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An Experimental Study of Steel Fibre and Glass Powder Reinforced Concrete Under Compression

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ABSTRACT

Concrete, though widely used for its compressive strength and durability, remains limited by its brittle behavior and low tensile capacity. To address this, the present study investigates the synergistic effect of steel fibers extracted from waste rubber tyres and finely ground waste glass powder as a partial replacement of fine aggregate. Concrete mixes were prepared with 0.5% steel fibers and glass powder varying from 0% to 18%. Standard cube specimens were tested for compressive strength at 3, 14, and 28 days. Results indicated that the addition of steel fibers alone slightly reduced compressive strength compared to the control mix. However, when combined with glass powder, notable improvements were observed. The optimum performance was achieved at 0.5% steel fiber with 12% glass powder, yielding a compressive strength of 35.49 MPa at 28 days, exceeding that of the control mix. The findings highlight the potential of hybrid reinforcement using recycled steel fibers and waste glass powder to enhance mechanical performance while promoting sustainable concrete development.

Keywords: Steel Fiber, Glass Powder, Hybrid Reinforcement, Compressive Strength, Sustainable Concrete

Introduction

Concrete is widely used for its high compressive strength and durability, but its brittleness and low tensile capacity limit structural performance. Steel fibers, particularly those extracted from waste rubber tyres, enhance fracture toughness, ductility, and crack resistance, while waste glass powder (WGP) exhibits pozzolanic reactivity that refines the microstructure and improves durability. Although both materials have been studied individually, their combined effect under compressive loading remains underexplored. This study investigates the hybrid reinforcement of concrete with recycled steel fibers and glass powder, focusing on the development of compressive strength at different curing ages.

Literature Review

Research into sustainable and high-performance concrete has led to a focus on using waste materials as partial replacements for cement and as reinforcing fibers. Several studies have explored the individual and combined effects of steel fibers and waste glass powder (WGP) on the mechanical properties of concrete, with significant findings reported by various researchers.

Early research by Shende & Pande (2012) focused on the use of steel fibers to enhance concrete strength. The study reported that a 3% steel fiber addition yielded the highest compressive, tensile, and flexural strengths. Their findings also highlighted the importance of fiber geometry, as fibers with a lower aspect ratio (50) performed better than longer, thinner ones. The strength improvements observed were notable, ranging from 11–24% for compressive strength, 12–49% for flexural strength, and 3–41% for tensile strength.

Another area of investigation has been the use of waste glass powder as a partial cement replacement. Raydan & Khatib (2024) found that a 10–15% replacement of cement with WGP enhanced compressive, tensile, and flexural strengths, in addition to improving durability. However, they observed a decrease in performance when the replacement level exceeded 15%. A beneficial side effect of WGP use was its ability to delay the setting time, thereby improving hydration. Similarly, Mustafa et al. (2023) reported that a 10% glass powder replacement increased compressive and tensile strengths by 4.7% and 1.7%, respectively. In a practical application, they found that reinforced concrete slabs with 10% glass powder showed an 8.8% increase in failure load and a 21.8% increase in stiffness.

More recent studies have explored the synergistic effects of combining both waste glass powder and steel fibers. Mohanta & Samantaray (2021) observed that a mix containing 9% WGP and 1% recycled steel fibers (RSF) produced the best compressive strength, showing an 11.8% increase over the control mix. They also noted improvements in flexural and tensile strengths, with diminishing returns beyond these specific percentages. Kumar et al. (2021) corroborated these findings, reporting that a similar mix of 9% WGP with 1% RSF achieved a maximum split tensile strength of 4.485 N/mm², which represented a 38.6% increase over the control mix. They also confirmed that higher WGP contents (12–15%) led to a reduction in strength. The benefits

of this combined approach were further supported by Mustafa et al. (2023), who found that adding 0.5–1% steel fibers to the mix with glass powder further enhanced the strength of concrete slabs by 20–38%. Prasad et al. (2020) also concluded that dual fiber mixes (steel + glass fibers) enhanced both compressive and tensile strength, with the optimum performance achieved at a 1% total fiber content. They noted that this combination had only a marginal effect on workability. Furthermore, they found that increasing the proportion of glass fiber while reducing steel fiber content lowered the compressive strength compared to mixes with 100% steel fiber.

