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Analysis Of Strength and Durability Characteristics of Geopolymer Concrete using Pet Bottle Fibers

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Abstract—
The rise in demand for green building materials has led to the creation of a new type of concrete, known as geopolymer concrete, to replace conventional concrete. This study is focused on analyzing the strength and durability of geopolymer concrete by incorporating recycled PET bottle fibers. For this research, fly ash is used as a main binder, activated by alkaline solutions such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), replacing ordinary Portland cement. These alkaline solutions are used to prevent carbon emissions. PET bottle fibers, derived from waste plastic bottles, are used in this research to improve the mechanical properties of concrete.

Experimental investigations were conducted to study the compressive strength, split tensile strength, and flexural strength of geopolymer concrete at different curing periods of 7, 14, and 28 days. From this study, it is clear that incorporating PET fibers improves tensile and flexural strength. It is observed that the optimum percentage of PET fibers is about 1%, beyond that, the strength of concrete decreases slightly. It is also observed that incorporating PET fibers in geopolymer concrete improves durability. From this study, it is clear that PET fiber-reinforced geopolymer concrete is a green and efficient concrete for modern construction.

Keywords— Geopolymer concrete, PET bottle fibers, Durability characteristics, Sustainable construction, Waste plastic recycling, Eco-friendly concrete.

I. INTRODUCTION

The idea of geopolymer concrete was first conceived in the late 1970s by French scientist Joseph Davidovits, who suggested the idea of using alumino-silicate materials activated with alkaline solution as a replacement for ordinary Portland cement[1]. His studies showed that industrial waste products like fly ash could be employed to create strong and durable binders with much lower carbon dioxide emissions [2]. The development of fibers in concrete started with the inclusion of steel and synthetic fibers to enhance crack resistance and tensile strength in concrete. Later, with the rise of plastic waste problems, plastic fibers were also incorporated in the early 2000s. PET bottle fibers have also gained more importance in the field of fiber-reinforced concrete due to their availability and longevity in the environment. Recent studies have also highlighted the inclusion of PET fibers in geopolymer

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concrete to enhance its strength and promote sustainable development and waste management practices.

II. LITERATURE REVIEW

Zhang & Wang., (2020)— investigated PET fiber-reinforced geopolymer concrete and found that compressive strength was slightly affected, but tensile and flexural strength were improved. PET fibers showed good performance in terms of cracking resistance and sustainability by utilizing plastic wastes.

Elena and Ion.(2021) – The study evaluated the behavior of PET fiber-reinforced geopolymer concrete after cracking by conducting flexural and fracture tests. The results revealed that the load-deflection behavior, energy absorption, and toughness of the concrete were significantly improved by the addition of PET fibers, which effectively controlled the cracks in the concrete, as confirmed by the microstructural analysis.

Rahman and Yusoff., (2022) — The research investigated the mechanical and microstructural properties of geopolymer concrete using PET fibers. It revealed improvements in tensile and flexural strength, ductility, and energy absorption. The ratio of the alkaline activator and optimum percentage of fibers were investigated and recommended for enhanced performance and utilization of plastic wastes.

Martinez et al., (2023)— The study was a comparison of OPC and geopolymer concrete with PET fibers, where it was evident that geopolymer concrete mixes offered a lower carbon footprint and comparable or higher strength. PET fibers improved flexural strength and post-cracking behavior, whereas geopolymer concrete offered improved chemical resistance and sustainability.

