



Experimental Investigation on Strength Characteristics of Concrete Using Waste Glass Powder and Polypropylene Fibers



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Abstract: The most common construction material is concrete, yet the high consumption of natural materials and cement leads to the destruction of the environment. As a solution to this, alternative waste materials and fibres are being applied to concrete. This work examines how the waste glass powder can be used as a partial replacement of cement and polypropylene fibres as reinforcement in the concrete mechanical properties. Glass powder, a non-biodegradable waste, was incorporated at 5% and 10% partial replacement of cement, and the polypropylene fibres were incorporated at 1% by volume. Concrete specimens were cast in the three forms of cubes, beams and cylinders using M30 grade concrete. Some of the tests that are performed are slump cone test, compressive strength, split tensile strength and flexural strength. The findings showed that the workability was slightly lowered with the addition of waste glass, but the tensile and flexural properties were enhanced considerably with the addition of polypropylene fibres. This research paper concludes that waste glass powder and polypropylene fibres are effectively applicable in the sustainable production of concrete, which minimises the environmental impact and increases ductility.

Introduction

The most widely utilized construction material in the world is concrete, mainly because of its flexibility, strength and the fact that it is easy to manufacture. It consists of cement, fine aggregates, coarse aggregates and water. Nonetheless, the high rate of urbanisation and industrialisation has caused a frightening situation regarding the consumption of cement and natural aggregates, which induces depletion of natural resources, emission of CO₂ and environmental degradation. This has encouraged scientists to consider other materials that are more sustainable in construction and are environmentally friendly (Singh, 2022; Mohammed, 2024).

Waste glass powder (WGP) is a promising material. The amount of waste glass in the world is huge, and mismanagement of waste products is an extreme environmental issue, as glass cannot be biodegraded. Waste glass is pozzolanic and therefore appropriate in its finely ground form when used as a partial substitute for cement. WGP allows not only to eliminate landfill waste but also to reduce the use of cement, thus reducing the total carbon footprint of the construction of concrete (Loganathan et al., 2020; Hussain and Aljalawi, 2022; Malek et al., 2021).

Concrete is compressively strong, but tensionally weak and therefore has a tendency to crack and brittle failure. To overcome this, fibres are added to the mixture,



resulting in the formation of Fibre Reinforced Concrete (FRC). Polypropylene fibers (PPF) are among the most widely used forms of fiber because they are lightweight, resistant to corrosion, and low-cost, and they also possess the ability to control shrinkage cracks. Polypropylene fibres are added to concrete in order to increase tensile strength, ductility, and toughness and consequently, use them in structural applications that perform better (Najaf et al., 2022a; Aswini et al., 2020).

WGP and PPF combination in concrete is a two-sided advantage:

1. Sustainable use of industrial and domestic waste materials, and
2. Enhancement of mechanical and durability characteristics of concrete.

The glass powder and polypropylene fibers have been individually investigated in a number of studies; however, there are few studies that have been conducted on their combination (Najaf et al., 2022b; Orouji and Najaf, 2023; Asgarian et al., 2023). The latest research studies provide evidence that WGP is an effective modifier of compressive and flexural strength, and PPF is an effective modifier of ductility and impact protection, which makes the combination potentially sustainable in construction (Najaf et al., 2022).

The purpose of this research is to demonstrate that the use of WGP and PPF not only helps eliminate environmental issues but also contributes to the development of sustainable, long-lasting, and ductile concrete suitable for contemporary building practices.

Literature review

The application of waste glass powder (WGP) and polypropylene fibers (PPF) in concrete has been investigated on various angles: pozzolanic reactivity and strengthening of WGP, mechanical and durability advantages of PPF and synergetic attributes when they are used together.

