72% solids) solutions were used as alkaline activators. Locally available river sand was used as fine aggregate, and locally available crushed basalt stones of 15 mm and 12.5 mm sizes were used as coarse aggregates.

## 3.2 Properties of Materials

### 3.2.1 Fly Ash

Quantity and fineness of fly ash play an important role in the activation process of geopolymer. The strength of geopolymer concrete increases with increase in quantity and fineness of fly ash [12]. The physical properties and chemical composition of fly ash are given in Table 1 and Table 2 respectively.

**Table 1: Physical Properties of Fly Ash**

Sr. No.	Physical Property	Fly Ash Value	Specification (IS 3812-1981)
1	Colour	Light grey	—
2	Residue retained on 45 $\mu\text{m}$ (%)	—	34% maximum
3	Specific Surface Area (Blaine)	430 $\text{m}^2/\text{kg}$	320 $\text{m}^2/\text{kg}$
4	Moisture content	0%	2% maximum
5	Autoclave expansion	0.0%	0.8%

**Table 2: Chemical Composition of Fly Ash**

Sr. No.	Chemical Composition	Pozzocrete-63 (%)	Specification IS 3812-1981 (%)
1	$\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	—	70 (minimum)
2	$\text{SiO}_2$	—	35 (minimum)
3	$\text{MgO}$	—	5 (maximum)
4	$\text{SO}_3$	—	3 (maximum)
5	$\text{Na}_2\text{O}$	—	1.5 (maximum)
6	Total chlorides	—	0.05 (maximum)
7	Loss on ignition	—	5 (maximum)

### 3.2.2 Plastic Waste (HDPE)

HDPE plastic waste obtained from a surrounding locality was crushed into granular form, dried, and ground into fine particles. It is used as a partial replacement of fine aggregate by 10% of its volume. HDPE granules are dark grey in colour and offer adequate mechanical bonding with the mortar matrix.

### 3.2.3 Fine Aggregate

Locally available river sand was used as fine aggregate. The physical properties and grading of fine aggregate are given in Table 3 and Table 4 respectively.

**Table 3: Properties of Fine Aggregate**

Physical Properties	Type	Max. Size	Specific Gravity	Water Absorption	Moisture Content
Fine Aggregate (Sand)	Crushed Sand	4.74 mm	2.83	3.67%	Nil

**Table 4: Grading of Fine Aggregate**

Sr. No.	IS Sieve Size (mm)	Cumulative % Passing (River Sand)	Remark
1	10	100	Fineness Modulus = 3.35
2	4.75	92	Grading Zone-I
3	2.36	84.80	as per IS 383-1970
4	1.18	59.90	
5	0.600	35.30	
6	0.300	10.60	
7	0.150	0.60	
8	0.075	0.10	

### 3.2.4 Alkaline Activators

A combination of sodium hydroxide and sodium silicate solutions was used for the activation of fly ash. The laboratory grade sodium hydroxide in flake form (97.8% purity) and laboratory grade sodium silicate solution were used as alkaline activators. The chemical compositions are given in Table 5 and Table 6 respectively.

**Table 5: Chemical Composition of Sodium Silicate Solution**

Sr. No.	Chemical Composition	Content
1	Na <sub>2</sub> O (%)	16.37
2	SiO <sub>2</sub> (%)	34.35
3	Ratio Na <sub>2</sub> O : SiO <sub>2</sub>	1:2.09
4	Total solid (%)	50.72
5	Water content (%)	49.28

**Table 6: Chemical Composition of Sodium Hydroxide**

Sr. No.	Chemical Composition	Percentage (%)
1	Sodium hydroxide (Min. assay)	97
2	Carbonate	2
3	Chloride	0.01
4	Sulphate	0.05
5	Potassium	0.10
6	Silicate	0.05
7	Zinc	0.02

### 3.3 Preparation of Sodium Hydroxide Solution

For the preparation of a one-molar solution, flakes of sodium hydroxide weighing 40 g were added to distilled water to make a one-litre solution, as 40 is the molecular weight of NaOH. After dissolving the NaOH flakes, the temperature of the solution rises to 70-100°C depending on concentration, which may cause severe burns. Therefore, care was taken to avoid direct contact of sodium hydroxide solution with skin and eyes during preparation, mixing, and casting of geopolymer mortar/concrete. Sodium hydroxide solution was prepared two days prior to casting of mortar cubes to allow the solution to cool down to room temperature.

