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DEVELOPMENT OF SUSTAINABLE GEOPOLYMER CONCRETE USING INDUSTRIAL WASTES: FLY ASH, COPPER SLAG, CERAMIC TILES

V. malathi
Department of civil Engineering, Research scholar in BEST Innovation University, Gorantla, A.P..
Assistant professor in shadan college of Engineering & Technology , Hyderabad.
Dr. k Suresh, professor,
Department of civil Engineering ,Nalla Malla Reddy Engineering College, Hyderabad.
corresponding **author email ID. 2024spciv001@gmail.com**

Abstract: The construction industry plays a crucial role in infrastructure development but is also one of the largest contributors to environmental degradation. Conventional Ordinary Portland Cement (OPC) concrete is widely used due to its strength, durability, and versatility; however, the production of cement is highly energy-intensive and responsible for significant carbon dioxide (CO_2) emissions. It is estimated that for every ton of cement produced, approximately one ton of CO_2 is released into the atmosphere, accounting for nearly 8% of global anthropogenic CO_2 emissions. This research develops eco-friendly, cement-free geopolymer concrete by fully or partially replacing traditional components with industrial wastes: **fly ash** (as a primary binder source rich in silica and alumina), **copper slag** (as a dense fine/coarse aggregate substitute), and **ceramic tile waste** (as supplementary pozzolanic powder or recycled aggregate). Activated using alkaline solutions like sodium hydroxide and sodium silicate, the mixture achieves high mechanical strength, reduces carbon emissions, and solves local waste disposal challenges… To develop and evaluate sustainable geopolymer concrete by utilizing **fly ash, copper slag and waste ceramic tiles** as alternative construction materials and to determine their influence on the fresh, mechanical and durability properties of concrete.

Keywords : Fly Ash Usage, Copper Slag , Ceramic Tile Waste , Alkaline Activator, Geo polymer, waste disposal **etc..**

1. Introduction

The rapid growth of the construction industry has resulted in extensive consumption of natural resources and increased generation of industrial and construction wastes. Conventional Portland cement concrete has a significant environmental impact because cement manufacturing consumes large quantities of energy and releases substantial amounts of carbon dioxide. Therefore, the development of sustainable and low-carbon alternatives to conventional concrete has become an important area of research.

Geopolymer concrete is an alternative cement-free concrete in which industrial by-products rich in silica and alumina are activated using alkaline solutions to form a binding material. Fly ash is one of the most widely available industrial wastes suitable for geopolymer production because of its high content of reactive silica and alumina. The utilization of fly ash in geopolymer concrete reduces the dependence on Portland cement and provides an effective method of industrial-waste management.

Copper slag is a by-product generated during the extraction and refining of copper. It possesses desirable physical and mechanical properties and can be used as a partial replacement for natural fine aggregate. Its use can reduce the consumption of natural river sand while providing a productive application for an industrial waste material.

Waste ceramic tiles are generated in large quantities during tile manufacturing, transportation, construction and demolition activities. Crushed ceramic tile waste can be used as a partial replacement for natural coarse or fine aggregate depending on its particle size. Ceramic waste also contains significant amounts of silica and alumina, which can contribute to the development of sustainable cementitious materials.

The present study focuses on the development of geopolymer concrete incorporating fly ash as the primary binder, copper slag as a partial replacement for natural fine aggregate, and waste ceramic tiles as a partial replacement for conventional aggregate. The combined utilization of these wastes can reduce environmental pollution, conserve natural resources and improve the sustainability of concrete construction.

2. LITERATURE SURVEY:

one of the earliest researchers to introduce geopolymer materials as an alternative to Portland cement–based

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binders. In his experimental studies, aluminosilicate-rich materials such as metakaolin and industrial by-products were activated using alkaline solutions containing sodium hydroxide and sodium silicate. Test specimens were cast and cured under controlled temperature conditions to study strength development and durability behavior. The experimental results demonstrated that geopolymer binders form a strong three-dimensional polymeric Si–O–Al network, resulting in high compressive strength, excellent thermal stability, and superior resistance to chemical attack. The study concluded that geopolymer concrete significantly reduces CO_2 emissions and energy consumption compared to conventional cement concrete.