Concrete incorporating Waste Glass Powder (WGP)

Ground waste glass is a supplementary cementitious material because, in a fine state, it is a silica-based material with a pozzolanic action. Loganathan et al. (2020) indicated that the replacement levels of cement with WGP can be kept at a low percentage (usually 5-15) to enhance the compressive strength in later ages and refine the pore structure. Hussain & Aljalawi (2022) reported that reactive powder concretes with the addition of WGP showed better indicators of durability (a decrease in permeability), and Mašek et al. (2021) reported that cemented-glass composites exhibited desirable physical and mechanistic characteristics in case

the glass is ground to the right fineness. Singh (2022) highlighted that WGP can lower the strength at early ages when applied in high ratios, although the best replacement percentages have both positive environmental and performance outcomes. Mohammed (2024) also demonstrated that the use of coarse aggregate (in combination with WGP) from crushed glass affects workability and density and mix proportioning is crucial.

Polypropylene Fibers (PPF) in Concrete

Polypropylene fibres are also commonly used to prevent plastic and drying shrinkage cracking, as well as to improve post-cracking behaviour. Mašek et al. (2021) and Aswini et al. (2020) found that PPF enhance toughness, energy absorption, and crack-bridging capacity, but the fibers have no significant effect on uniaxial compressive strength. Najaf et al. (2022a, 2022b) and Najaf, Orouji and Zahrai (2022) have shown that recycled or produced polymeric fibers may contribute significantly to flexural and impact resistance, and ductility, in particular, when applied with reactive auxiliary materials. Hussain and Aljalawi (2022) also observed that PPF lowers microcracking and enhances freeze-thaw resistance on some of the high-performance mixes.

Combined Use of WGP and PPF

Recent research indicates positive synergies in combining WGP and PPF. Najaf et al. (2022) examined lightweight mixes that were composed of WGP, nanosilica, and recycled polypropylene fibers and found that they increased nonlinear behavior and tensile performance over mixes with no fibers. Asgarian et al. (2023) compared the strength, microstructure, and life-cycle consequences of WGP and PPF mixes and revealed that WGP increases the densification of the matrix and PPF regulated crack propagation - both enhancing the post-peak toughness and ecological footprint. Orouji and Najaf (2023) examined high-performance beams using glass powder, microsilica and PPF (and GFRP rebars) and found that it resulted in increased flexural resistance and ductility. Another possibility investigated by Loganathan et al. (2020) is a hybrid fiber system with glass powder, in which toughness and residual load capacity during flexure were enhanced.

Practical, Workability, and Mix Design

Several authors draw attention to practical issues: WGP may have a positive effect on water demand and decrease slump unless it is substituted with admixtures or optimised particle packing (Loganathan et al., 2020; Mohammed, 2024). PPF is more likely to decrease workability when used in large quantities and possibly necessitate the use of superplasticisers in order to achieve

the target slump (Singh, 2022; Malek et al., 2021). It is important to optimise fibre volume fraction and glass powder fineness, then, with experimentations generally showing optimum performance of modest WGP replacements (of about 510 percent) and minimal doses of PPF (0.51.5 percent by volume) to balance strength, ductility, and workability (Najaf et al., 2022; Hussain and Aljalawi, 2022).

Gaps and Motivation to Current Study

Despite the extensive evidence that WGP and PPF alone enhance certain concrete properties, a comparatively small number of systematic experimental studies have been conducted on their combined effect across various mechanical tests (compressive, split tensile, and flexural) for a single grade (e.g., M30). Also, such aspects as long-lasting behaviour, optimum replacement/fibre ratios of local materials, and trade-offs between early-age strength and sustainability indicators should be investigated (Asgarian et al., 2023; Najaf et al., 2022). This gap encourages the current experimental program in determining the WGP (5 and 10 % cement replacement) and PPF (0.75-1.0% by volume) at controlled M30 mix and workability and mechanical performance of the 7, 14 and 28 days.

Research objectives

The primary objective of this research is to investigate the effect of waste glass powder (WGP) as partial cement replacement and polypropylene fibers (PPF) as reinforcement on the strength and workability of M30 grade concrete.

The specific objectives are:

#To determine the impact of cement replacement 5 percent and 10 percent WGP on the compressive strength of concrete.

#To investigate the effect of polypropylene fibers (0.75 to 1.0 in terms of volume) on split tensile strength and flexural strength of concrete.

#To test the workability of fresh concrete with WGP and PPF through the slump cone test.

