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Replacement of Fine Aggregate with Glass Powder in High Performance Concrete

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Abstract: The utilization of glass powder (GP) in concrete production contributes to a more sustainable and environmentallyfriendly construction practice. In commercial establishments, damaged glass sheets and glass cuttings are often discarded as waste and sent to landfills, as recycling of such materials is not commonly practiced. Incorporating glass powder in concrete offers a promising approach for reducing waste disposal and promoting environmental conservation.

This study investigates the feasibility of using glass powder as a partial replacement for fine aggregates in concrete. Natural sand was substituted with glass powder at varying proportions of 10%, 20%, and 30%. The compressive strength of concrete cubes was evaluated at curing ages of 3, 7, and 28 days, and the results were compared with those of conventional concrete made with natural sand.

Keywords: Glass powder, Natural sand, Compressive strength.

I. INTRODUCTION

Concrete is the most widely used construction material in the world, consisting mainly of cement, aggregates, and water. The growing demand for natural resources such as river sand has resulted in excessive extraction, leading to significant environmental issues including depletion of riverbeds, ecological imbalance, and increased construction costs. Therefore, the search for alternative and sustainable materials to partially replace natural aggregates has become an essential research focus in the construction industry.

Glass is a non-biodegradable material that poses serious environmental challenges when disposed of in landfills. A large amount of waste glass is generated from households, industries, and commercial establishments in the form of damaged sheets, bottles, and cuttings. Since waste glass is not easily recycled, it often ends up as a waste material, contributing to land pollution. However, glass possesses a high silica content, which makes it potentially suitable for use as a fine aggregate or supplementary cementitious material in concrete.

Utilizing glass powder (GP) as a fine aggregate replacement not only provides a means of effective waste management but also contributes to reducing the consumption of natural sand. Previous studies have indicated that finely ground glass particles can enhance certain mechanical properties of concrete, particularly compressive strength, when used in appropriate proportions. Additionally, the incorporation of glass powder can reduce the overall cost of concrete production and promote sustainable construction practices.

This research focuses on evaluating the feasibility of using glass powder as a partial replacement for natural sand in concrete. The study involves the preparation of concrete mixes with varying percentages of glass powder (10%, 20%, and 30%) and the assessment of their compressive strength at different curing ages (3, 7, and 28 days). The results are compared with conventional concrete mixes to determine the optimum replacement level and its impact on mechanical performance and environmental sustainability.

II. LITERATURE REVIEWS

1) Byars, E. A. et al.

Byars et al. [1] have highlighted that the major limitation in the utilization of waste glass aggregates, either in coarse or fine form, is the occurrence of the Alkali–Silica Reaction (ASR), which adversely affects the strength and durability of concrete. Although mineral admixtures such as Pulverized Fuel Ash (PFA) and Ground Granulated Blast Furnace Slag (GGBS) have been found effective in mitigating ASR, the long-term feasibility of incorporating glass aggregates in concrete remains uncertain [2],[3] .

2) Ankur Meena and Randheer Singh

Ankur Meena and Randheer Singh [4] investigated the influence of glass powder particle size on the strength properties of concrete. Glass powder with particle sizes ranging from 150 µm to 100 µm and 100 µm to 50 µm was used in the study. The results revealed that smaller particle sizes exhibited higher reactivity with lime, leading to improved compressive strength of concrete [5]. Moreover, finer glass powder concrete demonstrated slightly higher early-age as well as long-term strength[6].

3) Shilpa Raju and Dr. P. R. Kumar

Shilpa Raju and Dr. P. R. Kumar [7] reported that glass powder exhibits pozzolanic activity when its particle size is less than 75 µm. Their experimental work, conducted using glass powder of 45 µm size, showed a significant improvement in compressive strength [8]. The enhancement was attributed to the fine particle size of glass powder, which likely acted as an effective filler material or possessed sufficient pozzolanic characteristics to serve as a partial cement replacement [9]. Furthermore, they observed that increasing the replacement percentage of glass powder led to a reduction in the effects of ASR [10].

Fig 2.1 – waste glass

4) Professor Narayanan Neithalat

Professor Narayanan Neithalath [11], from the Department of Civil and Environmental Engineering at Clarkson University, received a research grant of $200,000 for two years from the New York State Department of Economic Development – Environmental Investment Program (EIP). The study aimed to evaluate the potential application of waste glass powder, generated by Potters Industries in Potsdam, in the production of high-performance concrete. Potters Industries, one of the largest glass bead manufacturers in the United States, produces approximately 8,000 tons of waste glass powder annually from its Potsdam facility [12].

