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# Performance Study of Plain Cement Concrete Containing Quartz Powder and Eggshell Powder as Partial Replacement of Cement

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**Abstract:** Concrete remains a mainstay among construction materials despite ongoing improvements to enhance its environmental friendliness and effectiveness. This study explores the effects of adding quartz and eggshell powder to concrete. The experimental investigation measures concrete samples' compressive strength, split tensile strength, and flexural strength at 7, 28, and 90 days. Concrete mixes with varying percentages of quartz powder and eggshell powder and their combinations were prepared and tested. The findings show that using quartz and eggshell powder improves the strength characteristics of concrete, with several mixtures performing better than conventional concrete. The examination of experimental data highlights the potential of these supplementary materials to enhance the sustainability and durability of concrete structures. It provides valuable insights into the mechanisms contributing to the strength improvement. These results advance the field of construction materials by contributing to ongoing efforts to create high-performance, environmentally friendly concrete compositions.

**Keywords:** Concrete, Eggshell Powder, Quartz Powder, Sand.

## 1 INTRODUCTION

Concrete is a key material in contemporary construction, known for its adaptability, durability, and economic viability. However, its reliance on ordinary Portland cement (OPC) presents certain challenges, especially concerning environmental impact. One way to address these concerns is by incorporating alternative materials, such as quartz powder and eggshell powder, into concrete mixtures. Quartz powder is a finely ground form of quartz, a crystalline mineral composed primarily of silicon dioxide ($SiO_2$). Quartz is one of the most abundant minerals on Earth and is valued for its diverse industrial applications due to its unique physical and chemical properties. Its use as an additive in concrete is grounded in its long-standing geological and industrial significance. On the other hand, Eggshell powder is a finely crushed product made from eggshells, typically sourced from chicken eggs. It is a natural and sustainable material recognized for its potential applications in various industries, including construction. Fig. 1 and Fig. 2 illustrate the appearance of quartz powder and eggshell powder, respectively.

Fig. 1 Quartz Powder

Fig. 2 Eggshell Powder

Incorporating alternative materials like quartz and eggshell powder into concrete mixes offers significant environmental and performance-related benefits. The production of ordinary Portland cement is energy-intensive and contributes substantially to global $CO_2$ emissions. The overall carbon footprint of concrete production can be reduced by partially replacing cement with supplementary materials such as quartz and eggshell powder. Quartz powder, with its high silica content, can enhance the mechanical properties of concrete, such as compressive strength and durability, due to its pozzolanic activity. Similarly, eggshell powder, primarily composed of calcium carbonate ($CaCO_3$), can act as a filler material, improving the workability of the mix and potentially contributing to the hydration process. These materials help mitigate the environmental impact of cement production and promote the recycling of industrial and agricultural waste products.

## 2 LITERATURE SURVEY

Concrete is widely used in construction due to its strength and durability. Researchers have extensively investigated using alternative materials as partial replacements for cement to address sustainability concerns and reduce environmental impact. This approach minimizes concrete's ecological footprint while improving its overall properties. Mehta and Monteiro emphasized the need to explore substitute materials, highlighting the potential for more sustainable development and reduced dependence on traditional cement production, significantly contributing to carbon emissions [1]. Their research identified quartz powder, a byproduct of the mining industry, as a potential substitute for ordinary Portland cement. A study by Lee et al. provided compelling evidence for the effectiveness of quartz powder as a cement replacement. According to their findings, the addition of quartz powder significantly improved the strength and durability of concrete [2]. The fine quartz particles act as nucleation sites during hydration, resulting in a more densely packed microstructure. This enhanced microstructure improves mechanical properties, such as compressive strength and durability. By utilizing a waste product from the mining industry, quartz powder not only enhances concrete performance but also addresses environmental concerns.

Eggshell powder, derived from food waste, has also gained attention as a sustainable cementitious material for environmentally friendly construction. Studies showed that incorporating eggshell powder into concrete mixtures increased compressive strength, a key factor in maximizing the material's performance. The calcium carbonate in eggshells reacts with cementitious materials, enhancing the concrete's overall strength. Beyond its technical benefits, recycling eggshells reduces waste and promotes resource-efficient construction practices. This aligns with the broader objective of fostering sustainable practices in the construction industry. Additional studies, such as Niyasom and Tangboriboon [3], and Yong et al. [4], have explored using eggshell powder and other biomaterials in green concrete construction, further demonstrating its environmental and structural benefits. Similarly, Chen et al. investigated the mechanical properties of cement pastes with various proportions of modified quartz tailings (MQT) replacing cement [5]. They produced MQT by heating a mixture of quartz tailings and 50% carbide slag (CS) at 1050°C for two hours. The study found that incorporating MQT improved the cement paste's mechanical performance.