#To determine the mechanical and physical properties of control concrete (CC) in comparison to the WGP- and PPF-modified concrete mixes.

#To determine the best replacement level of WGP and dosage of PPF to provide the best balance between the strength, ductility and workability.

#To show the prospects of integrating WGP and PPF as an environmentally friendly, sustainable approach to the contemporary building process.

Research Methodology

Nomenclature of Mixes

To identify the specimens with different percentages of waste glass powder (WGP) and polypropylene fibers (PPF), the following mix designations were used:

- **CC** : Conventional concrete (control mix, no replacement).
- **WG5** : Concrete with **5% cement replaced by WGP**.
- **WG10** : Concrete with **10% cement replaced by WGP**.
- **WG10 + PF1** : Concrete with **10% WGP and 1% polypropylene fibers** by volume.

Mix Proportion

- **Grade of Concrete:** M30 (as per IS 10262:2019).
- **Mix proportion (Cement : Fine Aggregate : Coarse Aggregate):** 1 : 1.5 : 2.8.
- **Water–cement ratio:** 0.45.
- **Cement:** OPC 53 grade.

Details of Specimens

For the experimental investigation, specimens of three different geometries were prepared to evaluate the **compressive, split tensile, and flexural strengths** of concrete mixes. Each mix category (CC, WG5, WG10, WG10 + PF1) was cast in sufficient numbers to allow testing at different curing ages.

(a) Cube Specimens

- **Size:** 150 × 150 × 150 mm
- **Purpose:** To determine the compressive strength of concrete.
- **Number of specimens:** 24 (6 specimens per mix).
- **Curing ages:** 7, 14, and 28 days.

(b) Cylindrical Specimens

- **Size:** 150 mm diameter × 300 mm height
- **Purpose:** To determine the split tensile strength of concrete.
- **Number of specimens:** 24 (6 specimens per mix).
- **Curing ages:** 7 and 28 days.

(c) Beam Specimens

- **Size:** 500 × 100 × 100 mm
- **Purpose:** To determine the flexural strength of concrete under two-point loading.
- **Number of specimens:** 24 (6 specimens per mix).
- **Curing age:** 28 days.

Properties of Materials

The properties of all the constituent materials in this investigation were calculated according to pertinent IS codes. Ordinary Portland Cement (OPC 53 grade) was the primary binder, natural river sand was the fine aggregate, crushed granite was the coarse aggregate, crushed glass powder (WGP) was the partially replaced cement and polypropylene fibres (PPF) were secondary

reinforcement. A summary of the detailed properties of each material is given in Table 1.

Table 1. Properties of Materials Used in the Study.

Material	Property	Value / Range	Standard / Remarks
Cement (OPC 53 grade)	Specific Gravity	3.14	IS 4031 (Part 11)
	Fineness (%)	3.2	IS 4031 (Part 2)
	Standard Consistency (%)	31	IS 4031 (Part 4)
	Initial Setting Time	110 minutes	IS 4031 (Part 5)
	Final Setting Time	320 minutes	IS 4031 (Part 5)
Fine Aggregate (Sand)	Specific Gravity	2.63	IS 2386 (Part 3)
	Fineness Modulus	2.72	Zone II (IS 383)
	Bulk Density (kg/m ³)	1600	Rodded condition
Coarse Aggregate (20 mm)	Specific Gravity	2.70	IS 2386 (Part 3)
	Bulk Density (kg/m ³)	1500	Rodded condition
	Water Absorption (%)	0.5	IS 2386 (Part 3)
Waste Glass Powder (WGP)	Specific Gravity	2.55	Laboratory tested
	Particle Size	< 75 μ m	Ground glass dust
	Major Component (SiO ₂)	68–72 %	XRF analysis
Polypropylene Fibers (PPF)	Fiber Length	12 mm	Manufacturer data
	Diameter	30–40 μ m	Manufacturer data
	Tensile Strength (MPa)	400–600	ASTM C1116
	Modulus of Elasticity (GPa)	3.5–4.0	ASTM C1116
	Density (g/cm ³)	0.91	–

Results and analysis

The experimental study was conducted using M30 grade concrete with some cement being replaced by waste glass powder (WGP) at 5 per cent and 10 per cent, and polypropylene fibres (PPF) at 1 per cent in terms of volume. The modified concrete mixes were compared to the control concrete (CC) in terms of their performance. Workability, compressive strength, split tensile strength and flexural strength test results are shown below.

