# Mechanical and Durability Performance of Primary Blended Geopolymer Concrete Incorporating Quarry Dust: A Sustainable Approach

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***Abstract:*** Rapid industrial growth in developing countries often relies on fossil fuels, leading to increased carbon emissions. The large-scale production of cement contributes significantly to carbon dioxide emissions and creates a substantial carbon footprint. Conventional concrete typically requires lengthy curing times to achieve its full strength and necessitates water during this process. To address these challenges, we propose a complete replacement of traditional concrete with geopolymer concrete. This innovative material considerably reduces the carbon footprint associated with construction. Unlike conventional concrete, which relies on Portland cement—a primary source of CO2 emissions—geopolymer concrete utilizes industrial by-products such as fly ash or slag. The conventional concrete use natural materials as aggregates. The scarcity of this material affects the quality and also the time span of the construction. The extraction of aggregate from quarries and mines presents significant environmental challenges, including habitat destruction, soil erosion, and disruption of local ecosystems. Additionally, the blasting activities associated with quarrying can adversely affect the quality of life in surrounding communities. In light of these concerns, there is a growing interest in exploring sustainable alternatives in construction materials to minimize environmental impact.By repurposing materials that would otherwise be discarded, this approach not only addresses waste management issues but also reduces reliance on natural resources. Geopolymer concrete, which incorporates industrial by-products such as fly ash and blast furnace slag in place of traditional cement, has emerged as an innovative option within the construction sector. This type of concrete has the potential to lower carbon emissions by up to 70% compared to traditional concrete, while also providing a sustainable method for waste disposal.The current project aims to assess the feasibility and effectiveness of using quarry dust in geopolymer concrete by replacing fine aggregate with these materials. A series of mechanical tests, including compressive and split tensile strength assessments, will be conducted to evaluate the concrete's performance across different aggregate blends. Furthermore, the project's scope includes durability assessments through water absorption, freezing and thawing, and carbonation tests to determine the material's resilience to environmental stresses over time. By identifying the optimal blend of recycled aggregate and quarry dust within geopolymer concrete, this research seeks to achieve a balance between mechanical performance and environmental sustainability. The findings have the potential to promote the adoption of eco-friendly practices in the construction industry, contributing to a more sustainable future for generations to come.

***Keywords:*** Geopolymer concrete, Quarry Dust, Sustainability

# 1. Introduction

Conventional concrete, primarily composed of Portland cement and natural aggregates, is well-known for its considerable environmental impact, particularly regarding carbon emissions and resource depletion. The production of Portland cement alone is responsible for approximately 8% of global $CO_2$ emissions, a result of the calcination of limestone and the energy-intensive clinker production process. Moreover, the extraction of natural aggregates leads to habitat destruction, groundwater depletion, and a decline in biodiversity. These sustainability issues are exacerbated by the linear nature of traditional concrete production, which depends on non-renewable resources and generates substantial amounts of construction and demolition waste. In light of these challenges, geopolymer concrete has emerged as a promising sustainable alternative. By utilizing industrial by-products such as fly ash, slag, and metakaolin, geopolymer concrete reacts with alkaline activators to form a resilient aluminosilicate matrix. This method not only diverts significant volumes of industrial waste from landfills but also markedly reduces carbon emissions—potentially by up to 80% compared to conventional concrete. Furthermore, geopolymer concrete demonstrates superior mechanical properties, including enhanced compressive strength, improved chemical resistance, and greater durability under harsh environmental conditions, which ultimately extends the service life of structures and reduces maintenance needs. With its low shrinkage and rapid strength development, it is particularly well-suited for precast and modular construction methods, leading to faster and more efficient building processes. In the context of sustainable development and the global efforts to decarbonize the construction sector, the adoption of geopolymer concrete stands as an essential innovation, aligning material practices with the principles of a circular economy and environmental stewardship.