Rashad and Ouda explored the effects of adding quartz powder (QP) to alkali-activated fly ash (AAFA) and found that it improved workability and reduced water demand during mixing [6]. Kmali and Ghahremaninezhad analyzed the effects of different percentages of pozzolanic admixtures as cement substitutes, showing potential for improving the properties of concrete with common waste materials [7]. Even in alkali-activated slag (AAS) mixtures without additional admixtures, Rashad discovered that the workability was significantly enhanced using the appropriate slag-to-quartz powder ratio [8]. His findings indicated that mixtures containing up to 30% QP had approximately 3.5 times greater workability than those without QP. Many methods are proposed to use different materials as partial replacement to cement and indeed the resulting material has better quality [9]-[12].

## 3 MATERIALS AND EXPERIMENTATION

### 3.1 Cement

Cement forms the backbone of concrete, acting as the primary binding agent that imparts strength and cohesion to the mixture. The properties of the cement used in this study are provided in Table 1, while Fig. 3 illustrates the cement.

Fig. 3 Cement

Table 1. Properties of the Cement

| S. No | Particulars | Value |
|---|---|---|
| 1 | Specific Gravity | 3.10 |
| 2 | Initial setting time | 36 minutes |
| 3 | Final setting time | 320 minutes |
| 4 | Fineness (%) | 94 |

### 3.2 Fine Aggregate

Fine aggregate plays a critical role in concrete by filling the voids within the coarse aggregate, thereby contributing to the compactness and strength of the concrete matrix. Fig. 4 shows the fine aggregate, and its properties are listed in Table 2. These parameters are essential for selecting and utilizing fine aggregate in concrete mix designs.

Fig. 4 Fine Aggregate

Table 2. Properties of the Fine Aggregate

| S. No. | Particulars | Value |
|---|---|---|
| 1 | Type | Normal sand |
| 2 | Specific gravity | 2.68 |
| 3 | Grading size | 4.75mm – 0.075mm |
| 4 | Water absorption | 0.60% |
| 5 | Fineness modulus | 2.7 |
| 6 | Bulk density in Loose state<br>Compacted state | 1378.82 kg/m$^3$<br>1544.67 kg/m$^3$ |

### 3.3 Coarse Aggregate

Coarse aggregate, characterized by its larger particle size, is essential for providing bulk and stability to concrete mixes. This study uses crushed granite aggregate with a particle size of 20mm. Fig. 5 illustrates the coarse aggregate; its properties are listed in Table 3.

Fig. 5 Coarse Aggregate

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Table 3. Properties of the Coarse Aggregate

| S. No. | Particulars | Results |
|---|---|---|
| 1 | Type | Crushed stone |
| 2 | Specific gravity | 2.66 |
| 3 | Maximum size | 20 mm |
| 4 | Water absorption | 0.5% |
| 5 | Fineness modulus | 3.9 |
| 6 | Bulk density | 1688 kg/m$^3$ |

### 3.4 Mix Proportions

In this study, M40 grade concrete is used with a constant water-to-cement (W/C) ratio of 0.5. Concrete mixes are prepared by varying the percentage of cement replacement with eggshell powder (10%, 20%, and 30%) and quartz powder (10%, 20%, and 30%) and their combinations. The mix proportions are detailed in Table 4.