Workability (Slump Test)

Table 2 presents the slump values of the various mixes. We have observed that workability decreases with increasing WGP content, which is due to the angular form of the glass powder and its greater surface area. An additional slump was observed to be reduced by adding PPF since the fibres prevent the free flow of the concrete mix.

Table 2. Slump Values of Concrete Mixes.

Mix ID	% WGP	% PPF	Average Slump (mm)	Variation (%) from CC
CC	0	0	120	–
WG5	5	0	105	-12.5
WG10	10	0	95	-20.8
WG10 + PF1	10	1	80	-33.3

Compressive Strength

The compressive strength results at 7, 14 and 28 days are presented in Table 3 and Fig. 1. The results indicate that replacement of cement with 5% WGP improves strength compared to CC, due to the pozzolanic action of finely ground glass. At 10% WGP, a slight reduction was observed, but strength remained within acceptable limits. The addition of 1% PPF (WG10 + PF1) improved compressive strength compared to WG10, as fibers helped in controlling microcracks.

Table 3. Compressive Strength of Concrete (N/mm²).

Mix ID	7 days	14 days	28 days	% Variation from CC (28d)
CC	22.1	25.4	30.0	–
WG5	23.5	27.1	32.2	+7.3
WG10	21.8	24.2	28.6	-4.7
WG10 + PF1	23.0	26.0	31.0	+3.3

Split Tensile Strength

The results of split tensile strength at 7 and 28 days are given in Table 4 and Fig. 2. The inclusion of PPF significantly enhanced tensile strength due to the fiber bridging effect. At 10% WGP, tensile strength decreased slightly, but the combination of WGP and PPF showed improved performance.

Table 4. Split Tensile Strength of Concrete (N/mm²).

Mix ID	7 days	28 days	% Variation from CC (28d)
CC	1.80	2.45	–
WG5	1.85	2.55	+4.1
WG10	1.70	2.35	-4.1
WG10 + PF1	1.95	2.70	+10.2

Flexural Strength

Table 5 and Fig. 3 present the flexural strength values obtained after 28 days. WGP did not produce a significant impact on flexural strength, but the addition of PPF resulted in a significant effect on ductility and post-cracking behaviour.

Table 5. Flexural Strength of Concrete (N/mm²).

Mix ID	28 days	% Variation from CC
CC	4.20	–
WG5	4.35	+3.6
WG10	4.00	-4.8
WG10 + PF1	4.55	+8.3

Discussion

The experimental findings exhibit the effect of the waste glass powder (WGP) and polypropylene fibers (PPF) on fresh and hardened properties of concrete. It is possible to discuss the following key observations:

Workability: The values of the slump diminished gradually as the content of WGP was added and even further reduced by the addition of PPF. This may be explained by the fact that the surface area of WGP particles is high and thus enhances water demand, and that the fibre interlocking effect limits the mobility of fresh concrete. They found similar results when Loganathan et al. (2020) and Hussain and Aljalawi (2022) reported lower workability when using WGP and PPF incorporation. The mixes became reduced in terms of workability, but that was still an acceptable range to be compacted properly.

Compressive Strength: Compressive strength increased at 7 and 28 days with the replacement of 5% WGP in comparison to the control concrete. The pozzolanic reaction of finely ground glass can explain this and as such, the reaction leads to the formation of secondary calcium silicate hydrate (C–S–H) to refine the pore structure and increase the strength. Nevertheless, when WGP was as high as 10% the strength was found to be slightly lower since excess replacement lowered cementitious content, which also happened with Singh (2022) and Mohammed (2024). When WG10 and PF1 were mixed and PPF was added, the strength was improved relative to that of WG10, with fibers reigniting microcracks and slowing down the crack propagation as noted by Najaf et al. (2022a).