The extraction of natural aggregates—such as sand, gravel, and crushed stone—carries significant environmental and social repercussions. These include the destruction of habitats, loss of biodiversity, soil erosion, and sedimentation of water bodies, depletion of groundwater, and air and noise pollution resulting from quarrying activities. Over time, such operations degrade the environment, disrupt ecosystems, and negatively impact local communities, leading to heightened regulatory constraints and public opposition. The increasing scarcity of natural aggregates, spurred by rapid urbanization, infrastructure development, and legal restrictions on extraction, further complicates the situation. As local sources of aggregates become depleted, construction projects encounter supply interruptions, longer transportation distances, and elevated material costs. This scarcity not only causes delays in project timelines but also raises overall construction expenses. Furthermore, the shortage of high-quality natural aggregates may compel a dependence on inferior materials, jeopardizing structural integrity, durability, and long-term performance.

To tackle these challenges, there is a growing exploration of sustainable alternatives. Recycled aggregates sourced from demolished concrete and construction waste, manufactured sand (M-sand) created by crushing rocks, and industrial by-products like slag and fly ash present viable substitutes for natural aggregates. These alternatives help alleviate pressure on natural resources while promoting the principles of a circular economy and environmental conservation. Additionally, the integration of advanced technologies such as geopolymer concrete and 3D printing in construction reduces reliance on traditional aggregates and enhances efficiency and quality. In this context, a paradigm shifts towards sustainable materials, efficient resource management, and innovative construction practices is crucial for mitigating the environmental impact of aggregate extraction and ensuring the timely and high-quality delivery of construction projects.

# 2. Experimental Programme

## *2.1 Materials*

This study employs a combination of Class F fly ash and Ground Granulated Blast Furnace Slag (GGBFS) as binder materials. The specific gravity and fineness of the fly ash are 2.13 g/cc and 360m²/kg, respectively. In comparison, the specific gravity and fineness of GGBFS are 2.88 g/cc and 365m²/kg. An alkali activator solution is prepared using a liquid mixture of sodium silicate and sodium carbonate. M-sand is utilized as the fine aggregate, while a mixture of 6 mm and 12 mm crushed stone serves as the coarse aggregate. The material properties of the coarse, fine aggregates and quarry dust are presented in Table 1. Figures 1, illustrate the particle size distribution curves.

**Table 1. Properties of Coarse and Fine Aggregate**

| Sr. No: | Property | Values | | | |
|---|---|---|---|---|---|
| | | Coarse Aggregate | | M-Sand | Quarry Dust |
| | | 6mm | 12mm | | |
| 1 | Bulk density | 1.63g/cc | 1.71g/cc | 1.59g/cc | 1.66g/cc |
| 2 | Porosity | 43.0% | 42.6% | 33.0% | 32.3% |
| 3 | Void ratio | 0.77 | 0.75 | 0.48 | 0.50 |
| 4 | Specific gravity | 2.89 | 2.98 | 2.48 | 2.45 |
| 5 | Fineness modulus | 4.89 | 4.89 | 2.84 | 2.84 |