Most of this waste material is currently disposed of in landfills, incurring significant costs to the producer. Since glass powder is a rich source of silica, Professor Neithalath hypothesized that it could react with calcium hydroxide in the cementitious matrix to form secondary binding compounds. These compounds could enhance the strength and reduce the overall porosity of concrete [13], thereby improving its long-term durability. Understanding the physical and chemical behavior of glass powder in cementitious systems is a crucial step in the development of future high-performance concrete mixtures.

5) Dr. Neithalath collaborated with two local concrete manufacturers—Woodruff Block Company and Graymont Concrete—to develop suitable mixture proportions incorporating waste glass powder [14]. Based on a series of experimental studies, he concluded that the secondary reaction capability of glass powder can reduce the cement content in concrete by at least 10% without compromising its long-term performance [15]. This finding is particularly significant from an economic standpoint, as cement is the most expensive component of concrete, accounting for over 75% of the total cost.

The optimal cementitious composition proposed by the study comprises approximately 30% to 80% Portland cement, 20% to 70% glass powder (as a pozzolanic material), and 0.1% to 10% alkali metal aluminates [16].

III. MATERIAL USED

The materials utilized in this research work include glass powder, cement, fine aggregates, coarse aggregates, and water — all required for preparing concrete specimens.

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A. CEMENT

Ordinary Portland Cement (OPC) is categorized into three grades based on 28-day compressive strength: 33, 43, and 53 grades. Advances in production technology, such as improved grinding, particle size control, and better packaging, have helped enhance cement quality. High-grade cement, though slightly more expensive, provides 10–20% savings due to reduced usage and faster strength gain, making it advantageous for high-strength construction [18].

For this study, OPC 53 grade conforming to IS 8112:2007 [17] was selected as it is generally recommended for standard concrete works. The cement was stored in sealed containers under controlled humidity to avoid moisture absorption [19].

Fig 3.1 – Cement

B. FINE AGGEREGATE

Fine aggregates are an important component of concrete as they fill the gaps between coarse aggregate particles and help in achieving a dense and workable mix [20]. They generally consists of natural sand or crushed materials with smaller particles sizes , which contribute to better bonding and improved concrete strength. By reducing voids in the concrete mix , fine aggregates help lower the amount of water and cement required making the concrete more economical and durable.

One significant property of fine aggregates is gradation, which refers to the distribution of particles according to size. When aggregates are graded properly, the smaller particles fit between the larger ones, reducing empty spaces in the mixture. This results in less water demand and enhances strength, cohesiveness, and finishing quality of concrete. Poor gradation can either lead to a harsh mix if too coarse or increase shrinkage and water demand if too fine.

The Indian Standard IS 383:1970 [21] classifies fine aggregates into four grading zones: Zone I, Zone II, Zone III, and Zone IV. These zones indicate the fineness or coarseness of sand based on the percentage passing through designated sieves.

Zone I represents the coarsest sand, which can offer higher strength but reduced workability.

Zone II and Zone III sands are moderately graded and are most suitable for reinforced concrete works due to their balanced properties.

Zone IV is the finest grade and may require additional cement and water to achieve workable concrete.

Apart from gradation, fine aggregates must also be free from harmful substances such as clay, silt, organic matter, or salts [22]. These impurities may weaken the concrete or interfere with the hydration process. Therefore, proper testing and selection of fine aggregate are essential for achieving strong and durable concrete.

Fig 3.2 – Fine Aggregate

C. COARSE AGGREGATE

The material that remains on the 4.75 mm IS sieve is identified as coarse aggregate. These aggregates are larger in size and help form the primary structure of concrete by providing bulk, strength, and stability to the mix. In typical concrete construction, the maximum size of coarse aggregate usually ranges between 10 mm and 20 mm.

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However, for certain types of concretes like Self-Compacting Concrete, even bigger sizes such as 40 mm or more may be utilized based on project requirements. Choosing proper aggregate size improves packing density and directly influences workability and strength development.

Aggregates can also be classified based on their grading. Sometimes, gap-graded aggregates are preferred as they reduce internal friction between particles, enabling easier flow of concrete. On the other hand, continuously graded aggregates may increase friction and restrict the movement of particles within the concrete mix, making it less workable. Therefore, proper selection of grading plays an essential role in achieving suitable concrete performance.

Aggregates also differ in shape. Crushed aggregates have angular and irregular particles that interlock better with cement paste, resulting in enhanced compressive strength and load-bearing capability [24]. Rounded aggregates, commonly sourced from riverbeds, tend to improve concrete workability because their smooth surface reduces friction during mixing and placement. Thus, the desired properties of concrete determine whether angular or rounded aggregates are more suitable.