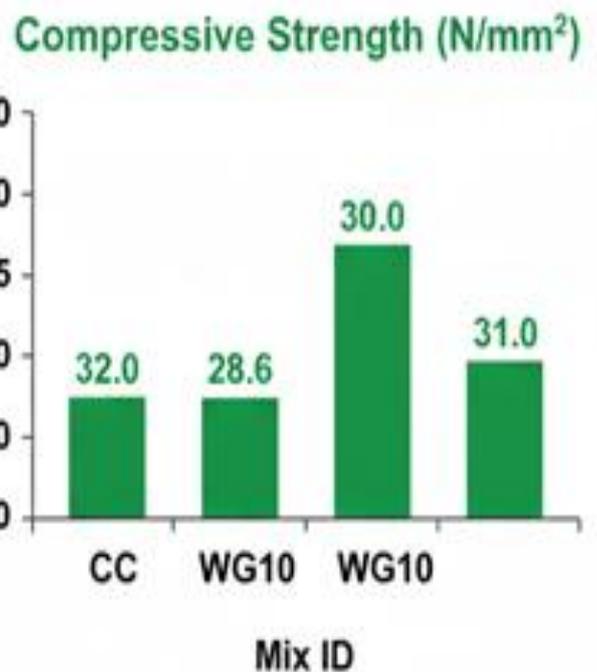
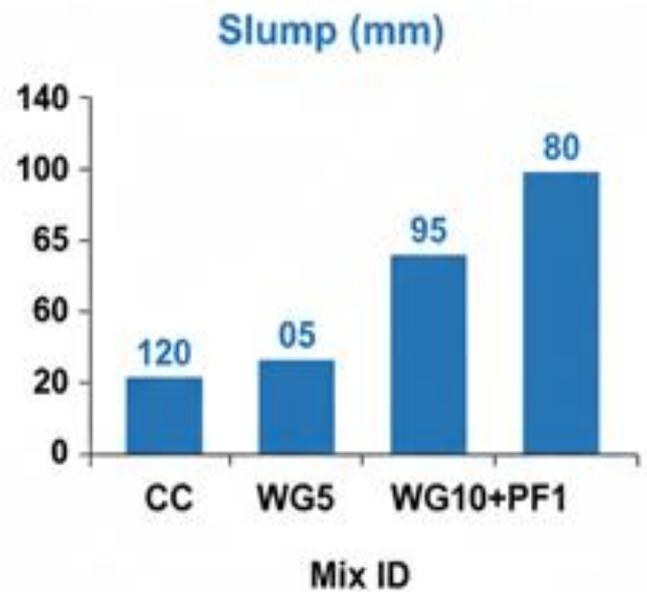
Split Tensile Strength: Microcracking is more likely to affect the tensile strength of concrete. The findings indicated that PPF was much stronger in split tensile compared to fiber-free mixes. The reason is that PPF was a crack-bridging mechanism, which passed stresses through microcracks and slowed their enlargement. In WG10 + PF1, the mitigation was the most significant of them, as fibers offset the decreased tensile strength of WGP. The results correspond to Malek et al. (2021), who emphasized the importance of polypropylene fibers in increasing toughness and ductility.

Flexural Strength: The flexural strength was improved marginally in the presence of WGP alone and considerably when used in combination with PPF. WG10 + PF1 mixture had the greatest flexural strength, which means that the synergetic effect of the WGP and PPF is favourable after the crack load carrying capacity. This is in line with the findings of Asgarian et al. (2023) and Orouji and Najaf (2023), who provided better flexural

performance with the use of fibers together with pozzolanic material.

Table 5. Concrete Mix Properties at 28 Days.

