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An Experimental Investigation on the Properties of Geopolymer Concrete with Partial Replacement of Marble Powder

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ABSTRACT

This research provides a geopolymer concrete investigation in which fly ash is partially replaced with marble powder. Geopolymer concrete uses waste materials such as fly ash (FA) and an alkaline solution (NaOH&Na2SiO3) to form a strong binder, replacing cement and including marble powder as a partial substitute. This experimental study looks at the tensile properties of geopolymer concrete with different quantities of fly ash replaced by marble powder. The major purpose is to use landfilling waste, such as marble powder, as a binding agent in geopolymer concrete at varying percentages (0, 5%, 10%, 15%, 20%, and 25%) instead of fly ash. The geopolymer mix is designed for a 12M, with an alkaline-to-binder ratio of 0.45. By adding fly ashwith marble powder, the concrete achieves 28-day cube strengths ranging from 40 to 60 MPa utilizing air curing procedures. This formulation allows for rapid strength development, making it appropriate for large structural elements (e.g., precast) without the requirement for extended conventional curing times. Superplasticizers, notably PCE (Poly Carboxylate Ether)-based ones, are used to improve workability. Mechanical property tests were performed, including compressive strength for 100*100*100 mm cubes, split tensile strength for 100*200 mm cylinders, and flexural strength for 500*100*100 mm prisms. When compared to conventional geopolymer concrete, which does not contain partial replacement marble powder, the concrete achieves 28-day cube strengths ranging from 40 to 60 MPa using air curing methods. This formulation allows quick strength growth, making it suited for heavy structural parts.

Keywords: Geopolymer concrete, Fly ash, Marble powder, Mechanical properties, Optimum percentage.

INTRODUCTION

Sustainable development is a crucial topic today due to the deterioration of the human environment and natural resources. Cement manufacture is a large contributor to air pollution, accounting for around 7% of global carbon dioxide emissions. Rapid urban development causes building construction and demolition, resulting in large volumes of waste that are frequently dumped in landfills. To address this issue, researchers are investigating the use of industrial waste materials such fly ash, powdered granulated blast furnace slag, and marble powder as alternatives to ordinary cement in construction. Geopolymer, a cement-free binder, is gaining popularity for its ability to include elements such as fly ash and marble powder. In a recent study, marble powder was studied as a partial replacement for fly ash in geopolymer to determine the impact on strength attributes. Various percentages (0%, 5%, 10%, 15%, 20%, and 25%) of marble powder were examined, and mechanical properties of the resulting geopolymer materials were evaluated. The data were compared to traditional concrete mixes to examine the feasibility and effectiveness of employing marble powder in geopolymer concrete manufacture.

This experimental investigation focuses on the strength behavior of geopolymer concrete when Fly Ash is partially replaced with Marble powder. The primary goal of the study is to determine the optimal proportion of Marble powder in enhancing the strength of Fly ash-based Geopolymer Concrete by partially substituting Fly ash with Marble powder at various percentages such as 0%, 5%, 10%, 15%, 20%, and 25%. The geopolymer is designed for 12M and has an alkaline-to-binder ratio of 0.45 and a sodium silicate-to-sodium hydroxide ratio of 2. The mechanical properties of geopolymer materials including fly ash, marble powder, fine aggregate, coarse aggregate, and alkaline solution were tested. For the compression test, 100mm x 100mm x 100mm cubes were constructed.For the purpose of testing split tensile strength, a 200mm diameter by 100mm length cylinder was used, and 500mm x 100mm x 100 mm prisms were constructed. The results of the flexural strength test were compared with the typical control mix, that is, without partial replacement.

Objectives:

- To find the optimum percentage of Marble Powder in developing the strength in Fly ash based Geopolymer concrete mix.
- To determine the mechanical properties of geopolymer concrete such as Compressive strength for cubes(100mm*100mm*100mm), Split tensile strength for cylinders(200mm*100mm), Flexural strength for prisms (500mm*100mm*100mm) at various replacement levels of Marble Powder dust as partial replacement of Fly ash in geopolymer concrete.
- To compare the mechanical properties of Fly ash based Geopolymer Concrete with partial replacement of Fly ash with Marble Powder to those of control concrete mix of Geopolymer Concrete.