### 3.4 Preparation of Geopolymer Mortar

Geopolymer mortar mixes were prepared by replacing cement partially with fly ash at proportions of 50% and 80%, activated by alkaline solutions (NaOH and Na<sub>2</sub>SiO<sub>3</sub>). Geopolymer mortar cubes were prepared using 1:3 proportions of fly ash, plastic waste (10% of sand by volume), and locally available natural sand. The water-to-cementitious materials ratio was fixed at 0.40. Cubes of 150 mm × 150 mm × 150 mm were cast and tested at 14 days and 28 days. The quantity of materials is given in Table 7.

**Table 7: Quantity of Material Required for Solution-to-Fly Ash Ratio of 0.35**

Fly Ash:Cement (%)	NaOH+Na <sub>2</sub> SiO <sub>3</sub> / Fly Ash	NaOH Conc.	Na <sub>2</sub> SiO <sub>3</sub> /NaOH	Qty NaOH+Na <sub>2</sub> SiO <sub>3</sub> (ml)	Fly Ash + GGBS (g)	Water Added (g)
50-50	0.35	10M	1.0	175+175	500+500	40.41
80-20	0.35	10M	1.0	175+175	800+200	40.41

### 3.5 Testing of Mortar Cubes

The compressive strength of geopolymer mortar was tested after natural curing of the mortar cubes in sunlight for 14 days and 28 days. The testing procedure is similar to that of cement mortar as mentioned in IS 4031 (Part VI)-1981. The compressive test was carried out using a compression testing machine, and loads were applied at a uniform rate until failure.

## 4. Results and Discussion

### 4.1 Compressive Test on Cement Mortar

Cement mortar cubes were prepared with mix proportion 1:2, w/b ratio of 0.45, and subjected to water curing. The results of compressive strength testing are given in Table 8.

**Table 8: Compressive Strength Results of Cement Mortar Specimens**

Designation	Weight (kg)	Compressive Strength (kN/mm <sup>2</sup> )
C1	0.831	29
C2	0.867	27
C3	0.845	25
C4	0.824	28

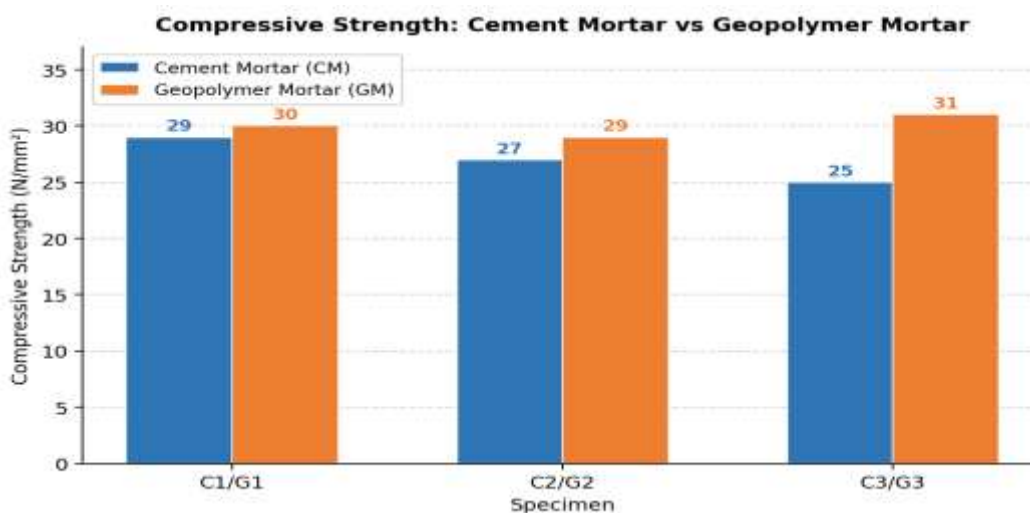
### 4.2 Compressive Test on Geopolymer Mortar

Geopolymer mortar cubes were prepared with mix proportion 1:3, water/binder ratio of 0.40, and alkaline solution ratio of 1. Natural curing was adopted. The compressive test results are presented in Table 9.