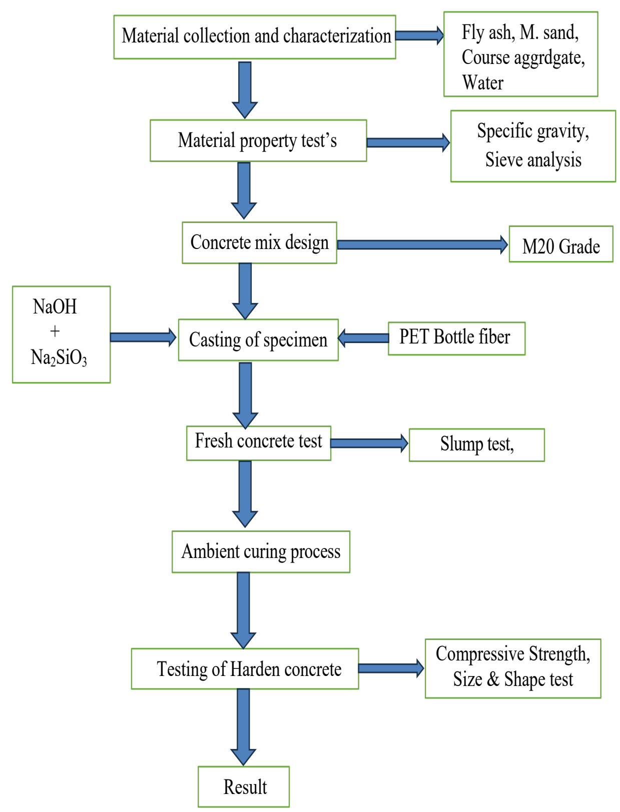
Zhou and Li., (2024) — The study evaluated durability of PET fiber–reinforced geopolymer concrete under acids, sulfates, and chlorides. Results showed excellent resistance to environmental factors, with PET fibers improving crack control and reducing structural damage, enhancing long-term durability and performance.

III. METHODOLOGY

This study adopts an experimental approach to evaluate the strength and durability characteristics of geopolymer concrete incorporating PET bottle fibers. The concrete mix is prepared using fly ash as the binder and alkaline activators such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Different percentages of PET fibers are

S. No	Property	Fly Ash
1	Specific Gravity	2.10 – 2.30
2	Bulk Density (Loose)	900 – 1100 kg/m³
3	Bulk Density (Compacted)	1100 – 1300 kg/m³
4	Fineness	300 – 500 m²/kg
5	Water Absorption	0.2 – 0.5 %

added to the mix, and specimens are cast and tested at various curing periods. The results are analyzed based on mechanical properties and durability performance to determine the optimum fiber content for practical applications.



- Preparation of geopolymer concrete using fly ash and alkaline activators (NaOH & Na_2SiO_3).
- Incorporation of PET bottle fibers in varying percentages.
- Casting of specimens (cubes, cylinders, and prisms).
- Curing of specimens for 7, 14, and 28 days.
- Testing of compressive, split tensile, and flexural strength.

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➢ Analysis of results to determine optimum fiber content and performance.

IV. MATERIAL PROPERTIES AND MIX DESIGN

A) FLY ASH

Fly ash is a by-product of a coal-fired power plant and contains a significant amount of silica and alumina. It is used as a binder for geopolymer concrete. It replaces cement. It is activated by NaOH and Na_2SiO_3. It forms a strong polymer network with low emissions. Class F fly ash is used to increase durability and strength.

Table:1 Material Properties of Fly Ash

B) Coarse Aggregates

Coarse aggregates constitute a major part of the Geopolymer Concrete. Coarse aggregates have the size of

S. No	Property	Sodium Hydroxide (NaOH)
1	Chemical Formula	NaOH
2	Molecular Weight	40 g/mol
3	Physical State	White solid (pellets/flakes)
4	Purity	97 – 99 %
5	Specific Gravity	2.13
6	Molarity Used in Mix	10 M
7	Solubility in Water	Highly soluble

10-20 mm. The coarse aggregate increases the strength of the Geopolymer Concrete. The quality of the aggregate is good, and the aggregate should not react with the Geopolymer Concrete.