MATERIALS USED

Fly ash

Fly ash, a residue derived from the combustion of pulverized coal in coal-fired thermal power plants, serves as a valuable component in hydraulic-cement concrete, significantly enhancing its properties. When mixed with hydraulic cement during hydration, fly ash contributes to the formation of a binding agent. This study employs class-F fly ash as a supplementary cementitious material, aiming to improve both the initial and long-term characteristics of concrete. Typically, fly ash utilized in concrete applications exhibits a color spectrum spanning from dark grey to yellowish tan.

Coarse aggregate

Well graded coarse aggregate conforming to the provision of IS: 383-2016 is going to use throughout the investigation. The aggregate of nominal size 12mm were blended to a desired proportion and mixed intimately to obtain well graded aggregate.

Table-1: Properties of Coarse aggregate

Specific gravity	2.65
Water absorption	0.73%
Fineness modulus	6.31

Fine aggregate

Locally available river sand conforming to is 383:2016 specifications passing through 4.75 mm sieve and retained on 75µm was used as the fine aggregate in the concrete mix. The fineness modulus, specific gravity were determined and sieve analysis of the fine aggregate and the corresponding grading curve is shown.

Table -2: Properties of Fine aggregate

Specific Gravity	2.58
Fineness modulus	3.15
Grading	Zone-II

Marble Powder

Marble powder entering open areas causes environmental, health and economic losses. Waste marble powders can be used in geopolymers to eliminate these disadvantages and provide sustainable environmental and eco-economic benefits. The Marble Powder is a calcium-rich waste material produced from processing plants sawing and polishing of marble blocks.

Table -3: Chemical composition of Marble Powder

Chemical composition	**Percentages**
Silica (SiO_2)	21.12
Iron Oxide (Fe_2O_3)	3.24
Alumina (Al_2O_3)	5.62
Calcium Oxide (Ca O)	62.94
Magnesium Oxide (MgO)	2.73
Potassium Oxide (K_2O)	0.25
Loss on ignition	38.65
Fineness	Completely passing through 90 Micron sieve

Sodium Hydroxide solution

Generally, the sodium hydroxides (NaOH) are available in solid-state in the forms of pellets or flakes. The price of sodium hydroxide varies a lot depending on how pure of product. The solution of NaOH was prepared by dissolving pellets in water for different molarity. It is recommended that NaOH solution should be made 24 hours before casting and should be used within 36 hours of preparing the solution otherwise it will be converted into a semi-solid state.

Sodium Silicate solution

Sodium metasilicate is also known as sodium silicate and is of industrial grade with SiO2 as 29.4% by mass and Na2O as 14.7%. As per the manufacturer, silicate is used as a bonding agent in detergent industries and textiles industries.

Super plasticizer

AURAMIX 450 is utilized as superplasticizer in this project. It is a polycarboxylate ether (PCE) based high performance super plasticizer. It is used for concrete requiring long workability retention. Appearance is light yellow colored and its pH is of minimum 6.

Water

The locally available potable water, which is free from the concentration of acids, organic substances, is used for mixing solution and concrete which promotes chemical reaction and also helps in the strength attaining of concrete. So bad quality of water affects the strength. It is necessary to follow quality analysis and water purity before being used in the project.

MIX DESIGN

Preparation of Alkaline solution

Alkaline solutions are created by mixing sodium hydroxide solution and sodium silicate at room temperature. When these solutions are combined, they initiate a reaction, known as polymerization, releasing a significant amount of heat. It is advisable to let the mixture sit for approximately 24 hours to allow the alkaline liquid to fully form as a binding agent. In this study, geopolymer concrete is prepared using 12 molarities of sodium hydroxide. The molecular weight of sodium hydroxide is 40. To prepare a 12M solution, 480g of sodium hydroxide flakes are measured and dissolved in distilled water to create a 1-liter solution. This process involves slowly adding sodium hydroxide flakes to distilled water in a 1-liter capacity pycnometer until fully dissolved. Water and Super plasticizer are used only for workability purpose. After many trial mixes by changing water and super plasticizer percentages at finally below mentioned percentages got high workability of 110 mm slump.

Table – 4: Ingredients of Geopolymer concrete

Material	Proportions (Kg/m^3)
Coarse aggregate	924
Fine aggregate	756
Binder	496.55
Sodium Hydroxide	74.48
Sodium Silicate	148.96
Super plasticizer	1% of Binder
Water	10% of Binder
Molarity	12M
Na_2SiO_3: NaOH	2

Mix design

In this design, a 12M solution of sodium hydroxide is utilized for alkaline preparation. The ratio between sodium hydroxide and sodium silicate is set at 2. The aggregate volume is determined as 70% of the total volume of the cube. The ratio of alkaline liquid to fly ash is maintained at 0.45. Fly ash is substituted with different percentages ranging from 0% to 25%, including 5%, 10%, 15%, 20%, and 25%.