In summary, the research collectively demonstrates that both steel fibers and waste glass powder are effective in improving the mechanical properties of concrete. While each material offers distinct advantages individually, their combination at optimal percentages—such as the widely reported 9% WGP and 1% RSF—appears to yield superior strength enhancements across compressive, tensile, and flexural properties. The findings provide a strong foundation for developing sustainable, high-performance concrete mixes. Previous studies clearly establish that steel fibers enhance strength and toughness, while glass powder improves durability and microstructure at optimum replacement levels. Hybrid systems combining WGP and steel fibers have also shown improved compressive, tensile, and flexural properties. However, most studies emphasize either fibers or glass powder individually, with limited focus on their combined behavior under compression. This gap highlights the need to investigate the synergistic influence of steel fibers and glass powder on the compressive performance of concrete, which is the objective of the present study. The Objectives of this work are to investigate the workability of concrete when fine aggregate is partially replaced with varying proportions of glass powder, to evaluate the effect of incorporating steel fibers and different percentages of glass powder on the compressive strength of concrete under controlled testing conditions and to provide insights into the sustainable use of waste glass powder, in combination with steel fibers, for the development of durable and high-performance concrete.

Materials and Methods

Cement: Ordinary Portland Cement (OPC) of 43 grade, conforming to IS:8112, was used.

Fine Aggregate: River sand conforming to Zone II grading as per IS:383, with a specific gravity of 2.56.

Coarse Aggregate: Crushed granite aggregates of maximum size 20 mm, with a specific gravity of 2.97.

Water: Potable water free from impurities was used for both mixing and curing.

Admixture: Conplast SP430 superplasticizer was used to enhance workability.

Steel Fibers: Recycled hooked-end steel fibers extracted from waste rubber tyres, with a length of 20–30 mm and an equivalent diameter of 0.5–1.0 mm.

Glass Powder: Waste glass ground to particles below 100 µm was used as a partial replacement for fine aggregate.

Mix Design & Experimental Work:

Concrete mixes were prepared with 0.5% steel fiber by volume of concrete, and glass powder replacing fine aggregates at varying percentages (0%, 6%, 12%, 18%). Cubes of size 150 mm × 150 mm × 150 mm were cast and tested for compressive strength at 3, 14, and 28 days.

Quantity Of Materials for 1m^3 in kg

Sl. No.	Materials	Percentage Variations				
		0%	0.5% SF & 0% GP	0.5% SF & 6%GP	0.5% SF & 12%GP	0.5% SF & 18%GP
1.	Cement	394.32	394.32	394.32	394.32	394.32
2.	Fine aggregate	642.56	642.56	604.00	565.45	526.89
3.	Coarse Aggregates	1216.5	1216.5	1216.5	1216.5	1216.5
4.	Glass powder	0	0	38.55	77.107	115.66
5.	Steel fibres	0	12.29	12.29	12.29	12.29
6	Conplast X421IC	7.89	7.89	7.89	7.89	7.89
7	Water	197.16	197.16	197.16	197.16	197.16

SF - Steel Fiber , GP - Glass Powder

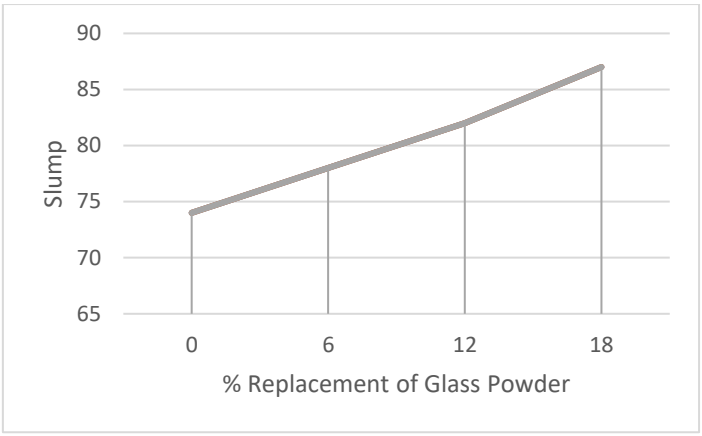

Figure 1: Slump Test Graph

Slump values increased with higher glass powder replacement due to its finer particles and smooth texture, which improved mix flowability. All mixes remained within medium workability, ensuring both ease of placement and stability for structural use.

