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Partial Replacement of Fine Aggregate in Concrete Mix using Recycled Glass Powder for Transportation Infrastructure

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***Abstract*— The entire sand mining process is thus adversely affecting nature and we are left with no other choice but to seek substitutes that are greener. Waste glass is a possibility: it is not biodegradable, but it contains a ton of silica and can react pozzolanically when finely ground into a fine powder, which could possibly increase the performance and the performance of concrete. We experimented with five replacement percentages in our study 0 percent which would be the control, 15%, 25%, 30% and 40%of the fine aggregate. We also tested fresh and hardened properties; the workability on slump, the strength of compression after 7, 14, and 28 days, and the amount of water the blend takes up. The evidence indicates that some of the WGP degrees in fact enhance compressive strength and still remain within a reasonable slump rate. In general, the findings indicate that waste glass powder may be a viable and friendly substitute for natural sand, which will make the production of concrete more long-lasting and handle garbage in a more effective way, particularly, when it is necessary to create roads and pavements.**

***Index Terms*— Glass powder, fine aggregates, concrete, slump cone test, water absorption, compressive test.**

I. INTRODUCTION

The high reliance of the structure domain using river sand as the fine aggregate has created great environmental issues. As the world continues to consume over several billions of tonnes of concrete every year, the problem of un-sustainable extraction of natural sand has come out to be a matter of concern. The intensive exploitation of river sand has also heralded the degradation of riverbeds, groundwater table exploitation, destruction of aquatic habitats, coastal erosion and an imbalanced ecosystem in general. [1]. These environmental effects dictate that alternative material that could minimise environmental degradation and at the same time preserve or improve structural performance has to be explored. Waste glass will become a viable two-fold solution to environmental degradation and waste management problems. Every year, enormous amounts of glass trash are produced worldwide, with a large portion ending up in landfills due to inadequate recycling facilities and financial limitations.[2] Glass cannot be biodegraded and instead it remains in the environment, consuming more useful landfill space, and adds to the waste management issues in the long run.

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Nevertheless, the chemical structure of the glass that constitutes 70-75 percent of the material, makes it chemically and physically identical to the natural sand, which may make it an appropriate substance to use in the construction.[3].

Waste glass is pozzolanic when finely ground to a fine powder of less than 150 μm, the waste glass is pozzolanic in nature and therefore it reacts with Ca(OH)2. This second pozzolanic step increases and improves the microstructural compressive strength, decreasing porosity, decreasing permeability, and increasing long-term durability. [3]. In addition, the particle fineness of glass powder is a significant source of reduction in harmful alkali-silica reaction (ASR), which is a significant issue normally linked with large-sized glass aggregates. ASR causes expansive gel that will cause cracking and structural degradation. This has been alleviated by the small particle structure of glass powder, making it especially desirable in highly sensitive services like road materials, bridge decks and transport infrastructure. [3].

A. Research Findings

Past research has shown some optimistic results in the partial replacement of the fine aggregate with waste glass powder. These researches suggest that a number of concrete properties are improved as they include better workability, increased compressive and tensile strength, greater chemical assault resistance, and reduced carbon footprint of concrete production[4] The replacement levels have been found to be between 20 to30 percent as optimal in other studies and the resulting concrete has the same or higher mechanical properties as the conventional concrete mixes [5]. Studies performed on high performance concrete have demonstrated that glass powder is added as a partial replacement of fine aggregate to as much as 30 % can retain or improve on strength performance whilst also aiding in sustainability objectives [4][5].

Further studies have suggested that glass powder might be utilized as sustainable substitution without compromising the optimum performance in terms of mechanical properties, durability properties, and density of concrete [6][7]. Research which has studied the replacement levels of 25% suggests that partial replacement with the waste glass powder within appropriate levels increases the overall concrete performance which proves it has the potential of being a sustainable alternative material.[7].

B. Research Gap and Objectives

Despite these positive findings, there are still some gaps in overall study. The overall evaluation regarding the waste glass powder behaviour in a wider scope of replacement rates is also not yet quite complete, especially in the case of the transportation infrastructure, in which the durability and performance under the conditions of long-term use are a priority. In addition, the cost-efficiency of glass-powder concrete in comparison with the traditional mixes has not been properly studied in the literature so far.[8][9]The current research paper is a systematic study of the part replacement of fine aggregate by recycled glass powder at the replacement level of 0% (control), 15%, 25%, 30%, and 40% by weight in M40 grade concrete. Combined with the fresh and hardened concrete characteristics, the research measures the workability, through slump tests, water absorption capacity, as a durability factor, and the development of compressive strength at the 7, 14, and 28 days of curing.[10] [11]Further, an extensive cost assessment is conducted in order to determine the viability of the economy and the savings that can be realized while substituting waste glass powder in place of fine aggregate. The aim of these results should be to identify the best replacement ratios which could be applied in transportation infrastructure projects and to improve environmentally friendliness in construction using efficient waste management and preservation of natural resources.