Table -5: Various mix proportions of Geopolymer concrete

Mixes	Fly ash (%)	Marble Powder (%)
M0	100	0
M5	95	5
M10	90	10
M15	85	15
M20	80	20
M25	75	25

Mix Procedure

In the lab, the dry mixing of fly ash and aggregates took about three minutes in a pan mixer. Aggregates were prepped in a saturated-surface-dry (SSD) condition. Alkaline liquid was combined with superplasticizer and water. This liquid mix was then added to the dry materials, followed by mixing for an additional four minutes. Workability was assessed via the conventional slump test. Air curing is typically advised for low-calcium fly ash-based geopolymer concrete, with curing time and temperature significantly impacting strength. Specimens were cured at room temperature for 24 to 48 hours, with longer durations enhancing polymerization and strength

Figure 1: Casted Specimens

Figure 2: Failure Specimens

RESULTS AND DISCUSSION

Compressive strength Test

The primary test for strength evaluation is compressive strength, commonly conducted on cube specimens measuring 100mm x 100mm x 100mm. Compaction of each layer is achieved using a tamping rod, followed by leveling the top surface of the mould with a trowel. Specimens are tested after 7 days, 28 days, and 56 days to assess compressive strength across varying curing durations.

Table-6: Compressive strength

Mixes	Compressive Strength (MPa)		
	7 days	28 days	56 days
M0(Std mix)	34.88	39.15	40.80
M5	25.52	44.16	45.74
M10	27.67	52.85	54.43
M15	33.43	59.65	60.75
M20	**33.84**	**60.47**	**62.34**
M25	31.87	53.26	54.20