Table 4. Mix Proportions

| Material | Unit of Quantity | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|---|
| **Cement** | Kg | 325.34 | 292.806 | 276.539 | 292.806 | 276.539 | 260.272 | 227.738 |
| **Water** | Liters | 162.67 | 162.67 | 162.67 | 162.67 | 162.67 | 162.67 | 162.67 |
| **Core aggregate (Sand)** | Kg | 1263.55 | 1263.55 | 1263.55 | 1263.55 | 1263.55 | 1263.55 | 1263.55 |
| **Fine aggregate (crushed Granite)** | Kg | 690.25 | 690.25 | 690.25 | 690.25 | 690.25 | 690.25 | 690.25 |
| **Eggshell Powder** | Kg | 0 | 32.534 | 48.801 | 0 | 0 | 32.534 | 48.801 |
| **Quartz Powder** | Kg | 0 | 0 | 0 | 32.534 | 48.801 | 32.534 | 48.801 |

### 3.5 Casting of Specimens

A total of 384 specimens were cast, consisting of 240 cubes, 96 RCPT (Rapid Chloride Permeability Test) specimens, and 48 specimens for water permeability testing. Fig. 6 shows the casting process of the specimens.

Fig. 6 Casting of Specimens

## 4 EXPERIMENTAL INVESTIGATION

Achieving concrete's desired strength and durability while optimizing material usage and cost requires a well-constructed mix design. For M40 grade concrete, mix proportions are determined, incorporating variations of eggshell powder (10%, 20%, 30%) and quartz powder (10%, 20%, 30%) as partial replacements for cement, both individually and in combination.

Fig. 7 Compressive strength

One crucial characteristic of concrete that significantly influences the development and propagation of cracks is its tensile strength.

Fig. 8 Before and after testing

Flexural strength also referred to as the modulus of rupture or bending strength, defines a material's capacity to withstand bending stresses before yielding. This property is evaluated through flexure tests.

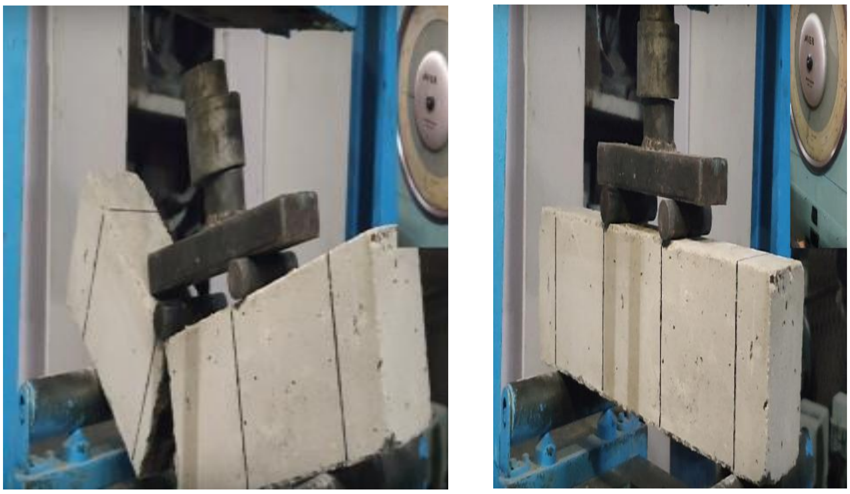

Fig. 9 Testing the specimen before and after failure.

Table 5. Slump Test Results

| | Slump (mm) |
|---|---|
| S1 | 99 |
| S2 | 98 |
| S3 | 95 |
| S4 | 98 |
| S5 | 96 |
| S6 | 94 |
| S7 | 92 |

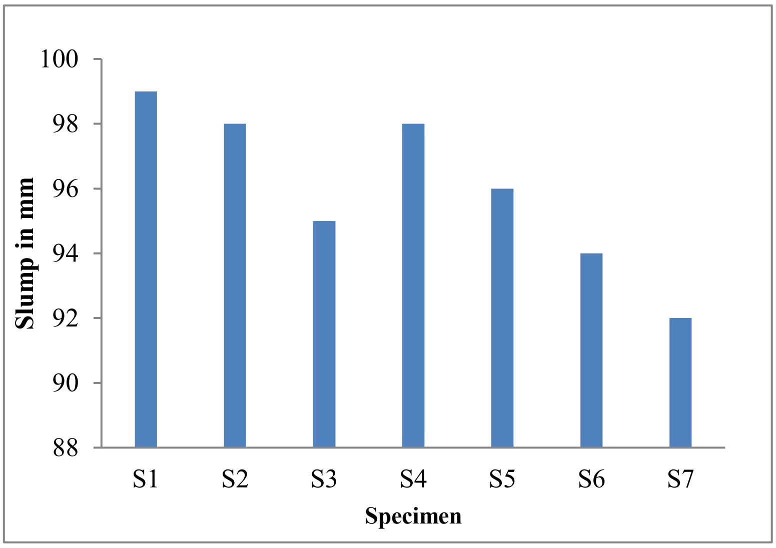


Fig. 10 Slump test results

Table 6 lists the compressive strength results at 7, 28, and 90 days. It is observed that increasing the amount of quartz and eggshell powder improves compressive strength. The combination of quartz and eggshell powder performs well, with sample S7 exhibiting the highest compressive strength.