3. SCOPE THE PROJECT

- The study is limited to the development of geopolymer concrete using fly ash as the primary binder material.
- Copper slag is used as a partial replacement of natural fine aggregate in varying percentages.
- Ceramic tile waste powder is incorporated as a supplementary aluminosilicate material in geopolymer concrete.
- The alkaline activator system is restricted to sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions.
- The effect of different replacement levels of copper slag and ceramic tile waste on concrete properties is evaluated.
- The study focuses on fresh properties, mainly workability and consistency of geopolymer concrete.
- Mechanical properties such as compressive strength and split tensile strength are investigated..

4. Proposed Materials TO BE USED:

4.1 Fly Ash

Fly ash obtained from thermal power plants can be used as the primary alumino silicate material for geopolymerization. Its chemical composition, fineness, specific gravity and particle size distribution should be determined before use.

4.2 Copper Slag

Copper slag can be processed and graded before incorporation into the concrete. It may be used as a partial replacement for natural fine aggregate at different percentages.The actual replacement range should be finalized based on preliminary trials and the required workability and strength.

4.3 Waste Ceramic Tiles

Waste ceramic tiles can be collected from construction and demolition sites or tile industries. The tiles should be cleaned, crushed and sieved to obtain the required aggregate size. They can be used as a partial replacement for coarse aggregate

4.4 Alkaline Activator

A combination of **sodium hydroxide (NaOH)** and **sodium silicate (Na_2SiO_3)** can be used as the alkaline activating solution. Different molarities of sodium hydroxide and different sodium silicate-to-sodium hydroxide ratios may be investigated to obtain the desired geopolymerization reaction.

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5. Proposed Flow Chart

Collection of Industrial Wastes
↓
Fly Ash + Copper Slag + Waste Ceramic Tiles
↓
Material Characterization
↓
Processing of Copper Slag and Ceramic Waste
↓
Preparation of Alkaline Activator
↓
Geopolymer Mix Design
↓
Preparation of Control Mix
↓
Preparation of Waste-Based Geopolymer Mixes
↓
Casting of Specimens
↓
Curing
↓
Fresh Property Tests
↓
Compressive Strength Tests
↓
Split Tensile Strength Tests
↓
Flexural Strength Tests
↓
Durability Tests
↓
Analysis and Comparison of Results
↓
Optimization of Mix Proportion
↓
Assessment of Sustainability.

6. Proposed Experimental Programme:

The experimental programme can be divided into the following stages:

Stage I – Characterization of Materials

The physical and chemical properties of fly ash, copper slag, ceramic tile waste, fine aggregate and coarse aggregate will be determined.

Tests may include:

- Specific gravity
- Fineness
- Particle size distribution
- Bulk density
- Water absorption
- Chemical composition
- Aggregate impact/crushing characteristics where applicable

Stage II – Preparation of Geopolymer Concrete

Fly ash will be used as the principal binder. Copper slag and crushed ceramic tile waste will be incorporated as partial replacements for conventional aggregates.

A control geopolymer concrete mix containing 0% waste aggregate replacement will first be prepared. Subsequently, different combinations of copper slag and ceramic tile aggregate will be investigated.

Stage III – Fresh Concrete Properties

The following properties can be evaluated:

- Slump/workability
- Compaction characteristics
- Density
- Fresh concrete temperature
- Setting characteristics, where applicable

Stage IV – Mechanical Properties

Specimens will be cast and tested for:

Compressive strength

Concrete cubes will be tested at selected ages such as 7, 28 and 56 days.

Split tensile strength

Cylindrical specimens will be tested to determine the tensile strength of the geopolymer concrete.

Flexural strength

Beam specimens will be tested to determine the flexural performance.

Stage V – Durability Properties

Depending on the scope of the project, the following durability tests can be conducted:

- Water absorption
- Sorptivity
- Acid resistance
- Sulphate resistance
- Chloride resistance
- Abrasion resistance
- Resistance to elevated temperature

Stage VI – Optimization

The test results will be compared to identify the optimum combination of fly ash, copper slag and ceramic tile waste that provides satisfactory strength, durability and workability.