In this study, coarse aggregates available locally were used, with a maximum particle size of 20 mm and a minimum of 12.5 mm. Before mixing, the aggregates were washed thoroughly to remove dust, dirt, and other impurities that could affect bonding or hydration [23]. They were then dried to a surface dry condition to maintain accuracy in water-cement ratio. All aggregates were examined and confirmed to meet the standards specified in IS 383:1970 [21], ensuring reliable quality and performance in the concrete prepared for experimentation.

Fig 3.3 – Coarse aggregate

D. GLASS POWDER

Recycled waste glass is processed by crushing it into fine particles so that it can be reused in concrete applications. In this study, discarded soda-lime glass bottles were collected from a local recycling facility in Kodad, Suryapet District of Telangana. The collected waste glass was cleaned and then finely ground using mechanical rammers to obtain a particle size comparable to that of natural fine aggregate. The intention behind reducing the size of glass pieces to sand-like grains is to ensure uniform distribution in the concrete mix and allow better bonding with cement paste.

The particle size analysis conducted on both natural sand and processed glass powder indicated that they possess a similar average particle size, approximately 2.36 mm [25]. Due to this similarity, glass powder can effectively substitute natural sand without significantly altering the gradation characteristics of the concrete mixture. Another important factor for evaluating the suitability of fine materials in concrete is specific gravity. The specific gravity of sand was observed to be 2.54, while that of glass powder was slightly lower at 2.40. Although there is a small difference, it does not adversely affect the performance of the concrete mix because the specific gravity of glass powder still lies within the acceptable range of fine aggregates used in structural concrete.

The surface texture and appearance of glass powder were also compared with natural sand. Glass powder tends to have a smoother and shiny texture due to its composition and method of production. This can contribute to reduced water absorption and better flow characteristics during mixing [5]. Testing of hardened concrete is crucial to validate the performance of glass powder as a fine aggregate replacement. Among different mechanical tests, the most widely used and significant one is the compressive strength test, as it helps to assess whether concrete containing glass powder is capable of providing sufficient structural strength and durability [6].

IV. METHODOLOGY

The concrete mix design was carried out as per IS:10262-2019 [1], considering durability requirements according to IS:456-2000 [2]. In this study, M40 grade High Performance Concrete (HPC) was used. The target mean strength was computed and a water–cement ratio of 0.38 was adopted. The mix consisted of 480 kg of cement, 650 kg of natural fine aggregate, 1150 kg of coarse aggregate and 182 liters of water per cubic meter of concrete. Glass powder obtained from recycled soda-lime waste was used to partially replace fine aggregate at 0%, 5%, 10%, 15%, and 20% by weight of sand. The properties of fine and coarse aggregates were verified as per IS:383-1970 [3].

The workability of fresh concrete was evaluated by the slump cone test as per IS:1199-1959 [4]. The control mix (0% glass powder) recorded a slump of approximately 80 mm. With increasing glass powder replacement, the slump gradually improved due to the smooth and finer surface texture of glass particles. At 15% replacement, a maximum slump of 110 mm was observed, showing enhanced flowability and reduced internal friction.

The compressive strength test was performed on cube specimens of 150 × 150 × 150 mm in accordance with IS:516-1959 (Reaffirmed 2018) [5]. Testing was conducted at 7 days and 28 days to assess the effect of glass powder on strength development [6]. The results obtained from the experimental study led to the following conclusions [7]:

A. Effect on Compressive Strength

Partial replacement of sand with glass powder exhibited a significant influence on compressive strength. The highest strength performance was achieved at 10% replacement, showing 28.90 MPa (7 days) and 42.75 MPa (28 days), which is approximately 15% and 19% higher than the control mix (0% replacement) [8],[9].

B. Optimum Replacement Level

Strength reduced beyond the optimum value. At 20% replacement, the 28-day compressive strength dropped to 39.10 MPa, which remained higher than the control but lower compared to 10% replacement. This reduction was attributed to increased brittleness and limited bonding at higher glass content due to its smooth texture [10],[14].

C. Hydration and Microstructure

Finer glass particles contributed to improved packing density and pozzolanic activity, resulting in additional formation of calcium silicate hydrate (C-S-H gel). This enhanced matrix densification and reduced void ratio in concrete mixes [12],[15].

D. Overall Performance

The 10% glass powder replacement level is recommended as the optimum proportion for achieving maximum strength and improved workability in High Performance Concrete while contributing to waste glass utilization and sustainability in the construction sector [6],[9].

V. CONCLUSION

The experimental investigation on the replacement of fine aggregate with glass powder has been successfully completed. The obtained results were analyzed and discussed in detail in the previous chapters. Based on the test outcomes for M50 grade concrete, the following conclusions are presented:

A. General Conclusions

1) Glass powder has shown considerable potential to act as an alternative fine aggregate in concrete, especially where natural sand scarcity is a concern.
2) Concrete containing glass powder exhibits good strength, satisfactory performance, and reliable durability, making it a more sustainable option compared to conventional sand-based concrete.