Table 6. Compressive Strength Results

| | 7 days N/mm$^2$ | 28 days/ N/mm$^2$ | 90 days/ N/mm$^2$ |
|---|---|---|---|
| **S1** | 11.57 | 19 | 32.6 |
| **S2** | 14.3 | 24.3 | 36.4 |
| **S3** | 16.1 | 26.1 | 38.7 |
| **S4** | 13.9 | 23.9 | 35.8 |
| **S5** | 15.4 | 25.4 | 36.2 |
| **S6** | 16.1 | 26.1 | 38.8 |
| **S7** | 16.8 | 26.8 | 40.1 |

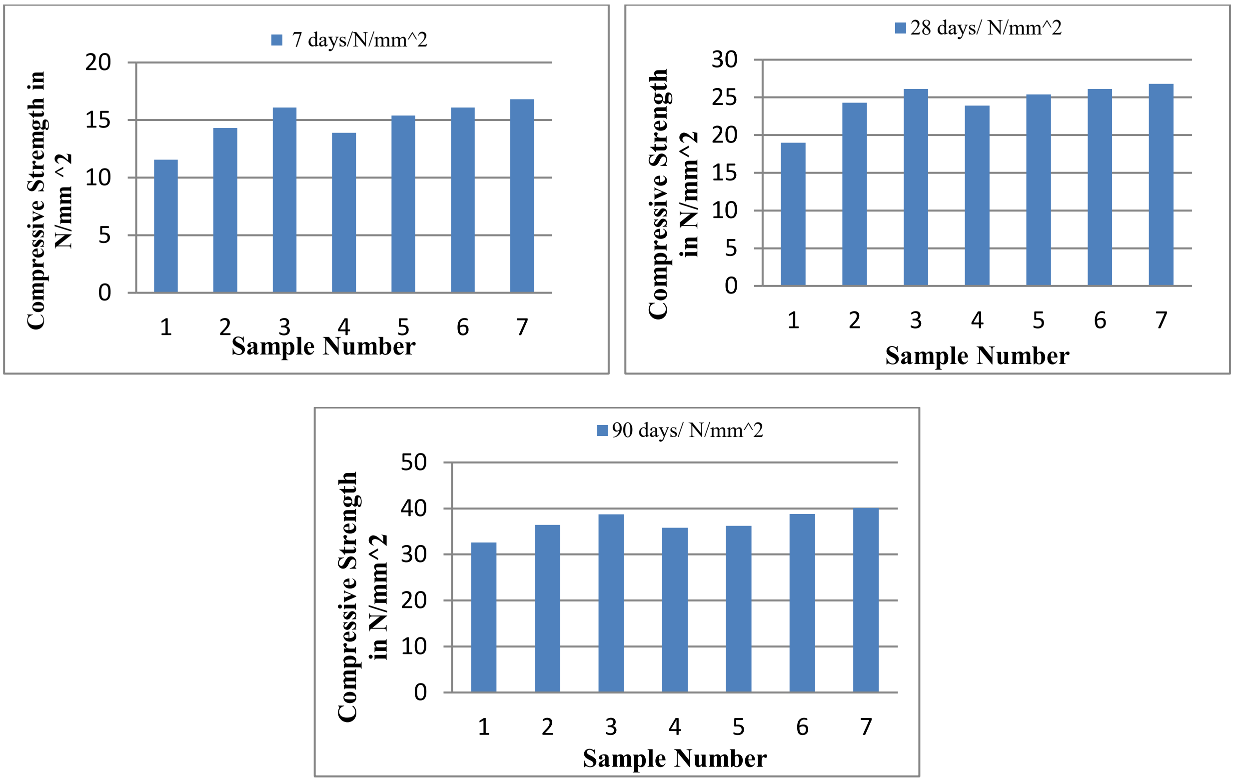


Fig. 11 Compressive Strength Results for 7/28/90 Days

Table 7 summarizes split tensile strength results for different curing periods. Tensile strength increases with higher percentages of eggshell and quartz powder, with sample S7 showing the maximum tensile strength.

