

Performance Evaluation of Silica Fume and Recycled Aggregate in High-Strength Concrete

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Abstract:

Concrete remains the most widely used construction material due to its strength, versatility, and durability; however, its large-scale production poses environmental challenges, particularly the depletion of natural resources and high carbon emissions from cement manufacturing. Concrete, made from cement, aggregates, and water, is widely used for its versatility. Supplementary cementitious materials like silica fume enhance strength, durability, and sustainability. Silica fume concrete offers higher compressive and flexural strength, improved resistance to chemical and environmental effects, and better workability due to its pozzolanic activity and filling effect. In this study, 13 mix proportions were prepared with M40 grades. Cement and coarse aggregate were partially replaced with silica fume and recycled aggregate at 0%, 15%, 30%, and 45%. Fresh and hardened properties were evaluated to assess workability and strength performance.

Keywords: Cement, Concrete, Recycled Aggregates (RA), SCMs, RCA, C&D.

1. Introduction

Concrete has played a vital role in addressing numerous infrastructure challenges and is regarded as one of the greatest achievements in the construction industry. However, with the increasing emphasis on sustainability, attention has shifted toward the use and reuse of recycled materials in construction. Rapid urbanization and the demolition of old structures generate large quantities of construction and demolition (C&D) waste. If not managed properly, this waste is often dumped in landfills, leading to the depletion of natural resources, uncontrolled disposal, and severe environmental impacts around dumping sites.

One of the most effective ways to recycle C&D waste is by utilizing Recycled Aggregate (RA) in concrete. However, RA is generally of lower quality compared to natural aggregates, as it exhibits higher water absorption, lower density, and greater porosity. These drawbacks

primarily result from the presence of old mortar and lime adhered to the surface of RA particles. Consequently, the performance of Recycled Coarse Aggregate (RCA) depends not only on the replacement level but also on its quality and the extent of adhered mortar.

The use of RA also affects the Interfacial Transition Zone (ITZ) the thin layer between the aggregate and cement paste, which plays a crucial role in determining the mechanical properties of concrete. A weaker ITZ reduces stiffness and elasticity, often leading to a greater loss of mechanical performance compared to compressive strength. Several studies have confirmed these limitations, suggesting that RA concrete performs better when partially replaced with natural aggregates or when RA undergoes pre-treatment to improve its quality.

In addition to quality concerns, another environmental challenge arises from unused fresh concrete frequently returned to batching

plants. Since it is difficult to accurately predict the exact quantity required for construction projects, surplus fresh concrete often becomes waste. This not only increases material wastage but also adds to the carbon footprint associated with cement production.

Therefore, the sustainable utilization of recycled aggregates in concrete is of great importance. It helps reduce landfill waste, conserve natural resources, and encourage environmentally friendly construction practices, thereby contributing to global efforts toward sustainability.

2. Material Used for Concrete Mix

The following materials were used in the preparation of concrete mixes:

- a) Cement
- b) Natural Coarse Aggregate (NCA)
- c) Natural Fine Aggregate (NFA)
- d) Recycled Concrete Aggregate (RCA)
- e) Silica Fume (SF)
- f) Admixture
- g) Water.

Table 1: Physical Properties of (NCA) and RCA of 10mm Size

| Properties of CA | NCA Test Value | CRCA |
|----------------------------------|-------------------|-----------------------------|
| Colour of CA | Colour= Grey | Dark Grey |
| Maximum size of CA (mm) | 10mm | 9-10mm |
| Specific Gravity of CA | SG=2.61 | SG=2.46 |
| Total Water Absorption (%) of CA | 0.5% | 5.5% |
| Fineness Modulus | 5.852 | --- |
| Location | Locally Available | Concrete Lab NIT, Jalandhar |