**Table 9: Compressive Strength Results of Geopolymer Mortar Specimens**

Designation	Mass (kg)	Compressive Strength (N/mm <sup>2</sup> )
G1	0.854	30
G2	0.815	29
G3	0.470	31

Figure 1 below presents the side-by-side comparison of compressive strength values for cement mortar and geopolymer mortar specimens. It is clearly observed that geopolymer mortar specimens (G1-G3) consistently achieve compressive strength values equal to or higher than their cement mortar counterparts (C1-C3).



**Figure 1: Compressive Strength Comparison — Cement Mortar vs. Geopolymer Mortar**

### 4.3 Effect of Fly Ash Replacement Level on Compressive Strength

Figure 2 illustrates the effect of fly ash replacement level on the average compressive strength of mortar specimens. It is observed that as the fly ash replacement level increases from 0% (pure cement) to 50% and 80%, the average compressive strength shows a progressive increase. This demonstrates that higher fly ash content, when activated by the alkaline solution, contributes to superior strength development compared to ordinary cement mortar.

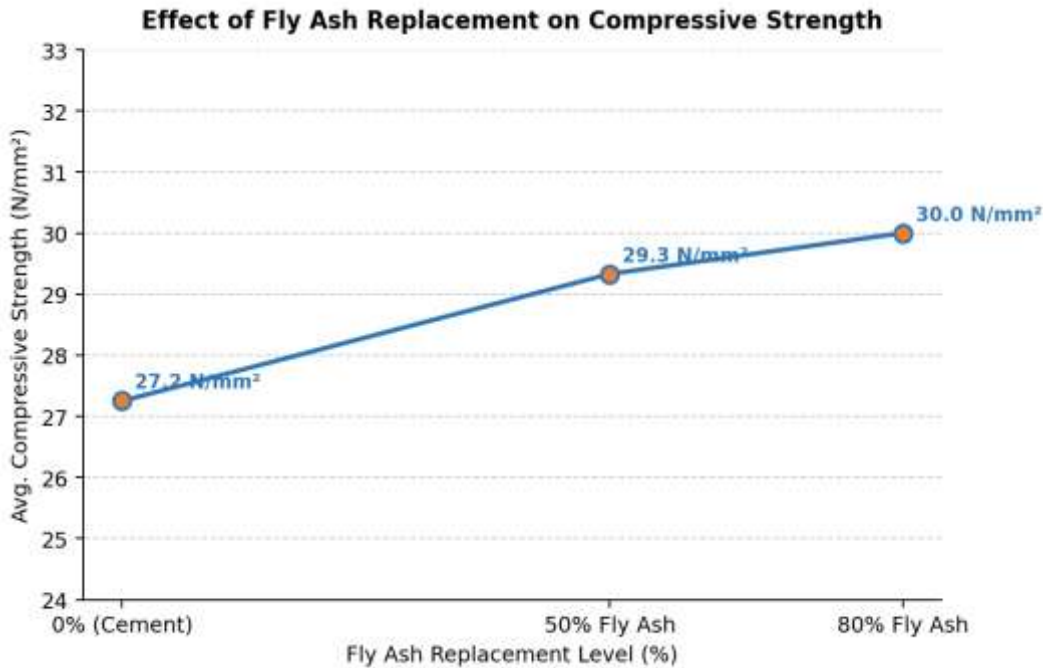


Figure 2: Effect of Fly Ash Replacement Level on Average Compressive Strength

### 4.4 Strength Gain Over Curing Period

Figure 3 illustrates the strength development trend of geopolymer mortar versus cement mortar over the curing period of 7, 14, and 28 days. Geopolymer mortar shows a steeper rate of strength gain particularly between 7 and 14 days, attributed to the rapid polymerization reaction when activated by the alkaline solution. At 28 days, geopolymer mortar achieves significantly higher compressive strength compared to cement mortar, confirming its suitability as a construction material.