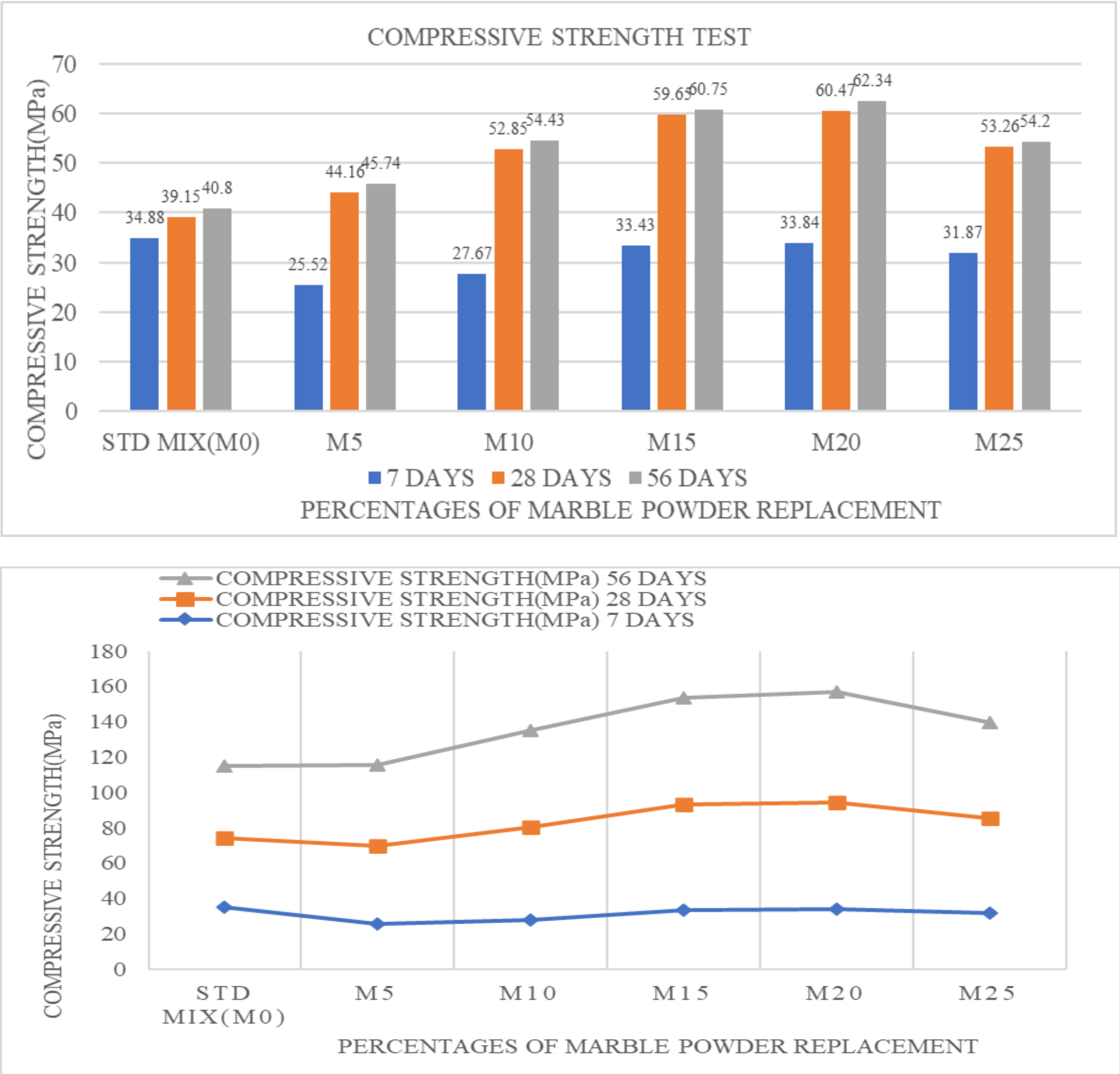

Figure 3: Comparison test of compressive strength on 7, 28 and 56 days with standard mix

Split tensile strength test

This test employs an indirect tension method, involving the placement of a cylindrical specimen horizontally between the compression testing machine's loading surfaces. Load is gradually applied until the cylinder fails along its vertical diameter. Notably, the same compressive testing machine and cylindrical specimen used for compression tests can be utilized. To mitigate high compressive stresses, narrow cracking strips of suitable material are incorporated. The split tensile test is known for its simplicity and ability to produce uniform results.

Table 7: Split Tensile strength

Mixes	Split tensile strength (MPa)
M0(Std mix)	1.71
M5	2.22
M10	2.51
M15	3.05
M20	**3.26**
M25	2.48

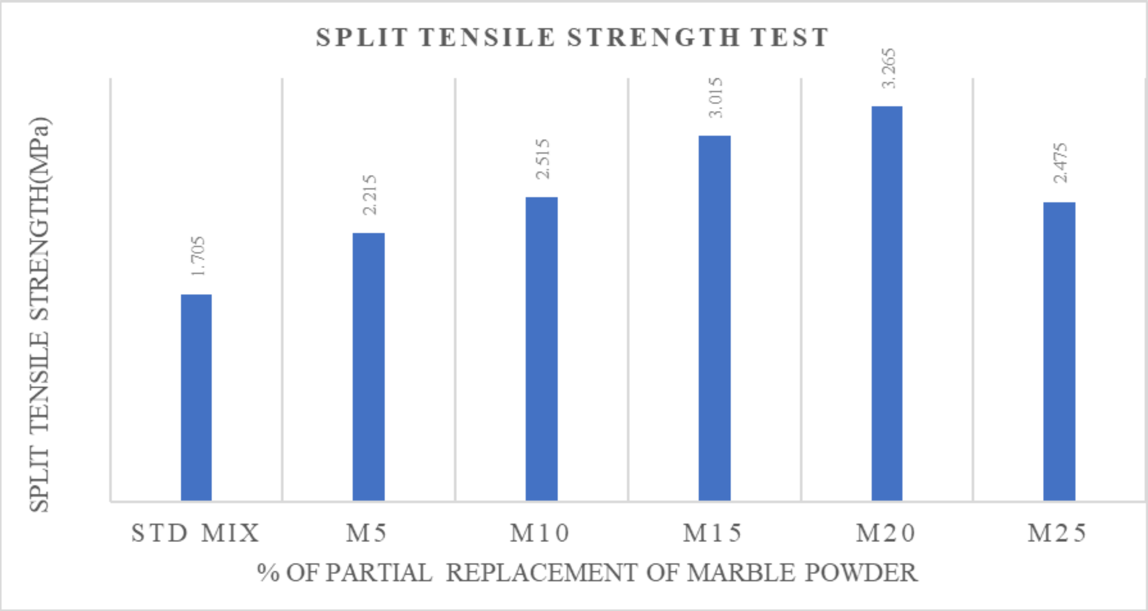

Figure 4: Variation of split tensile strength at 28 days with partial replacement of marble powder

Flexural Strength

The specimen was held on two rollers supports on the testing machine, Until its breakdown, the load was applied hydraulically through two equal rollers placed at the third point of the supporting span. The specimen is of 500 mm length, 100 mm breadth and100 mm height.