Figure 1: Recycled Coarse Aggregates

Table 2: Sieve Analyses of Natural Coarse Aggregates

| Sieve Size | Retained Wt. (gm) | Retained % Wt. (gm) | Retained Cumulative % Wt. | Passing % | Requirement As On BIS: 383-1970 |
|------------|-------------------|---------------------|---------------------------|-----------|---------------------------------|
| 20 mm | 0 | 0 | 0 | 0 | 100 |
| 12.5 mm | 110 | 5.50 | 5.50 | 110 | 85-100 |
| 10 mm | 305 | 15.25 | 20.75 | 305 | 0-20 |
| 6.3 mm | 705 | 35.25 | 56.00 | 705 | 0-5 |
| 4.75 mm | 530 | 26.50 | 82.50 | 530 | 0 |
| 1.18 mm | 350 | 17.50 | 100 | 350 | 0 |
| 0.60 mm | 0 | 0 | 100 | 0 | 0 |
| 0.30 mm | 0 | 0 | 100 | 0 | 0 |
| 0.15 mm | 0 | 0 | 564.75 | ---- | ---- |
| Pan | 2000 | 100 | ---- | ---- | ---- |

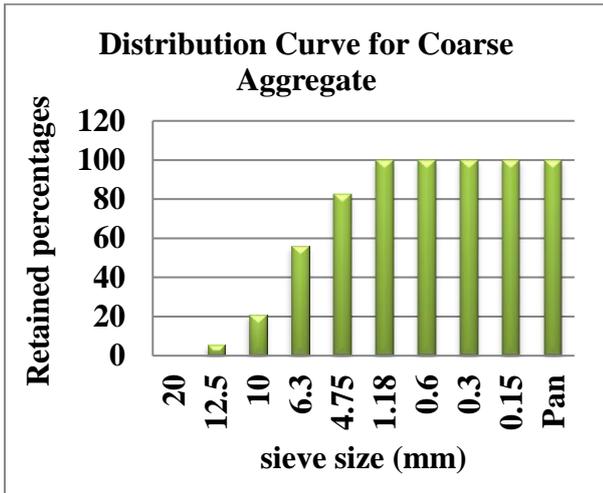


Figure 2: Distribution Curve for Coarse Aggregate

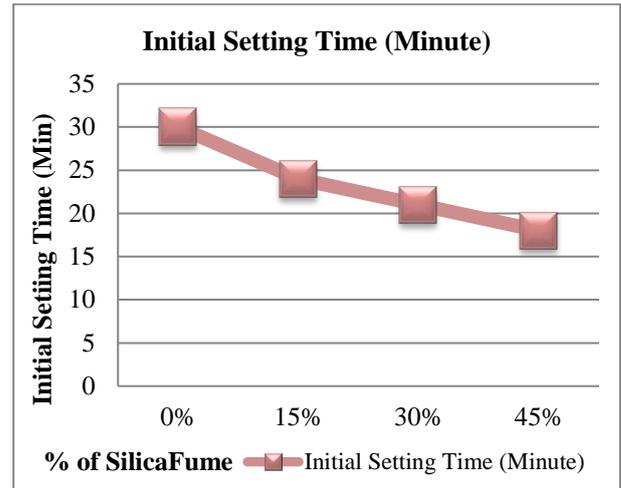


Figure 5: Initial Setting Time of Cement with Silica Fume Replacement

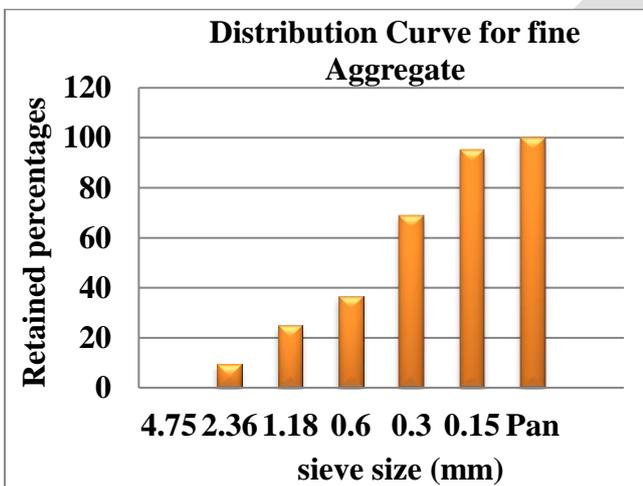


Figure 3: Distribution Curve for Fine Aggregate

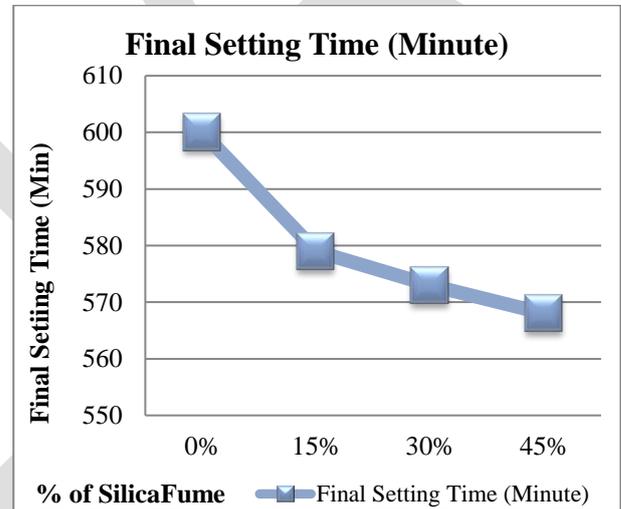


Figure 6: Graphical Representation of Final Setting Time of Cement Due to Replacement of Silica Fume