II. METHODOLOGY

A. Material

Cement : OPC 53 grade, which fulfills with IS 8112:2007, selected as this research since it is typically advised for typical concrete projects. According to the proportion of concrete mix taken as per IS:10262-2019 [12], with considering IS:456-2000 durability criteria [13]. High Performance Cement (HPC) of grade M40 was used in this research. With 0.45 water cement proportion. To prevent moisture absorption, the cement was kept in sealed containers with regulated temperature.

Aggregate : Clean River sand, which is consistent with grading zone II and possesses an optimal size of 4.75 mm, of the fine aggregate used in this research. The coarse rock aggregates used include angular-shaped, machine-smashed stone that was maintained to 4.75mm IS sieve with a specific gravity of 2.7 after passing through a 20mm IS sieve.

Glass powder: In order to reuse recycled waste glass in concrete projects as shown Figure 1, it is crushed into thin particles. Glass powder is obtained from local glass product businesses and suppliers in Nagpur Maharashtra which involves recycling scrap including glass powder. Waste glass was found to have a specific gravity of 2.40 and to be less than 150μm.

Figure 1. Glass powder

Water: The water used to prepare concrete needs to be pure, fresh and free of excessive levels of organic compounds, oil, and other impurities.

B. Testing

Test on fresh concrete: The slump cone test was used to assess the workability of freshly mixed concrete according to guidelines of IS: 1199–1959[14], The slump test measures the consistency and concrete flow and indicates its workability.

Water Absorption test: To ascertain the permeability and possible durability of concrete mixes that included waste glass powder at weight percentages of 0%, 15%, 25%, 30%, 40% in substitution of some fine aggregate the water absorption of mixture was studied.All specimens were cured in water for 28 days before testing and the mixes were proportioned for M40 grade concrete using a constant water-cement ratio of 0.45. Following testing, the results conclude as if the waste glass powder content goes from 0%to40%, the proportion of water absorption reduces significantly.

Compressive Test: Cube samples of 150x150x150 mm which were molded from each mixture containing varying amounts of cement, glass powder were used to measure the compressive strength of cured concrete. After layering the fresh concrete in steel cube molds and compacting it with a vibrator to eliminate any air voids, the top surface was cleaned and levelled to create a smooth plane that could be loaded. After a 24-hour period, the specimens were demoulded, moved to a curing tank, and kept under standard water-curing conditions for 7, 14 and 28 days according to IS 516:1959.

The compressive strength of each specimen was determined using a formula after the maximum load at failure was noted.

Compressive strength in MPa = failure load in N / Cross sectional area of the cube in mm2.

III. RESULT

A. Slump cone test

Following the recommendations of IS: 1199–1959, the slump cone test was used to know the workability of fresh concrete and the results are as follow:

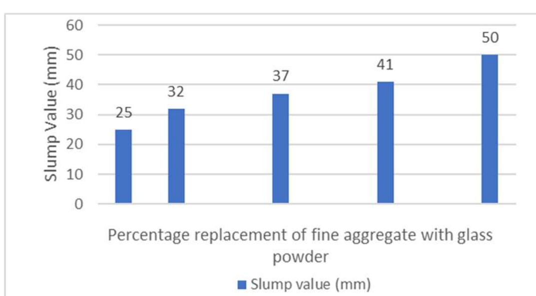

Figure 2. Slump cone test response to fine aggregate replacement with glass powder

The concrete compositions' suitability for work, shown in figure 2 evaluated through the slump cone test, demonstrated a consistent direct positive correlation with the increment of glass powder (GP) as an alternative of fine aggregate. Experimental data revealed that as the GP content increased from 0% to 40%, the slump values increased progressively from 25mm to 50mm.

B. Water Absorption test

The observation carried out in water absorption test is show in figure 3 follow as:

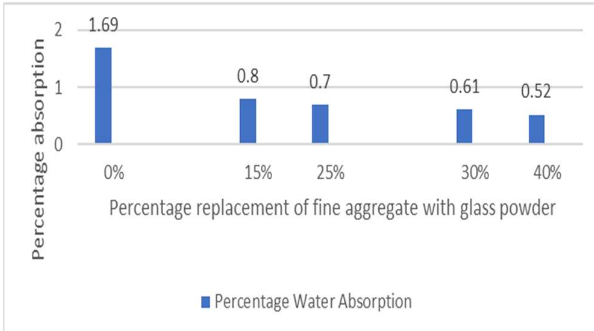

Figure 3. Water Absorption test response to fine aggregate replacement with glass powder

As illustrated in the experimental data, the percentage of water absorption decreased significantly as fine aggregate replace levels rose from 0% to 40%. The control mix exhibited the highest absorption rate at approximately 1.7%, whereas the 40% GP replacement mix recorded the lowest at approximately 0.5%. This marked reduction in water intake is attributed to the non-absorbent properties of glass and the improved particle packing density of the concrete.