Table:2 Material Properties of Coarse Aggregate

S. No	Property	Coarse Aggregate
1	Specific Gravity	2.67
2	Bulk Density (Loose)	1857.33 kg/m³
3	Flakiness Index	3 %
4	Bulk Density (Compacted)	2047 kg/m³
5	Water Absorption	0.6 %

C) Fine Aggregate

Fine aggregate is used to fill the space between the coarse aggregates and to improve the workability of geopolymer concrete. It is usually sand or artificial sand and helps to improve the density and strength of the concrete as well as its finish. It is also important to ensure purity and gradation to prevent impurities and improve the bonding of the geopolymer concrete.

Table:3 Material Properties of Fine Aggregate

S. No	Property	Fine Aggregate
1	Specific Gravity	2.60 – 2.65
2	Bulk Density (Loose)	1450 – 1600 kg/m³
3	Bulk Density (Compacted)	1600 – 1750 kg/m³
4	Fineness Modulus	2.6 – 2.9
5	Water Absorption	1 – 2 %
6	Zone (as per IS 383)	Zone II

D) ALKALINE ADMIXTURES

i)Sodium hydroxide (NaOH)

The Sodium hydroxide (NaOH), or caustic soda, is a strong alkaline activator used in geopolymer concrete. It is used to dissolve silica and alumina in the fly ash to form a binding polymer. It is used at a solution of 8-16M; increasing molarity increases strength.

Table:4 Material Properties of Sodium hydroxide (NaOH)

ii) Sodium silicate (Na_2SiO_3)

Sodium silicate, or water glass, also known as Na_2SiO_3, acts as an alkaline activator when it is mixed with NaOH, forming geopolymer concrete. It provides the necessary soluble silica, creating strong polymer bonds, thus enhancing the strength, durability, and setting of the concrete. Proper proportioning also improves the workability, chemical resistance, and permeability.

Table:5 Material Properties of Sodium Silicate (Na_2SiO_3)

S. No	Property	Sodium Silicate (Na_2SiO_3)
1	Chemical Formula	Na_2SiO_3
2	Molecular Weight	122.06 g/mol
3	Physical State	Colorless to slightly yellow liquid
4	Specific Gravity	1.45 – 1.50
5	pH Value	11 – 13
6	SiO_2 / Na_2O Ratio	2.0 – 3.2

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7	Solubility	Completely soluble in water

E) PET BOTTLE FIBER

PET bottle fibers are recycled materials obtained from plastic waste. They are used as reinforcement materials in geopolymer concrete. They are light in weight, strong, and resistant to corrosion. The fibers provide improved tensile strength and flexural strength. They also provide improved toughness and reduced crack formation. However, it reduces workability slightly.

Table:6 Material Properties of PET Bottle Fiber

S. No	**Property**	**PET Bottle Fiber**
1	Material Type	Polyethylene Terephthalate (PET)
2	Density	1.34 – 1.39 g/cm³
3	Tensile Strength	300 – 600 MPa
4	Length of Fiber	10 – 20 mm
5	Diameter	0.2 – 0.4 mm
6	Water Absorption	Negligible

FIGURE:1 Materials

F) MIX DESIGN

Activator liquid to Source material ratio
= 0.5
Sodium Silicate to Sodium Hydroxide liquid ratio
= 2.5
Concentration of NaOH liquid in terms of molarity
= 10 M
Curing method : Ambient Curing
Grade of Concrete : M30
PET Bottle Fiber Content = 0.5 % (by weight of binder)

i)Target Strength for mix proportion

The target mean compressive strength at 28 days is given by
fck' = fck + 1.65S
From IS 10262 : 2000
S = 5 N/mm² (S-Standard Deviation)
fck' = 30 + (1.65 × 5)
= 38.25MPa
fck' = 38.25 N/mm²

ii) Selection of Quantity of Fly Ash

The quantity of fly ash required is 550 kg/m³ for the target mean strength of 38.25 MPa at solution to source ratio of 0.5.
From previous literature studies, the fly ash content of 550 kg/m³ is suitable for geopolymer concrete.