Table 7. Split Tensile Strength

| | 7 days $N/mm^2$ | 28 days $N/mm^2$ | 90 days $N/mm^2$ |
|---|---|---|---|
| **S1** | 2.5 | 4.53 | 5.1 |
| **S2** | 2.8 | 4.63 | 5.4 |
| **S3** | 2.9 | 5.1 | 5.6 |
| **S4** | 2.6 | 4.58 | 5.2 |
| **S5** | 2.89 | 4.93 | 5.47 |
| **S6** | 3.1 | 5.2 | 5.61 |
| **S7** | 3.57 | 5.4 | 5.8 |

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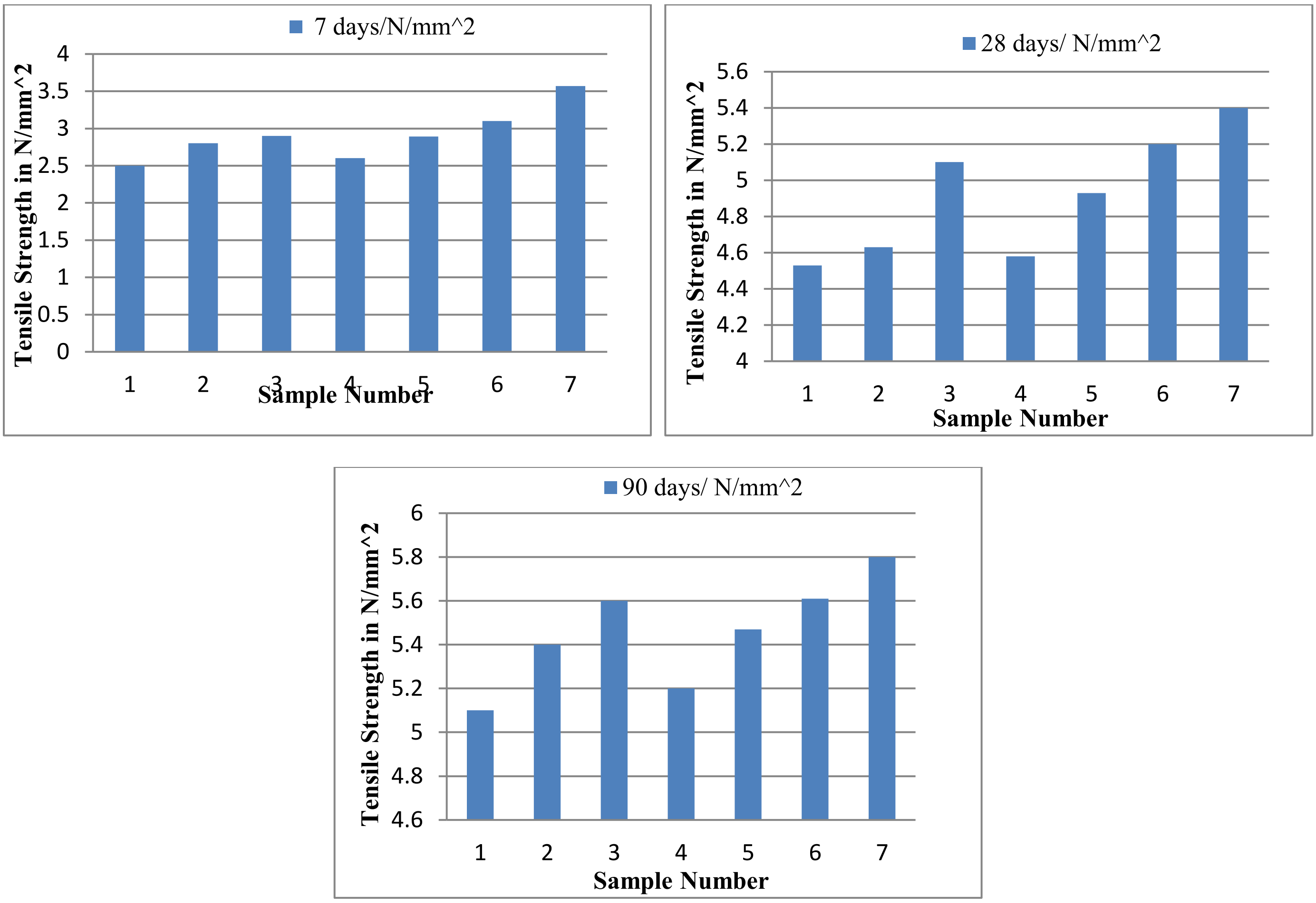


Fig. 12 Tensile strength results for 7/30/90 Days.