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7.. Conceptual Mix Design

Grade of concrete = M30 (1:0.75:1.5)

Size of cube = 150mm×150mm×150mm

Volume of one cube = 0.003375m^3

Volume of 3 cubes = 3× (0.003375)

= 0.010125 m^3

As per code book IS 875 Part-1

Unit weight of cement = 400kg/ m^3

Unit weight of fine aggregate = 700kg/ m^3

Unit weight of coarse aggregate = 1150kg/ m^3

Quantity of materials required for 3 cubes as follows:

Cement = 0.010125 x 400

= 4.05kg

Fine Aggregate = 0.010125 x 700

= 7.09kg

Coarse Aggregate = 0.010125 x 1150

= 11.64kg

Water Cement ratio = 180 x 0.010125

= 1.82 liters or kgs

Quantity of materials required to make cubes for each percentages as follows:

Table: 3.1 Quantity of materials to make cubes

Mix Details	Cement (kg)	Fly Ash (kg)	Fine Aggregate(kg)	Coarse Aggregate(kg)	NaoH	Na2sio3	Water
0%	4.05	0	7.09	11.64	0	0	1.82
80% Cement+ 20% Fly Ash	3.24	0.81	7.09	11.64	0.46	1.16	0
60% Cement+ 40% Fly Ash	2.43	1.62	7.09	11.64	0.46	1.16	0

Mix variations:

Copper Slag

(1) Cement: 100%, Copper Slag: 4% (replace FA - 96%), Coarse aggregate: 100%

- Cement: 400 × 0.010125 = 4.05 kg
- Sand: 700 × (1 − 0.04) × 0.010125 = 6.81 kg
- Coarse Aggregate (CA):1150 × 0.010125 = 11.64 kg
- Sand: 700 × (1 − 0.08) × 0.010125 = 6.52 kg
- Coarse Aggregate (CA):1150 × 0.010125 = 11.64 kg
- Copper Slag: 700 × 0.08 × 0.010125 = 0.57 kg
- NaOH: 0.46 kg
- Na_2SiO_3: 1.16 kg

(3) Cement: 100%, Copper Slag: 12% (replace FA - 88%), Coarse aggregate: 100%

- Cement: 400 × 0.010125 = 4.05 kg
- Copper Slag: 700 × 0.04 × 0.010125 = 0.28 kg
- NaOH: 0.46 kg
- Na_2SiO_3: 1.16 kg

(2) Cement: 100%, Copper Slag: 8% (replace FA - 92%), Coarse aggregate: 100%

- Cement: 400 × 0.010125 = 4.05 kg
- Sand: 700 × (1 − 0.12) × 0.010125 = 6.23 kg
- Coarse Aggregate (CA):1150 × 0.010125 = 11.64 kg
- Copper Slag: 700 × 0.12 × 0.010125 = 0.85 kg
- NaOH: 0.46 kg
- Na_2SiO_3: 1.16 kg

Ceramic Waste

(1) Cement: 100%, Fine aggregate: 100%, Ceramic Waste: 2% (replace CA -98%)

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- Cement: 400 × 0.010125 = 4.05 kg
- Sand: 700 × 0.010125 = 7.09 kg
- Coarse Aggregate (CA):1150 × (1 − 0.02) × 0.010125 = 11.41 kg
- Ceramic Waste: 1150 × 0.02 × 0.010125 = 0.23 kg
- NaOH: 0.46 kg
- Na_2SiO_3: 1.16 kg

(2) Cement: 100%, Fine aggregate: 100%, Ceramic Waste: 6% (replace CA -94%)

- Cement: 400 × 0.010125 = 4.05 kg
- Sand: 700 - Coarse Aggregate (CA):1150 × (1 − 0.06) × 0.010125 = 10.94 kg
- Ceramic Waste: 1150 × 0.06 × 0.010125 = 0.71 kg
- NaOH: 0.46 kg
- Na_2SiO_3: 1.16 kg

(3) Cement: 100%, Fine aggregate: 100%, Ceramic Waste: 10% (replace CA -90%)

- Cement: 400 × 0.010125 = 4.05 kg
- Sand: 700 × 0.010125 = 7.09 kg
- Coarse Aggregate (CA):1150 × (1 − 0.10) × 0.010125 = 10.48 kg
- Ceramic Waste:1150 × 0.10 × 0.010125 = 1.18 kg, - NaOH: 0.46, Na_2SiO_3: 1.16 kg.