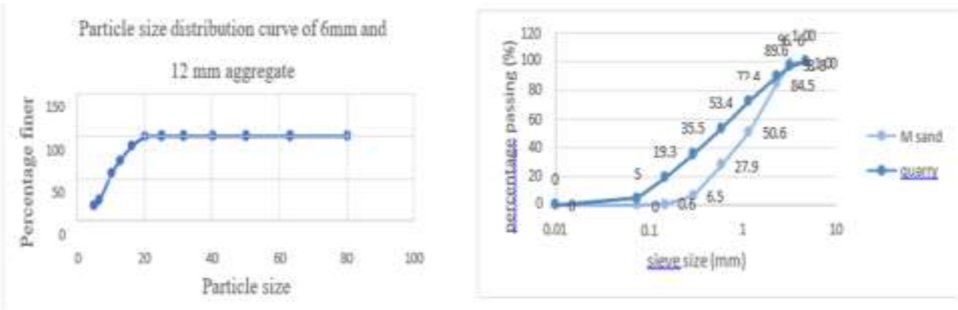


**Figure 1. Particle Size Distribution curve of Coarse and Fine Aggregate**

### *2.2 Mix Design and preparation of Specimens.*

According to IS 10262–2009, mix designs were made for 0%, 10%, 20%and 30% M sand replacement by Quarry dust on Geopolymer concrete. For the mix design, M40 concrete was adopted, with a mix ratio of 1:1.21:2.05. The binder to alkali ratio is 1:0.40 and the alkali activator ratio 1:1.5. Table 5.8 below illustrates the mix proportions of geopolymer concrete mixtures.

**Table 2. Quantity of constituent materials of GPC**

| Materials(kg/m$^3$) | GPC | GPC10 | GPC20 | GPC30 |
|---|---|---|---|---|
| Flyash | 384.88 | 384.88 | 384.88 | 384.88 |
| GGBS | 162.96 | 162.96 | 162.96 | 162.96 |
| NaOH | 88 | 88 | 88 | 88 |
| $Na_2SiO_3$ | 132 | 132 | 132 | 132 |
| Fine aggregate | 663.70 | 597.33 | 530.96 | 464.59 |
| Quarry Dust | 0 | 66.37 | 132.74 | 199.11 |
| Coarse aggregate | 1122 | 1122 | 1122 | 1122 |
| Water | 149 | 149 | 149 | 149 |

### *2.3 Mixing and Casting*

All constituent materials are measured and combined in accordance with the specified mix ratio. The coarse aggregates, comprising sizes of 12 mm and 6 mm, along with M sand, fly ash, and GGBFS, are thoroughly dry mixed. Once the dry mix is complete, a solution is prepared by combining the appropriate quantities of sodium hydroxide pellets and sodium silicate solution, which is then poured into the dry mix. All materials are subsequently mixed by hand or using a pan mixer, with water added in minimal amounts. This procedure describes the control mix, where no fine aggregate replacement with quarry dust occurs. The process includes the casting of cubes, cylinders, and beams. For the mix involving replacement, a calculated quantity of fine aggregate is substituted with quarry dust. After casting, all specimens undergo ambient curing for a duration of 7 days.

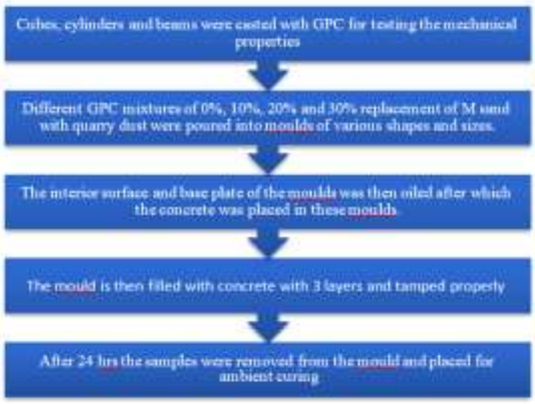


**Figure 2. Methodology**


**Figure 3. Mixing and Casting of Specimen**

### *2.4 Hardened and Durability Test*

To determine the hardened and durability properties the compressive strength, split tensile strength, flexural strength, modulus of elasticity and acid attack test were done in standard specimen according to the standard procedure. For acid resistance test the cube specimens were prepared with partial replacement of quarry dust. Specimens were ambient cured for 7 days and after 7days specimens were placed in sulphuric acids and hydrochloric acid. Acid solution was prepared with 3% concentration. The cube specimens were weighed before immersion in acid solutions. For 28 days, the solution was tested at regular intervals to ensure a constant concentration. The cube specimens were taken out after 60 days from solution and kept a side for 24 hrs. Noted down the specimen's weight and strength and calculated Percentage loss in weight and strength. Results compared to normal GPC and GPC with quarry dust showing less percentage of weight loss with quarry dust content.