Mix ID	Slump (mm)	Compressive Strength (28 days) N/mm ²	Split Tensile Strength (28 days) N/mm ²	Flexural Strength (28 days) N/mm ²
CC	120	30.0	2.45	4.20
WG5	105	32.2	2.55	4.35
WG10	95	28.6	2.35	4.00
WG10+PF1	80	31.0	2.70	4.55



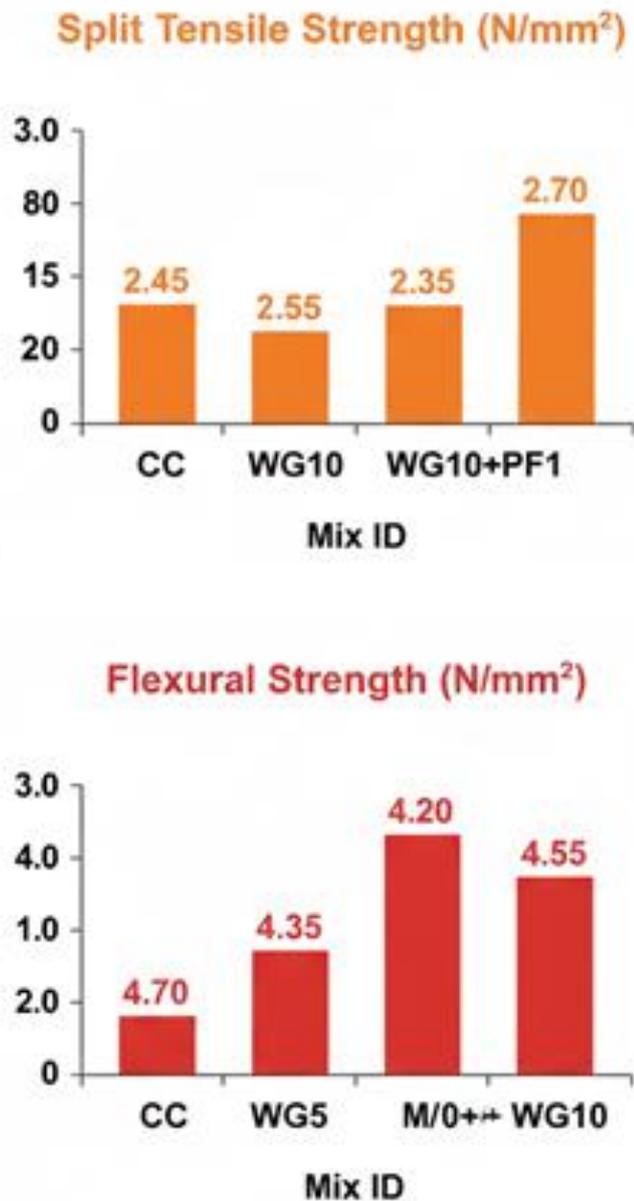


Figure 1. Concrete Mix Properties at 28 Days.

Conclusions

According to the experimental investigation of the M30 grade concrete partly substituted with waste glass powder (WGP) instead of cement and polypropylene fibers (PPF) added, the following conclusions were made:

- The workability of the concrete decreased with the concentration of WGP content and also decreased with the addition of PPF. The minimal slump was registered in the WG10 + PF1 mix.
- The compressive strength of the concrete improved by 5 per cent replacement with WGP over the control concrete, implying optimal performance at this level. Compressive strength reduced slightly at 10% replacement but the addition of 1% PPF aided in regaining strength loss.
- The tensile strength increased significantly after adding PPF as fibres, offering the

bridging action of cracks and increasing ductility. WG10 + PF1 had the most tensile strength amongst all mixes.

- PF addition to the flexural strength of concrete enhanced flexural strength and exhibited improved post-cracking behavior. WG10 + PF1 had a better flexural capacity than control concrete.
- The waste glass powder with its pozzolanic properties helps in contributing to the long-term strength development, whereas the polypropylene fibers help in the toughness and durability.
- A mixture of WGP (maximum 10%) and PPF (1%) produces concrete which is balanced in terms of strength, ductility and sustainability, an important attribute in structural as well as eco-friendly applications.
- On the whole, the present research confirms that the use of WGP and PPF is not only effective in enhancing the chosen mechanical properties but also a sustainable method of waste exploitation and decreasing cement usage during concrete production.