iii) Calculation of the quantity of alkaline activators

Solution- fly ash ratio by mass = 0.5
i: e: Mass of (Na_2SiO_3+ NaOH)/ fly ash
= 0.5
Mass of (Na_2SiO_3+ NaOH)/550= 0.5
Mass of (Na_2SiO_3+ NaOH) =275 kg/m³

iv) Amount of NaOH and Na_2SiO_3

Sodium Hydroxide-Sodium Silicate Ratio
= 1:2.5
Amount of Sodium Hydroxide
= 275/3.5
= 78.57 kg/m³
Amount of Sodium Silicate
= 275 - 78.57
= 196.43 kg/m³
For medium degree of workability and fineness of fly ash of 550 kg/m³, water content per cubic meter of geopolymer concrete

Quantity of water = 78.57 - 31.428
= 47.142 kg/m³
For the fly ash we use in GPC the additional water content taken is 5%
Total quantity of water added
= 550 x 5/100

= 27.5 kg/m^3

v) Calculation of total solid content in alkaline solution

Molarity to be used in concentration is 10 M in which 400 g of NaOH solids per litre of water 400g of NaOH
= 400 x 78.57
= 31.428 kg/m^3
Quantity of Solids = 31.428 kg/m^3

vi) Selection of water content

For medium degree of workability and fineness of fly ash of 550 kg/m^3,
water content per cubic meter of geopolymer concrete
Quantity of water = 78.57 - 31.428
= 47.142 kg/m^3

vii) Selection of wet density of geopolymer concrete

Wet density of geopolymer concrete is 2,620 kg/m^3 for the fineness of Fly Ash of 550 kg/m^3

viii) Calculation of fine and coarse aggregate content

Total aggregate content = [Wet density of GPC]-[Quantity of fly ash]+Quantity of both solutions + extra water]
= 2620- [550 + 275 + 27.5]
= 1767.5 kg/m^3
Sand content = [Fine to total aggregate content in %] x [Total quantity of All-in-aggregate]
= (35/100) x 1767.5
= 618.63 kg/m3
Coarse aggregate content = [Total quantity of all in-aggregate]-[Sand content]
= 1767.5- 618.63
= 1148.87kg/m3
Quantity of materials required per cubic meter for M30 grade of GPC

ix) Addition of PET Bottle Fiber

PET Bottle Fiber added = 0.5 % of fly ash weight
= 0.005 × 550
= 2.75 kg/m^3

V. TEST RESULTS AND DISCUSSIONS

Compressive strength is the key indicator of concrete quality, influenced by mix ratio, curing, and age. Tensile strength is lower but relates to compressive strength and is tested using cylinders. Modulus of elasticity determines deformation behavior and helps predict deflection and cracking in concrete structures.

A) Compressive Strength Test

The compressive strength test is a measure of the resistance of concrete to axial forces. Concrete cubes of 150x150x150mm are tested for compressive strength at 7 days, 14 days, and 28 days. Compressive strength is measured by the formula: Load/area. Compressive strength is a measure of quality, durability, and performance of concrete, depending on the mix design and materials used.

Table:7 Compressive Strength Test Results

PET Fiber Content (%)	7 Days (N/mm²)	14 Days (N/mm²)	28 Days (N/mm²)
0%	24.10	31.85	38.20
0.5%	25.76	33.42	40.18
1%	27.32	35.10	42.05
1.5%	26.40	34.05	40.90