C. Compressive strength test

Each specimen's maximum load at failure was observed and a formula was used to find out the compressive strength. The standard compressive strength of cubes was calculated for each mixture in order to determine the effects of replacing waste glass powder on M40 concrete strength improvement as shown in table no I. and figure 4

TABLE I: COMPRESSIVE STRENGTH RESULT

Percentage of glass powder used to replace fine aggregate	7 Days Result N/mm^2	14 Days Result N/mm^2	28 Days Result N/mm^2
0%	34.2	41.3	49.5
15%	36.1	44.2	52.2
25%	38.5	49.8	56.2
30%	40.1	45.7	55.1
40%	41.2	49.4	55.8

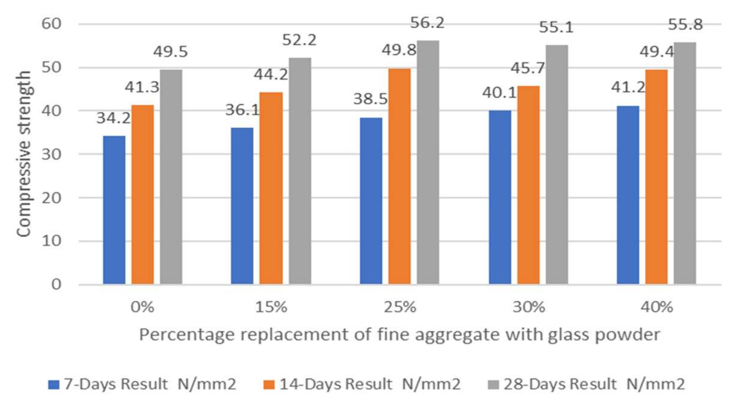

Figure 4. Water Absorption test response to fine aggregate replacement with glass powder

D. Material Saving

The substitution of fine aggregate with recycled glass powder straight away reduces consumption of natural sand, helping to conserve natural resources and reduce river sand dependency. Fine aggregate consumption shown in figure 5 to decrease significantly when replacement increases. At 40% replacement, natural fine aggregate is reduced by 260 kg/m³ for maximum material savings.

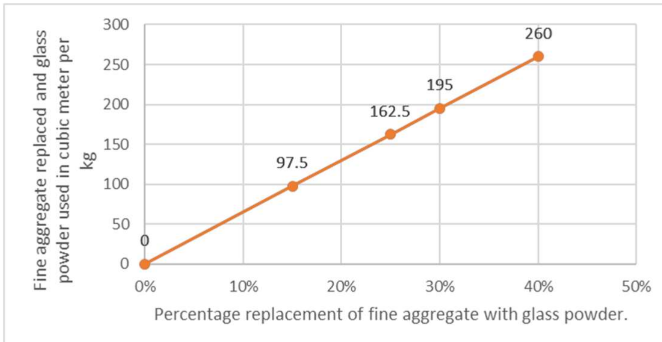

Figure 5. fine aggregate saving graph with respect to glass powder replacement

E. Cost Analysis

The cost saving due to replacement depends on the unit cost of fine aggregate and glass powder. This result shows in figure 6 that the replacement of fine aggregate with recycled glass powder provides measurable material and economic benefits, the material saving increases with replacement percentage .The maximum cost saved was observed at 40% replacement, yielding approximately at 312/m3 saving rates.

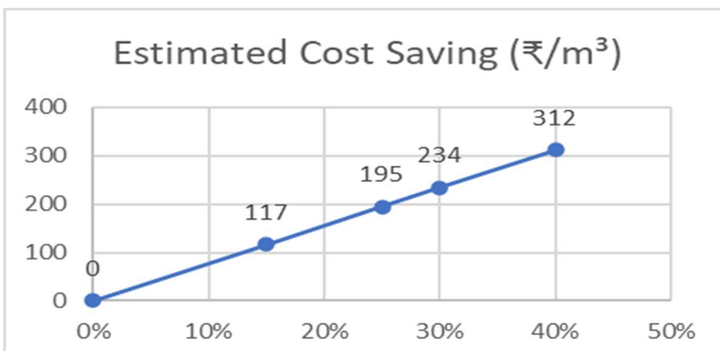

Figure 6. Cost analysis of fine aggregate replacement with respect to glass powder

IV. FUTURE SCOPE

- Investigation of long-term durability properties.
- Detailed evaluation of alkali-silica reaction.
- Optimization of particle size and grinding methods to enhance pozzolanic activity and performance.

V. CONCLUSION

- The current research conducts an assessment of Substituting glass powder in M40 grade concrete and reveals significant enhancement of workability, durability, strength, sustainability, and cost-effectiveness, which supports the use of the technology in transportation infrastructure.
- Workability: Slump values in 50 mm (control) were improved to 50 mm in 40 percent replacement, which is a 100 percent increase due to the smooth nature of the glass and the absence of absorbent particles. The percentage of water absorption reduced to 0.52 by 69% at 40% replacement.
- Compressive Strength: The maximum strength was at 25% replacement, giving 56.2 N/mm2 after 28 days and 38.5% and 49.8 % improvements were obtained at 7 and 14 days, respectively.

- Sustainability and Economics: The 30% replacement saved 195 kg/m3 of sand and diverted a comparable amount of waste glass out of landfills, which saved 234/m3 (1 kg of glass cost 28/kg as opposed to sand). The highest savings were achieved at 40 percent replacement of 260 kg/m3 and 312/m3. The 30 percent point gives the best balance of performance, having a 41mm slump, 0.61 percent absorption, and maximum strength making glass powder concrete.

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