Declaration of Conflicting Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

- Asgarian, A., Roshan, N., & Ghalehnavi, M. (2023). The Strength, Microstructure, and Ecological Assessment of Concrete Mix Incorporating Waste Glass Powder and Polypropylene Fiber. *SSRN Electronic Journal*, pp. 1-30. <https://doi.org/10.2139/ssrn.4238330>
- Aswini, R., Anees, K., & Rao, P. (2020). Influence of Polypropylene Fibre Additive in Cement and Glass Powder as Partial Replacement of Fine Aggregate in Compressive strength of Concrete.
- Bisen, H., Jethwa, K. B., Ray, M. R., Mishra, U., Kumar, K., Kumar, P., ... Singh, A. N. (2024). Analyze the Effect of Steel Waste on Performance Characteristics of Concrete. *International Journal of Experimental Research and Review*, 45(Spl Vol), 41–55. <https://doi.org/10.52756/ijerr.2024.v45spl.004>
- Hussain, A., & Aljalawi, N. (2022). Effect of Sustainable Glass Powder on the Properties of Reactive Powder Concrete with Polypropylene Fibers. *Engineering, Technology & Applied Science Research*, 12(2), 8388–8392. <https://doi.org/10.48084/etasr.4750>

- Loganathan, G., Sumathi, A., & Mohan, K. S. R. (2020). Influence of waste glass powder and hybrid fibers on high strength concrete. *The VIIth International Young Researchers' Conference – Physics, Technology, Innovations (PTI-2020)*, 2313, 020018. <https://doi.org/10.1063/5.0029749>
- Małek, M., Łasica, W., Kadela, M., Kluczyński, J., & Dudek, D. (2021). Physical and Mechanical Properties of Polypropylene Fibre-Reinforced Cement–Glass Composite. *Materials*, 14(3), 637. <https://doi.org/10.3390/ma14030637>
- Najaf, E., Abbasi, H., & Zahrai, S. M. (2022). Effect of waste glass powder, microsilica and polypropylene fibers on ductility, flexural and impact strengths of lightweight concrete. *International Journal of Structural Integrity*, 13(3), 511–533. <https://doi.org/10.1108/ijsi-03-2022-0039>
- Najaf, E., Orouji, M., & Zahrai, S. (2022). Improving nonlinear behavior and tensile and compressive strengths of sustainable lightweight concrete using waste glass powder, nanosilica, and recycled polypropylene fiber. *Nonlinear Engineering*, 11, 58 - 70. <https://doi.org/10.1515/nleng-2022-0008>
- Narayana Rao, U., Kumar, N. V., Kavitha, C., Madhavi, Y., & Chowdary, P. (2024). Polycarboxylate Superplasticizers Used in Concrete: A review. *International Journal of Experimental Research and Review*, 38, 69-88. <https://doi.org/10.52756/ijerr.2024.v38.007>
- Orouji, M., & Najaf, E. (2023). Effect of GFRP rebars and polypropylene fibers on flexural strength in high-performance concrete beams with glass powder and microsilica. *Case Studies in Construction Materials*, 18, e01769. <https://doi.org/10.1016/j.cscm.2022.e01769>
- Pawan D., & Sathe, Y. U. (2024). Exploring the synthesis processes of graphene oxide and silicon dioxide nanospheres: A comprehensive study. *Journal of the Textile Association*, 85(4), 416–421. <https://doi.org/10.5281/zenodo>
- Singh Rathore, S. (2022). Investigation On, The Effect Of Polypropylene Fiber and Waste Glass Powder On High Performance Concrete. *Journal of University of Shanghai for Science and Technology*, 24(03), 33–37. <https://doi.org/10.51201/jusst/22/0254>
- Somavanshi, P. D., & Sathe, Y. U. (2023). Evaluating the electrochemical performance of graphite and silicon-based materials in energy storage device. *REDVET - Revista electrónica de Veterinaria*, 24(4), 474–482. <https://doi.org/10.69980/redvet.v24i4.1277>
- Tamboli, S., Imam, A., Mishra, U., Kumar, K., Mishra, S., Ray, M., Kumar, P., & Yadav, N. (2024). A Research on Fresh and Hardened Concrete Residences with Partial Replacement of Recycled Coarse Aggregates Obtained from Demolition and Construction Waste. *International Journal of Experimental Research and Review*, 42, 343-350. <https://doi.org/10.52756/ijerr.2024.v42.030>

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