3. Result and Discussion

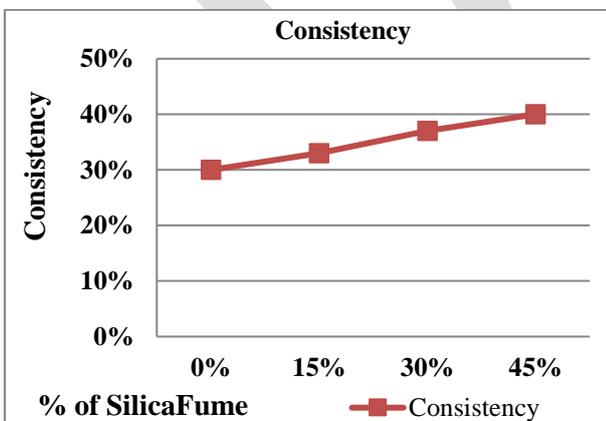


Figure 4: Consistency of Cement with Silica Fume Replacement

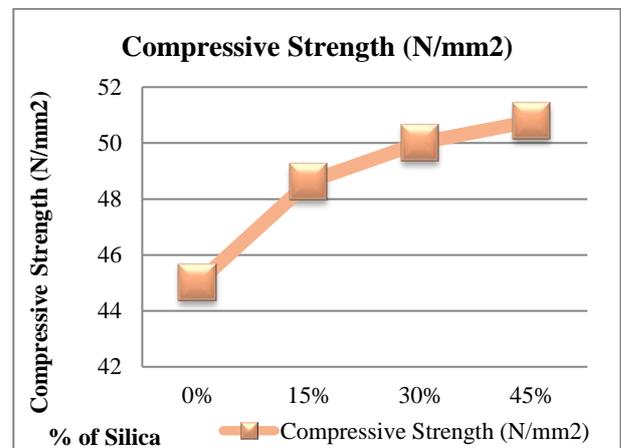


Figure 7: Compressive Strength of Cement Due to Replacement of Silica Fume

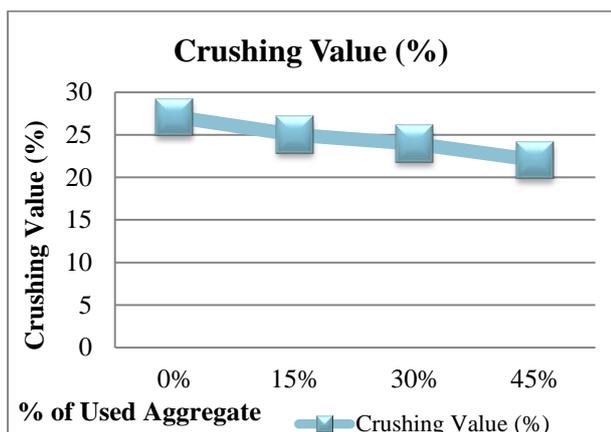


Figure 8: Crushing Test of Aggregate Due to Replacement of Used Aggregates

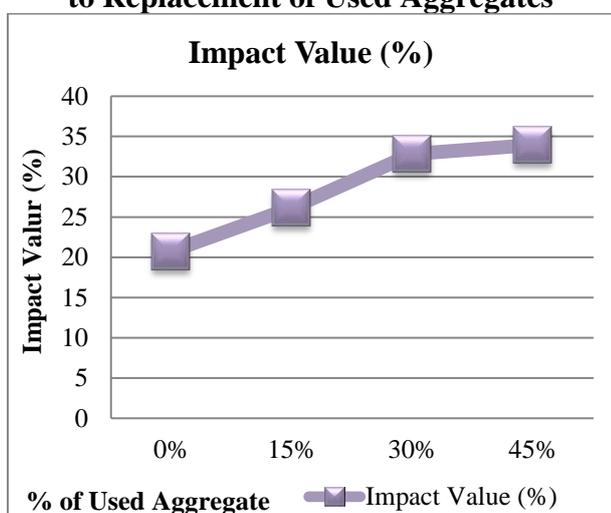


Figure 9: Impact Test of Aggregate Due to Replacement of Used Aggregates

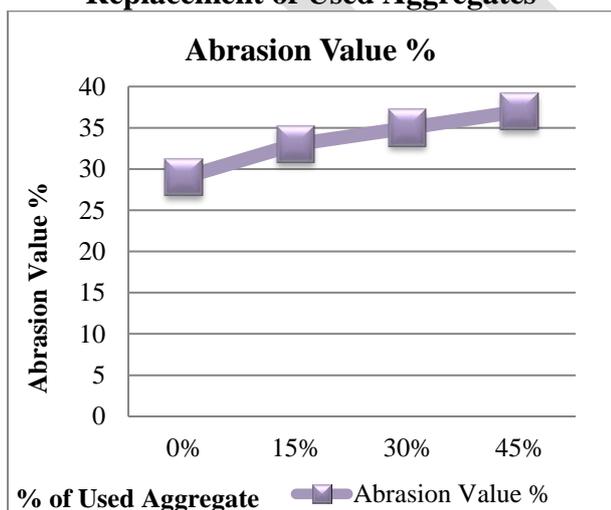


Figure 10: Abrasion Test of Aggregate Due to Replacement of Used Aggregates

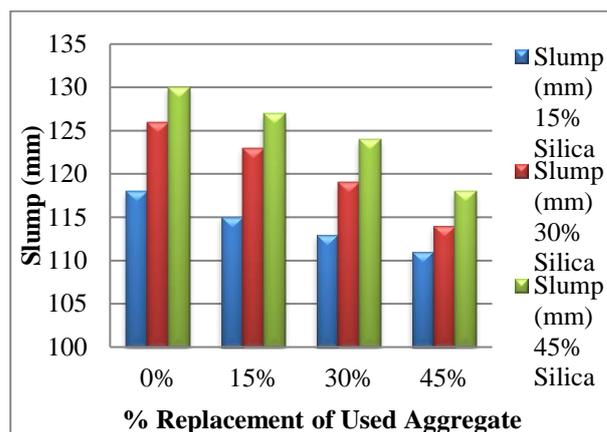


Figure 11: Slump Test for 15%, 30% and 45% substitute of Cement with Silica and Varying % of Aggregate replacement with Used Aggregate

4. Conclusion

This study investigated the effects of replacing cement with silica fume (SF) at 15%, 30%, and 45%, along with the replacement of coarse aggregates (CA) by recycled aggregates (RA) in varying proportions. The experimental results indicate that:

- **Cement Properties:** Normal consistency increased with silica fume content, while the initial setting time decreased and the final setting time increased. Compressive strength of cement improved with higher silica fume replacement.
- **Aggregate Properties:** The crushing value decreased with RA, while the impact and abrasion values increased.
- **Concrete Performance:** For M40, grades, slump decreased with higher RA content, though silica fume improved workability.