B. Specific Conclusions

1) A noticeable improvement was observed in the 28-day compressive strength of concrete incorporating glass powder. An increase of around 9% was recorded when compared with the standard control mix.
2) The cylinder strength results indicate an enhancement in durability characteristics. Approximately a 23% rise was achieved in the 28-day split tensile strength of glass powder concrete compared to standard concrete specimens.
3) A significant improvement in flexural strength was also achieved. The 28-day flexural strength exhibited an increase of nearly 74% in comparison with conventional concrete, indicating better resistance to cracking and bending.

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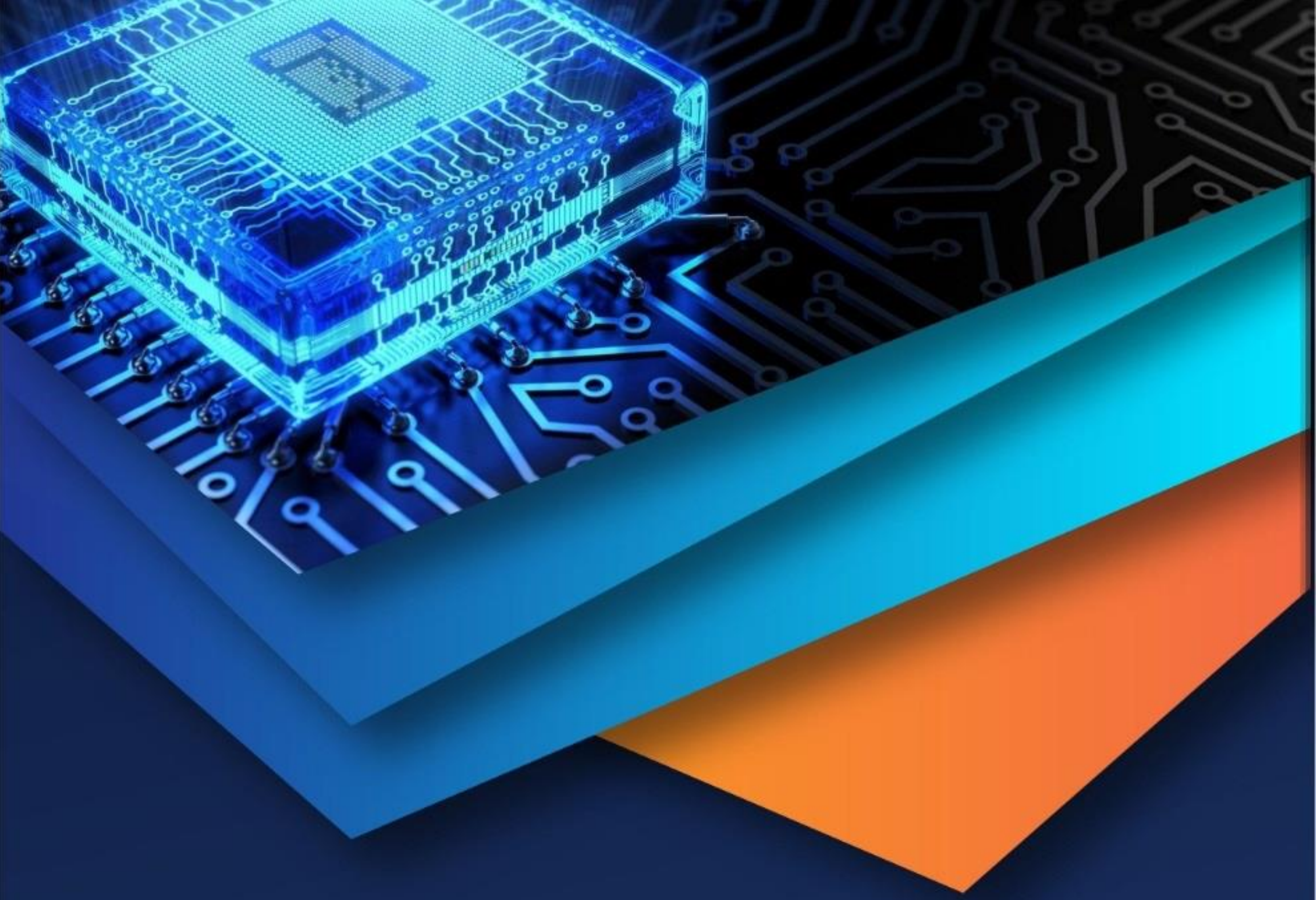

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