Combined mix

Cement: 80%, Fly Ash: 20%, Copper Slag: 8% (replace sand-92%), Ceramic Waste: 6% (replace CA-94%)

- Cement: 400 × 0.80 × 0.010125 = 3.24 kg
- Fly Ash: 400 × 0.20 × 0.010125 = 0.81 kg
- Copper Slag: 700 × 0.08 × 0.010125 = 0.57 kg
- Sand: 700 × 0.92 × 0.010125 = 6.52 kg
- Coarse Aggregate (CA): 1150 × 0.94 × 0.010125 = 10.94 kg
- Ceramic Waste/CT: 1150 × 0.06 × 0.010125 = 0.71 kg
- NaOH: 0.46 kg

× 0.010125 = 7.09 kg

- Na_2SiO_3: 1.16 kg

8.RESULTS

8.1 COMPRESSIVE STRENGTH TEST

Table - 8.1 Compressive strength test results

Conventional concrete	7 Days (Mpa)	14 Days (Mpa)	28 Days (Mpa)
0%	16.5	22.5	28

Table - 8.2 Compressive strength test results

For Fly Ash			
% Replacement	7 Days (Mpa)	14 Days (Mpa)	28 Days (Mpa)
20%	15.2	21.5	29.8
40%	13.8	19.8	27.2

Table - 8.3 Compressive strength test results

For Copper Slag			
% Replacement	7 Days (Mpa)	14 Days (Mpa)	28 Days (Mpa)
4%	17.2	23.5	29.5
8%	18.0	25.2	31.2
12%	17.6	24.5	30.0

Table - 8.4 Compressive strength test results

For Ceramic Waste			
% Replacement	7 Days (Mpa)	14 Days (Mpa)	28 Days (Mpa)
2%	17	23.5	29.2
6%	17.8	24.8	30.8
10%	17.3	24.0	29.6

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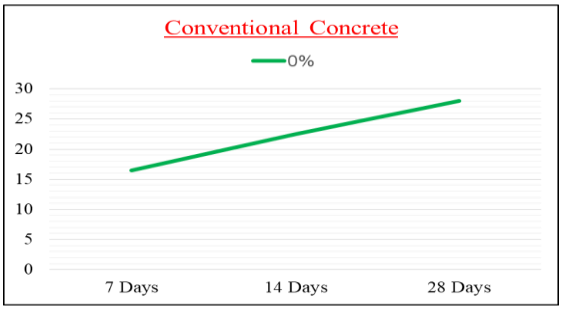
Table - 8.5 Compressive strength test results

For Combined Mix			
% Replacement	**7 Days (Mpa)**	**14 Days (Mpa)**	**28 Days (Mpa)**
20% Fly ash + 80% Cement 8% Copper slag + 92% Fine Aggregate 6% Ceramic waste + 94% Coarse Aggregate	16.0	23.8	32.5



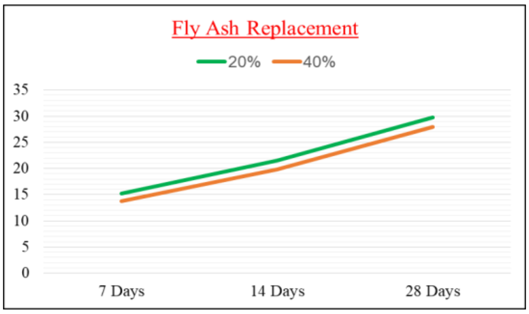
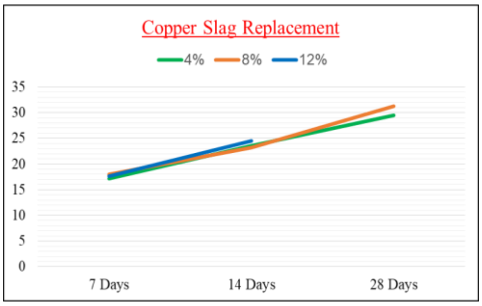