Table 8 shows the results of the flexural strength tests. Sample S7 again demonstrates the highest flexural strength among all tested samples.

Table 8. Flexural strength results

| | 7 days N/mm$^2$ | 28 days N/mm$^2$ | 90 days N/mm$^2$ |
|---|---|---|---|
| **S1** | 2.6 | 4.3 | 5.2 |
| **S2** | 2.8 | 4.5 | 5.4 |
| **S3** | 2.9 | 4.7 | 5.6 |
| **S4** | 2.7 | 4.4 | 5.3 |
| **S5** | 2.89 | 4.67 | 5.5 |
| **S6** | 3.17 | 4.89 | 5.78 |
| **S7** | 3.52 | 5.12 | 5.97 |

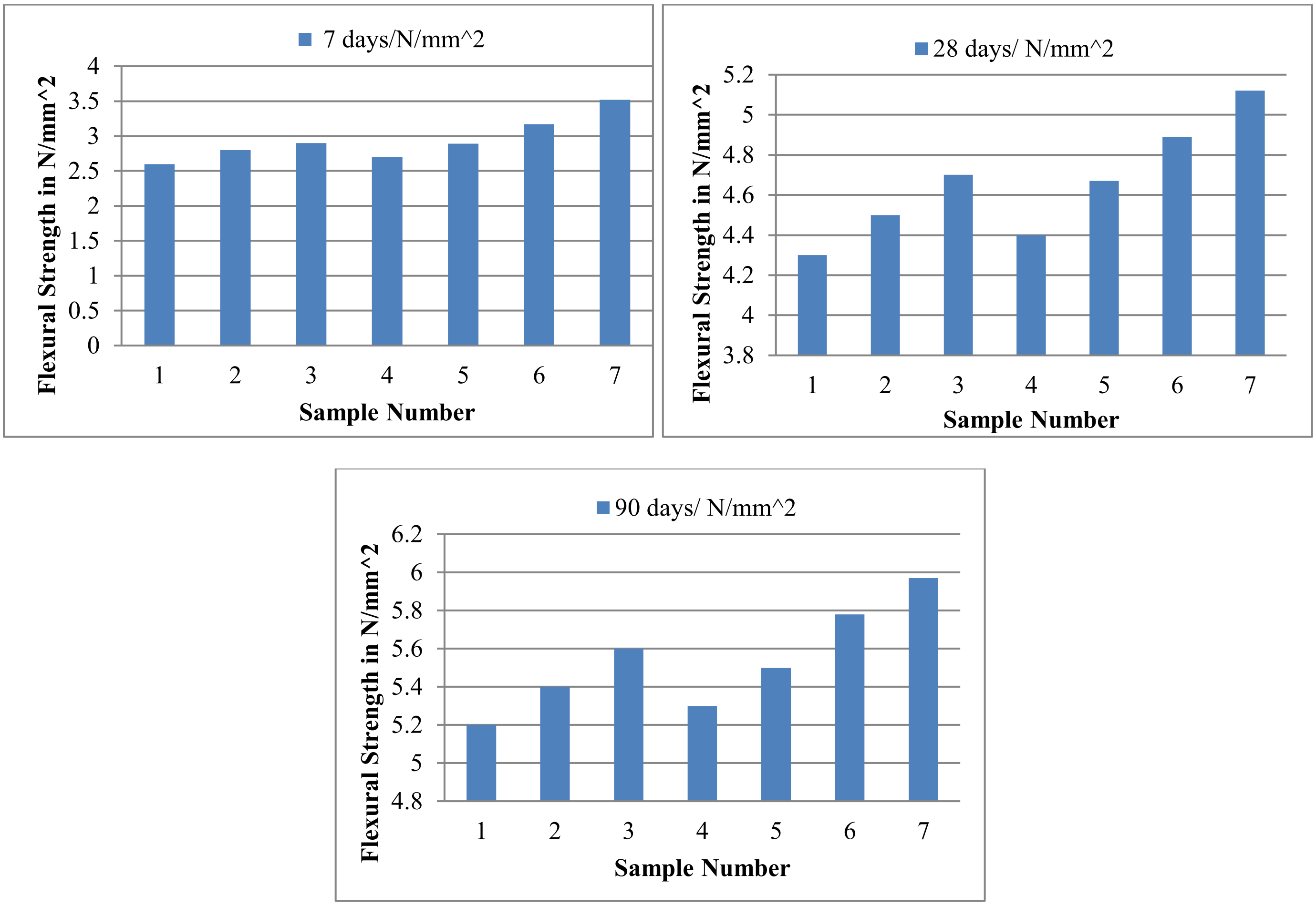


Fig. 13 Flexural strength for 7/30/90 days

## 5 OBSERVATIONS AND DISCUSSIONS

The experimental results reveal that both quartz powder and eggshell powder positively affect the mechanical properties of concrete, with particular improvements in compressive, tensile, and flexural strengths. The inclusion of eggshell powder, primarily due to its calcium carbonate content, appears to contribute to the strength increase through pozzolanic reactions that enhance cement hydration. This effect aligns with previous studies, which demonstrated improvements in compressive strength when using eggshell powder.

Similarly, the fine quartz particles are nucleation sites during cement hydration, leading to a denser microstructure. This finding is consistent with Lee et al. [2], who emphasized the role of quartz in improving concrete's durability and compressive strength. The enhanced performance of specimen S7 (which contains both quartz and eggshell powder) suggests a potential synergistic effect, where combining these additives leads to greater improvements in concrete strength than when used individually.

However, this study has some limitations. First, while the study focused on mechanical strength properties, other aspects, such as the long-term durability, permeability, and thermal properties of these modified concrete mixes, remain unexplored. Additionally, while the additives improved mechanical properties, their impact on workability was not extensively measured. Rashad [8] noted that higher quartz powder content can significantly enhance workability, but this was not systematically evaluated in this research.

Moreover, while both quartz powder and eggshell powder are waste products, their sourcing and processing could affect the environmental benefits of using them. Future studies could assess the life-cycle impacts of incorporating these materials into concrete, particularly regarding carbon footprint reduction and cost-effectiveness.