In summary, silica fume enhances the strength properties of concrete, while the use of recycled aggregates contributes to sustainability with minimal compromise in workability.

References

- [1]. N. Khandelwal, S. Bhargava, H. K. Sain, "A study on Kota stone powder slurry and ground-granulated blast-furnace slag as an ingredient in

- concrete,” *International Journal of Engineering Science Technology and Research (IJESTR)*, vol. 7, no. 3, pp. 12–16, 2022.
- [2]. N. Goyal, H. K. Sain, A. K. Agwan, “A study on fiber reinforced concrete using different types of geo-polymer fiber in preparation of concrete sample,” *Journal of Emerging Technologies and Innovative Research (JETIR)*, vol. 9, no. 9, pp. 750–753, 2022.
- [3]. G. S. Soni, I. C. Sharma, “Sustainable concrete: Utilization of glass and sawdust waste in composite materials,” *International Journal of Engineering Trends and Applications (IJETA)*, vol. 12, no. 4, 2025.
- [4]. H. K. Sain, V. Sharma, B. Nisar, “Effect of rock cracks on RC structures,” *AIP Conference Proceedings*, vol. 2901, no. 1, 050005, 2023.
- [5]. Meena, D., Agwan, M. K., & Sain, H. K., “An experimental study on the behaviour of concrete by partial replacement for rice husk ash, silica fume & iron slag with cement,” *International Journal of Engineering Trends and Applications (IJETA)*, vol. 10, 2023.
- [6]. I. C. Sharma, G. S. Soni, “Assessment of limestone dust and chips as eco-friendly alternatives in concrete production,” *International Journal of Engineering Trends and Applications (IJETA)*, vol. 11, no. 3, 2024.
- [7]. G. Ganguly, I. C. Sharma, “Sustainable solid waste management, smart cities and Swachh Bharat initiative,” *Institute of Technology & Engineering, Jaipur*, 2017.
- [8]. I. C. Sharma, A. K. Jonwal, “Strength and durability properties of concrete using recycled concrete aggregate,” *International Journal (IJLCIET)*, vol. 3, no. 7, 2014.
- [9]. K. Choudhary, H. K. Sain, “Seismic behavioural analysis of one bay structure with composite beam and RCC columns,” *International Journal of Engineering Research and Generic Science (IJERGS)*, vol. 7, no. 6, pp. 27–36, 2021.
- [10]. M. Shmls, D. Bozsaky, and T. Horváth, “Literature review on steel fibre, silica fume and fly ash: improving methods for recycled and multiple recycled aggregate concretes,” *Acta Technica Jaurinensis*, vol. 14, no. 1, pp. 60–79, 2021.
- [11]. S. Nunes, P. M. Oliveira, J. S. Coutinho, and J. Figueiras, “Robust SCC mixes through mix design,” *Journal of Materials in Civil Engineering*, vol. 25, pp. 183–193, 2013.
- [12]. M. Omrane, S. Kenai, E. H. Kadri, and A. Aït-Mokhtar, “Performance and durability of self-compacting concrete using recycled concrete aggregates and natural pozzolan,” *Journal of Cleaner Production*, vol. 165, pp. 415–430, 2017.
- [13]. J. Ortiz, A. De La Fuente, F. M. Sebastia, I. Segura, and A. Aguado, “Steel-fibre-reinforced self-compacting concrete with 100% recycled mixed aggregates suitable for structural applications,” *Construction and Building Materials*, vol. 156, pp. 230–241, 2017.