## 3. Results and Discussions

### *3.1 Compressive Strength*

Atotalof12cubeswerecastedandtestedwith0%,10%,20%and30%withMsand replacement with quarry dust having a mould size of 150 mm x 150 mm x150 mm. The Fig 3 shows the graph showing compressive strength of different percentages of M sand with quarry dust.

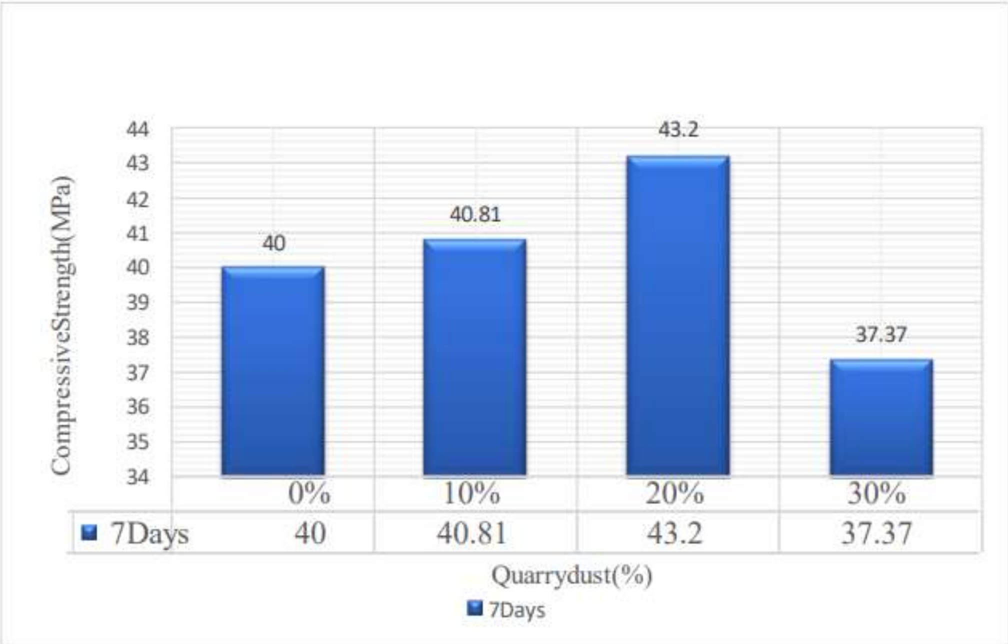


**Figure 4. Compressive strength with different percentages**

### *3.2 Split Tensile Strength*

Atotalof12cylinderswerecasted and tested with 0%, 10%, 20% and 30%withthe replacement of M sand with quarry dust having a mould size of 150 mm diameter and300mmheight.TheFig4 shows the graph showing split tensile strength of different percentages of M sand with quarry dust.