Lastly, while the study suggests an optimal mix ratio for strength, further research is needed to explore how these additives perform under different environmental conditions, such as varying humidity levels, freeze-thaw cycles, and chemical exposures, to ensure their suitability for diverse applications in construction.

This study presents a thorough investigation of concrete strength characteristics—including compressive strength, split tensile strength, and flexural strength—at different curing intervals (7, 28, and 90 days), providing valuable insights into the effects of his study presents a thorough investigation of concrete strength characteristics—including compressive strength, split tensile strength, and flexural strength—at different curing intervals (7, 28, and 90 days).

## 6 CONCLUSIONS

This study presents a thorough investigation of concrete strength characteristics—including compressive strength, split tensile strength, and flexural strength—at different curing intervals (7, 28, and 90 days), providing valuable insights into the effects of incorporating eggshell powder and quartz powder as partial replacements for cement. The results demonstrate that these additives enhance the mechanical properties of concrete, particularly in terms of compressive strength.

The standout performance of specimen S7, which includes a 15% combination of quartz and eggshell powder, suggests a synergistic effect between these materials. This emphasizes the importance of optimizing additive ratios to achieve superior results. Specimen S7 consistently outperforms other mixtures across all measured properties, especially in split tensile strength and flexural strength, demonstrating the significant benefits of this combined approach.

The study's findings validate the potential of eggshell and quartz powders to enhance concrete's strength properties, contributing to the development of high-performance, environmentally friendly concrete mixtures. These results offer valuable guidance for engineers and researchers aiming to optimize concrete mixtures for improved durability and sustainability in construction. The precise adjustment of additive ratios is highlighted as critical for achieving desired strength outcomes, further advancing the field of sustainable construction materials.

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## ETHICS STATEMENT

This study did not involve human or animal subjects and, therefore, did not require ethical approval.

## STATEMENT OF CONFLICT OF INTERESTS

The authors declare no conflicts of interest related to this study.

## LICENSING



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