fig :Compressive Strength of conventional concrete and fly ash



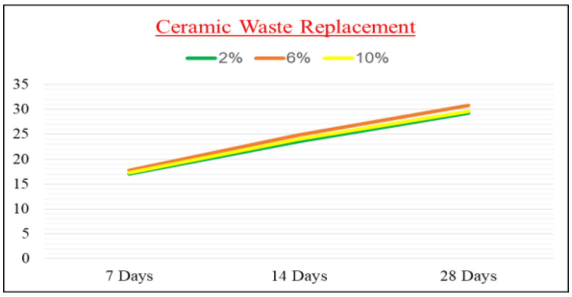


Fig: Compressive Strength of Copper Slag Concrete & Ceramic Waste Concrete

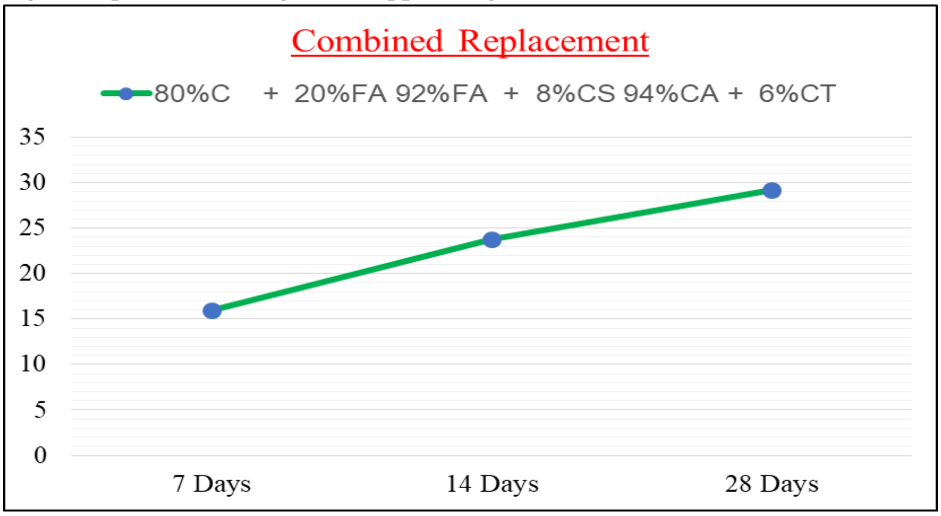


Fig: Compressive Strength of Combined Replacement Concrete

8.2 SPLIT TENSILE STRENGTH TEST

Table - 8.6 Split tensile strength test results

Conventional concrete	**7 Days (Mpa)**	**14 Days (Mpa)**	**28 Days (Mpa)**

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0%	22.7	26.6	29.6

Table - 8.7 Split tensile strength test results

For Fly Ash			
% Replacement	**7 Days (Mpa)**	**14 Days (Mpa)**	**28 Days (Mpa)**
20%	21.8	26.0	30.6
40%	20.8	24.9	29.2

Table - 8.8 Split tensile strength test results

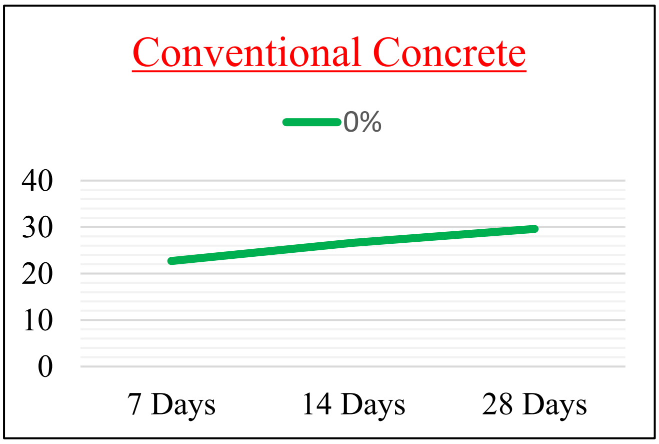
For Copper Slag			
% Replacement	**7 Days (Mpa)**	**14 Days (Mpa)**	**28 Days (Mpa)**
4%	23.2	27.2	30.4
8%	23.8	28.1	31.3
12%	23.5	27.7	30.7

Table - 8.9 Split tensile strength test results

For Ceramic Waste			
% Replacement	**7 Days (Mpa)**	**14 Days (Mpa)**	**28 Days (Mpa)**
2%	23.1	27.2	30.2
6%	23.6	27.9	31.0
10%	23.3	27.4	30.5

Table - 8.10 Split tensile strength test results

For Combined Mix			
% Replacement	**7 Days (Mpa)**	**14 Days (Mpa)**	**28 Days (Mpa)**
20% Fly ash + 80% Cement 8% Copper slag + 92% Fine Aggregate 6% Ceramic waste + 94% Coarse Aggregate	22.4	27.3	31.9