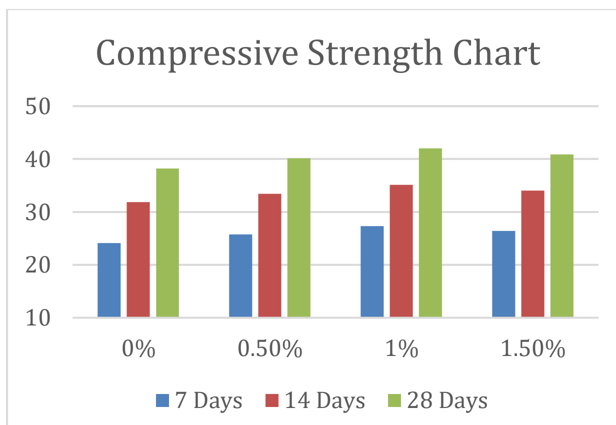

Figure:2 Compressive Strength Chart

B) Split Tensile Strength Test

The split tensile strength test measures the tensile capacity of concrete using cylindrical specimens. A compressive load is applied along the diameter until failure occurs. This test evaluates crack resistance and tensile behavior. It is conducted at different curing ages to assess strength development and overall performance of concrete.

Table:8 Split Tensile Strength Test Results

PET Fiber Content (%)	7 Days (N/mm²)	14 Days (N/mm²)	28 Days (N/mm²)
0%	2.10	2.85	3.25
0.5%	2.38	3.12	3.58
1%	2.65	3.45	3.92
1.5%	2.48	3.28	3.70

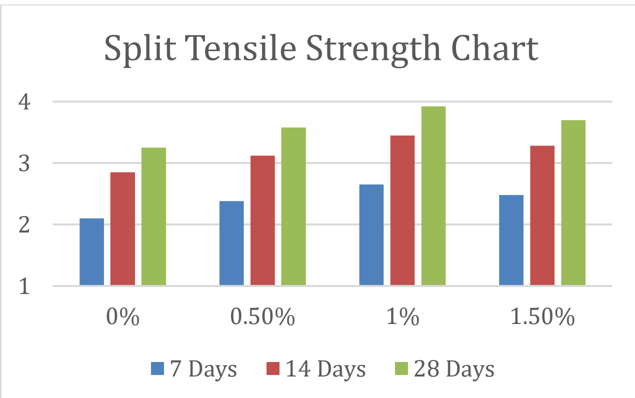

Figure:3 Split Tensile Strength Chart

C) Flexural strength Test

The flexural strength test measures the bending strength of concrete using prism specimens. A load is applied until the specimen fails under bending. It evaluates the concrete's resistance to cracking and its tensile behavior in bending. Tests are conducted at different curing ages to assess strength development and performance.

Table:9 Flexural Strength Test Results

PET Fiber Content (%)	7 Days (N/mm²)	14 Days (N/mm²)	28 Days (N/mm²)
0%	3.10	4.05	4.85
0.5%	3.45	4.42	5.20
1%	3.78	4.86	5.68
1.5%	3.60	4.65	5.40

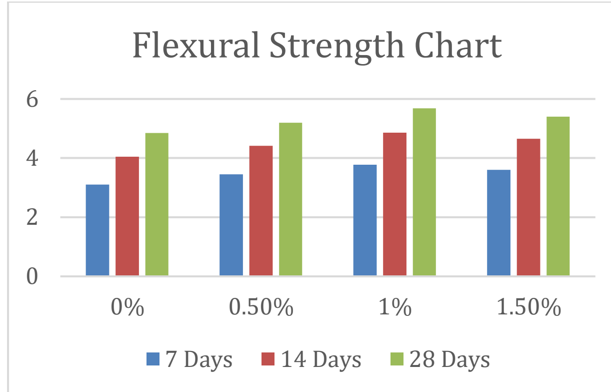

Figure:4 Flexural Strength Chart

VI. CONCLUSION

Experiments on PET fiber–reinforced geopolymer concrete showed improved strength and durability. Using fly ash with NaOH and Na_2SiO_3 produced sustainable concrete. Compressive, tensile, and flexural strengths increased up to 1% fiber content. PET fibers enhanced crack resistance, toughness, and ductility. The use of fly ash reduced cement usage, lowering carbon emissions, while recycled PET fibers promoted eco-friendly construction and effective plastic waste management.

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