Table 8: Flexural strength test

Mixes	Flexural strength (MPa)
M0(Std mix)	4.27
M5	5.46
M10	5.51
M15	5.83
M20	**5.97**
M25	5.94

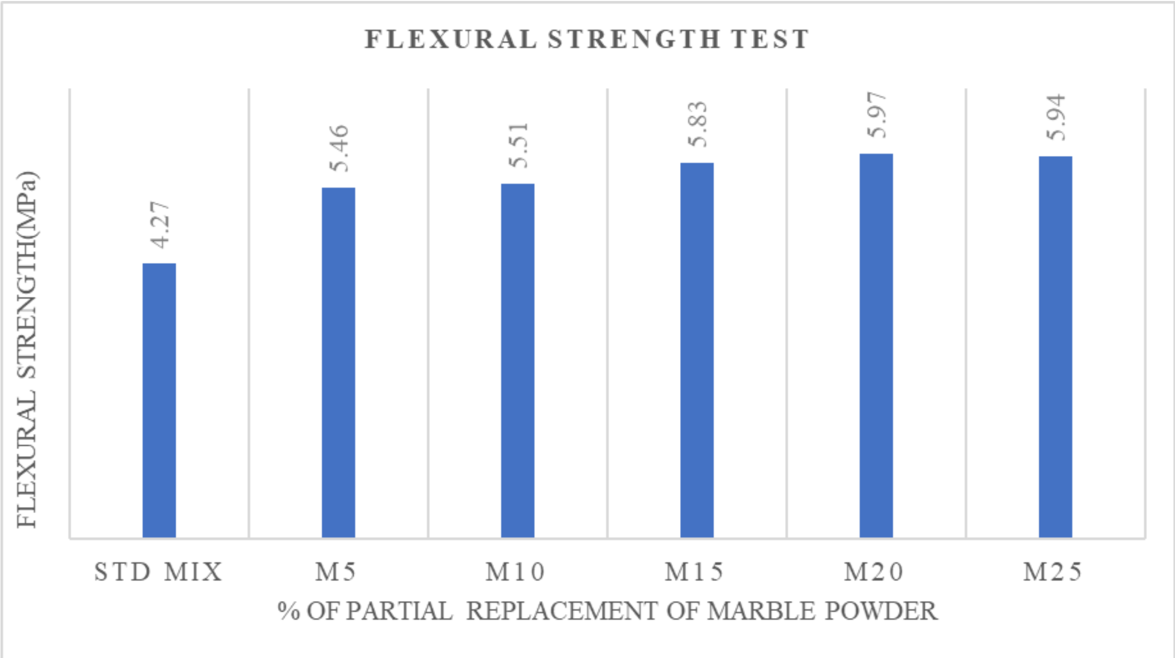

Figure 3: Variation of Flexural strength with partial replacement of Marble powder at 28 days

CONCLUSION

Durable, eco-friendly materials are sought for by the construction sector. GGBS and fly ash provide benefits over regular concrete. Optimizing the use of marble powder is the project's goal. The compressive strength of marble powder substitute peaks at 20% replacement by 28 days, and it is comparable to the regular mix after 7 days. Marble powder can boost the strength of geopolymer concrete by up to 20%. Structure is somewhat impacted by strength when it approaches 20% replacement. Marble powder has a compressive strength of 60.75 MPa at 20% replacement, which is 54% higher than that of normal mix. Marble powder outperforms normal mix, increasing strength by 76% (@M20) at 20% replacement in the split tensile test. At 20% replacement, flexural strength peaks at 5.97 MPa, representing a 40% increase (@M20) above normal mix. Slump value increases with the percentage of marble powder and exceeds that of traditional geopolymer concrete. The ease of geopolymer innovation is especially advantageous for precast applications. Particularly in harsh conditions, geopolymer concrete provides strength and a greater range of applications than regular concrete. Marble powder, an industrial waste that is only used for landfilling, is a very cost-effective addition to geopolymer concrete, and is the primary cause of the compressive strength increase of up to 60 MPa. It also contributes to the geo-polymerization process, which gives strength to the concrete. Instead of using cement, geopolymer concrete employs industrial waste as a binder, which reduces pollution and is also utilized in areas with limited fly ash production. There are therefore numerous benefits to employing these industrial wastes in the geopolymer concrete used for many heavy structural works.

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