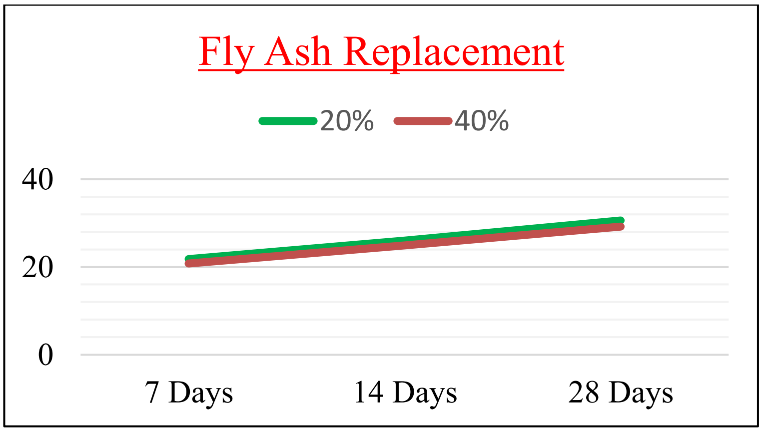


Fig: Split Tensile Strength of Conventional Concrete& Fly Ash Concrete

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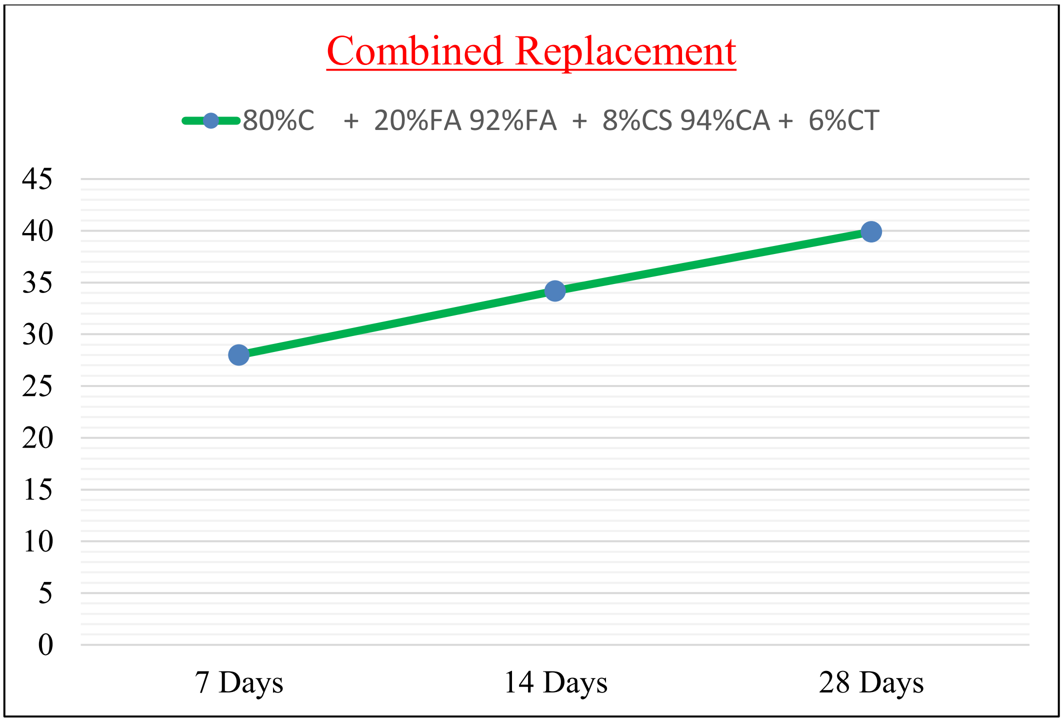

Fig: 5.15 Flexural Strength of Combined Replacement Concrete

10. Conclusion

The proposed research aims to develop a sustainable geopolymer concrete by combining **fly ash, copper slag and waste ceramic tiles**. Fly ash serves as the principal geopolymer precursor, while copper slag and ceramic tile waste reduce the requirement for conventional natural aggregates. Systematic investigation of different replacement levels will help identify an optimum mixture that provides an appropriate balance between workability, strength, durability and environmental sustainability. The successful development of such a material can provide a practical approach for industrial-waste management and contribute to the development of economical, resource-efficient and environmentally sustainable concrete for future construction..

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