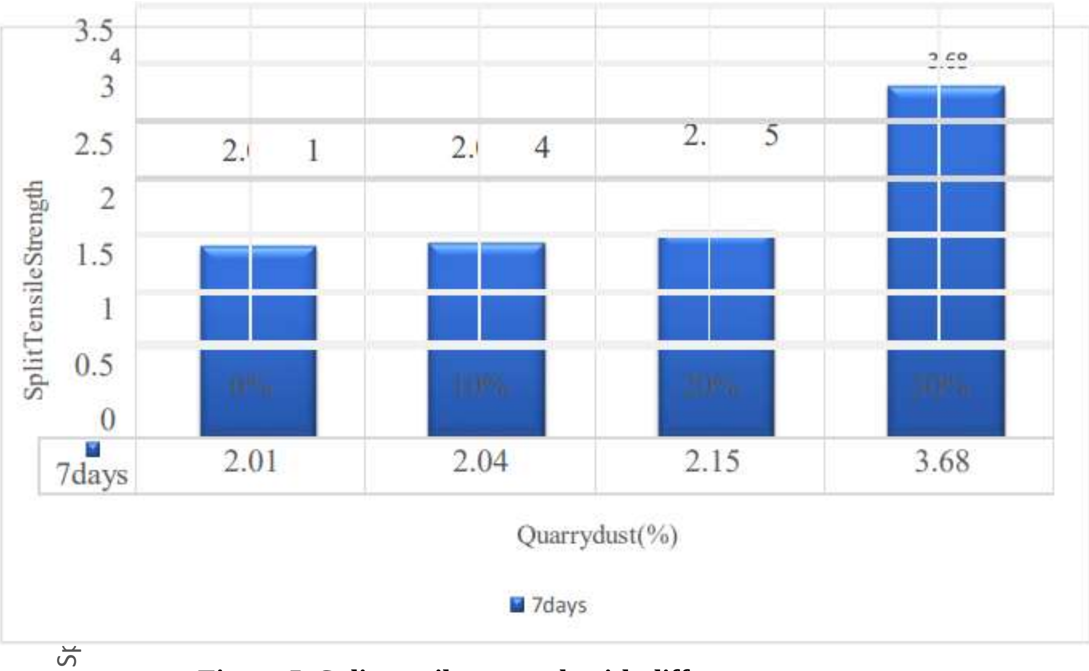


**Figure 5. Split tensile strength with different percentages**

### *3.3 Flexural Strength*

A total of 12 beams were casted and tested with 0%, 10%, 20% and 30% with the replacement of M-sand with quarry dust having a mould size of 50 mm x 100mm x 100mmheight.The fig 5 shows. The graph showing flexural strength of different percentages of M sand with quarry dust.

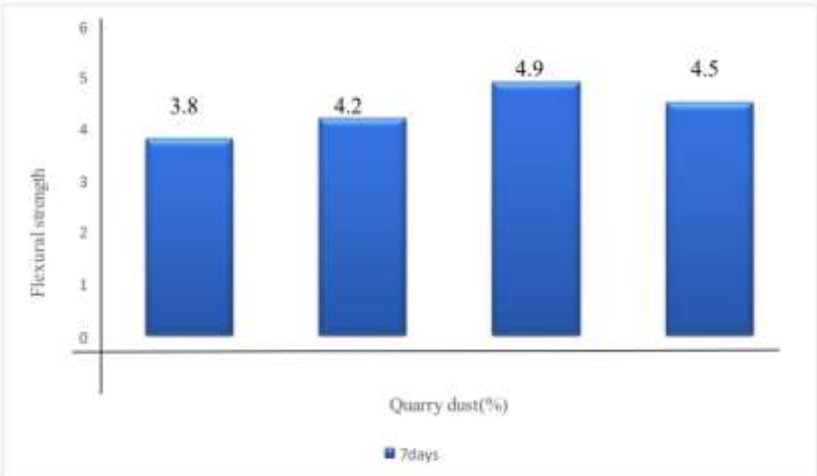


**Figure 6. Flexural strength of different percentages**

### *3.4 Modulus of elasticity*

Atotalof12cylinderswerecasted and tested with 0%, 10%, 20% and 30%with the replacement of M sand with quarry dust having a mould size of 150 mm diameter and 300 mm height. After curing specimens were placed for testing by marking 75 mm from both sides and lateral extensometer were placed on the specimen and subjected to loading. Table 3shows the modulus of elasticity of various percentages.

**Table 4. Modulus of elasticity of various percentages**

| Replacement level(%) | Modulus of elasticity(N/mm2) |
|---|---|
| 0 | 3.15 |
| 10 | 3.14 |
| 20 | 3.16 |
| 30 | 3.153 |

### *3.5 Chloride Resistance Test*

The test was performed to study the chloride resistance property of geopolymer concretebyexposingtheconcretespecimenstohydrochloricacid.Hydrochloricacid diluted with water by 3 % of water volume. Specimens were immersed in solution for 60 days. After the period of exposure compressive strength was calculated. Compressive strength loss was compared with before acid dipping and after dipping. The colour change is also observed for the cubes before and after dipping are shown in thefig6.The table4 below shows there results after and before the chloride.