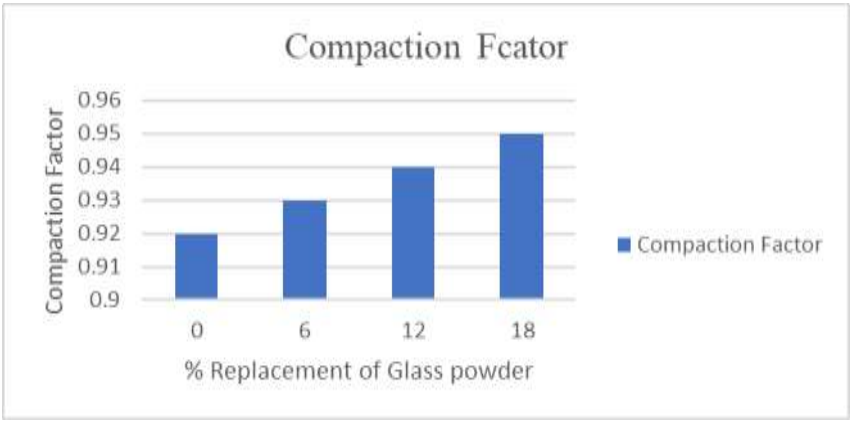

Figure 2 : Compaction Factor

From Figure 2 we see that increasing glass powder replacement improves the compaction factor, meaning the concrete becomes slightly more workable and denser with higher replacement levels.

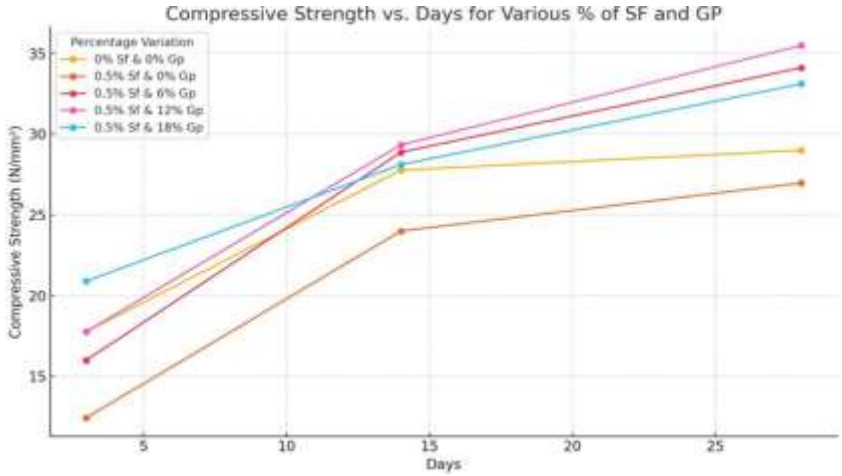

Figure 3 : Compressive Strength

The variation of compressive strength with curing age for different proportions of steel fibers (SF) and glass powder (GP) is presented in Figure 3 . The results indicate that the inclusion of 0.5% SF consistently improves compressive strength compared to the control mix. Further enhancement is observed with the addition of GP, where 6% and 12% replacement levels significantly increase strength at all ages. The optimum performance is achieved with 0.5% SF and 12% GP, reaching approximately 36 N/mm² at 28 days. However, a slight reduction in strength is noted at 18% GP replacement, suggesting that excessive GP content may adversely affect performance. Overall, the combined use of SF and moderate levels of GP leads to notable improvements in compressive strength due to synergistic effects of fiber reinforcement and pozzolanic activity.

Conclusions

1. The addition of 0.5% steel fiber alone, extracted from waste rubber tyres, reduced compressive strength compared to the control mix, showing that fibers without supplementary materials are not sufficient to enhance strength.

2. Incorporating glass powder with 0.5% recycled steel fiber significantly improved compressive strength at all curing ages, with early-age strength increasing from 12.44 MPa (0.5% SF & 0% GP) to 20.89 MPa (0.5% SF & 18% GP).

3. The optimum performance was achieved at 0.5% SF and 12% GP, reaching 29.33 MPa at 14 days and 35.49 MPa at 28 days, consistently surpassing the control and all other combinations.

4. Increasing GP content beyond 12% (i.e., 18%) slightly reduced the 28-day strength (33.11 MPa), confirming that 12% GP replacement is the optimum level.

5. The study demonstrates that combining recycled steel fiber from waste tyres with glass powder not only enhances mechanical properties but also promotes sustainability by valorizing two major waste streams, reducing cement demand, and lowering the carbon footprint of concrete.

Hence, the mix containing 0.5% steel fiber from waste tyres and 12% glass powder is identified as the most effective and sustainable solution for achieving high compressive strength.

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