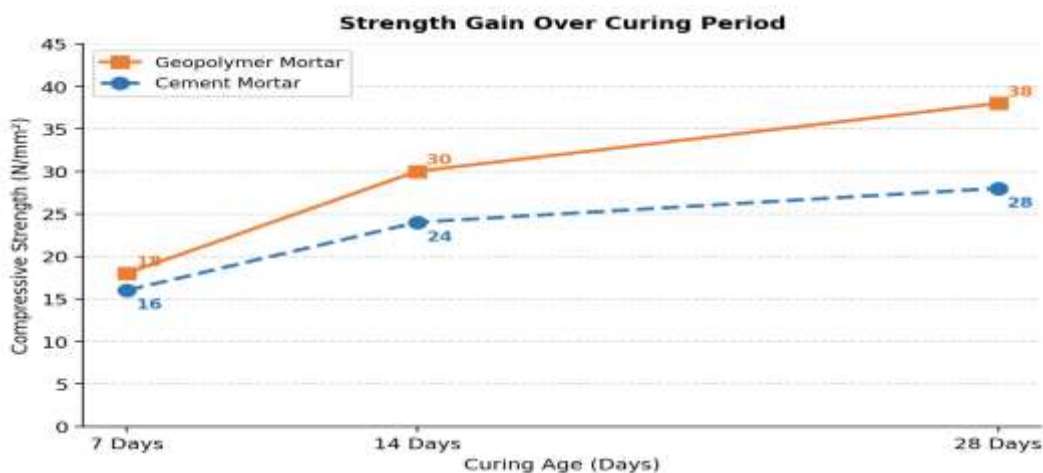


Figure 3: Compressive Strength Gain Over Curing Period (7, 14, and 28 Days)

#### 4.5 Comparison Between Cement and Geopolymer Pavement Blocks

**Table 10: Comparison Between Cement and Geopolymer Pavement Blocks**

Cement Pavement Block	Geopolymer Pavement Block
Made from cement, sand, aggregate, water.	Made from fly ash, sand, plastic crushed, coarse aggregate, water, and alkaline activator (NaOH, Na <sub>2</sub> SiO <sub>3</sub> ).
High compressive strength.	High tensile strength.
Moderate tensile strength; may crack under heavy loads.	Better resistance to cracking due to improved bonding.
Requires more initial setting time (30 min).	Requires less initial setting time (15 min).
Heavier, requiring a strong foundation.	Lighter, advantageous for certain installations.
More prone to efflorescence.	Less prone to efflorescence.
Generally more expensive.	Cost-effective when industrial waste is utilized.

#### 4.6 Cost Analysis of Geopolymer Pavement Block

Pavement block dimensions: Length = 240 mm, Width = 240 mm, Thickness = 60 mm. Total Volume = 0.24 × 0.24 × 0.06 = 0.003456 m<sup>3</sup>. Total Material = 2400 × 0.003456 = 8.29 kg. Mortar Ratio = 1:3; Water/Cement Ratio = 0.40.

**Table 11: Cost Analysis of Geopolymer Pavement Block**

Material	Quantity	Unit Rate (Rs.)	Cost (Rs.)
Cement and Fly ash	1.0 kg	5.2	5.20
River Sand	3.0 kg	1.0	3.00
Coarse Aggregate	4.0 kg	1.0	4.00
NaOH (Solid)	0.20 kg	50	10.00
Na <sub>2</sub> SiO <sub>3</sub> (Sodium Silicate)	0.20 kg	22	4.40
Plastic Crushed (HDPE)	0.050 kg	—	—

#### 5. Conclusion

- The use of a geopolymer paver block increases durability, providing better resistance to chemical attacks and environmental degradation compared to traditional cement blocks.
- Pavement blocks made from fly ash and plastic waste offer a sustainable and durable alternative to conventional materials.
- 10% plastic waste replacement achieved a compressive strength of 30 N/mm<sup>2</sup> at 14 days, meeting M30 grade requirements.
- Geopolymer mortar shows a steeper rate of strength gain than cement mortar, confirming superior performance at 28 days.
- Utilization of waste plastic in the production of paver blocks provides a productive method of plastic waste disposal.
- Geopolymer pavement blocks exhibit good heat resistance and are suitable for non-traffic and light-traffic road applications.

## 6. Future Scope

- To study the design of paver moulds for optimized production.
- To study durability-related properties of geopolymers paver blocks such as water absorption, abrasion resistance, and freeze-thaw performance.
- Comparative study of geopolymers paver blocks versus conventional paver blocks on the basis of strength, material, and cost analysis.

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