**Figure 7. Cubes Before and After Dipping in Diluted HCl**

**Table 4. Results after chloride resistance test**

| Replacement level (%) | Weight of specimen | | | Compressive Strength of specimen | | |
|---|---|---|---|---|---|---|
| | weight before dipping | Weight after dipping | Percentage loss in weight (%) | Strength before dipping | Strength after dipping | Percentage loss in strength |
| 0 | 8.15 | 7.78 | 4.53 | 40.00 | 36.25 | 9.82 |
| 10 | 8.20 | 7.89 | 3.78 | 40.81 | 37.05 | 9.21 |
| 20 | 8.00 | 8.02 | 0.24 | 43.20 | 39.57 | 8.40 |
| 30 | 8.09 | 7.85 | 2.96 | 37.37 | 33.60 | 10.08 |

### *3.6 Sulphate Resistance Test*

Sulphates are present in groundwater, soil or industrial waste water and it will enter into the concrete structure through the pores present in the concrete and affect the properties of the concrete structure. This test is conducted to determine effect of sulphate on concrete. Sulphuric acid was diluted with water by 3 % of water volume. Specimens were immersed in solution for 60 days. After the period of exposure compressive strength was calculated. Compressive strength loss was compared with before acid dipping and after dipping. The colour change is also observed for the cubes before and after dipping are shown in the figure7.Thetable5 below shows the results after and before the chloride resistance test.


**Figure 8. Cubes before and after dipping in diluted H2SO4**

**Table 5 Results after sulfate resistance test**

| Replacement level(%) | Weight of specimen | | | Compressive Strength of specimen | | |
|---|---|---|---|---|---|---|
| | weight before dipping | Weight after dipping | Percentage loss in Weight | Strength before dipping | Strength after dipping | Percentage loss in strength |
| 0 | 8.15 | 7.89 | 3.19 | 40.00 | 35.65 | 10.85 |
| 10 | 7.89 | 7.70 | 2.40 | 40.81 | 36.36 | 10.90 |
| 20 | 8.00 | 7.98 | 0.25 | 43.20 | 39.79 | 7.89 |
| 30 | 8.09 | 7.82 | 3.33 | 37.37 | 32.93 | 11.88 |

## 4. Conclusions

- The trend of compressive strength increases with the increase in quarry dust content till 20% replacement. A rise in 2.02% compressive strength was obtained from 0 to 10% replacement of M sand with quarry dust and from 10 to 20% replacement increase in compressive strength was 5.82%.A reduction of 13.49% was observed from 20% to 30% replacement.
- Split tensile strength increases from 0, 10, 20 and 30 % and maximum split tensile strength is obtained in 30%.Flexural strength increases from 0, 10 and 20% and decreases to 30%.
- Cubes after exposed to HCl, the percentage loss of weight for 0, 10,20 and 30% were 4.53,3.78,0.24 and 2.96 respectively and loss of compressive strength were 9.82,9.21,8.40 and 10.08 percent respectively. Compressive strength was higher at 20% replacement and percent weight loss also less in 20%.
- Cubes after subjected to sulfate attack the percentage loss in weight are 3.19, 2.40, 0.25 and

3.33 for 0, 10, 20 and 30% respectively.
- Percentage loss in compressive strength for 0, 10,20 and 30% were 10.85,10.90,7.89,11.88 respectively.
- Concrete has more acid resistance against sulfate attack than chloride attack. Colour change and precipitates were observed after the exposure period of 60 days.
- In conclusion the optimum dosage of quarry dust is at 20% replacement of M sand.

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