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INVESTIGATING THE IMPACT OF GGBS AND FLY ASH ON PET CONCRETE RC BEAMS

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ABSTRACT

Using recycled plastic as fiber aggregate in concrete has garnered attention due to its potential to enhance ductility properties, bolster durability, and mitigate cracking. By integrating recycled plastic fibers into concrete, sustainability is promoted by reducing new plastic production and extracting virgin aggregate. This research endeavors to explore the integration of finely graded Polyethylene terephthalate (PET) at a specific volume ratio of 1% in concrete. It is common practice to substitute cement with fly ash and ground granulated blast furnace slag (GGBS) to decrease the overall cement content. The primary aim is to augment mechanical properties and flexural behavior by partially substituting cement with GGBS and Fly Ash in PET concrete, thereby improving pore-filling effects. The investigation encompasses varying replacement percentages of GGBS (10%, 20%, 30%, 40%, 50%) and Fly Ash (10%, 20%, 30%, 40%, 50%) in PET concrete of M30 grade, determining the optimal replacement percentage to be 30% for both materials. Mechanical properties and flexural behavior of beams with two different cross-sections (1500 mm x 150 mm x 150 mm) and (1500 mm x 230 mm x 230 mm) are meticulously scrutinized using 30% replaced GGBS and Fly Ash in PET concrete. Test outcomes reveal that GGBS in PET concrete yields superior strength compared to Fly Ash, with the replacement of 30% GGBS demonstrating enhanced strength and durability in reinforced concrete beams.

Keywords: PET concrete, workability, plastic waste, flexural behaviour, fly ash, GGBS.

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1. INTRODUCTION

In recent decades, plastic pollution has emerged as a pressing global issue, affecting numerous regions due to the rapid expansion of the plastics industry. This problem poses threats to human health, contributes to environmental degradation and waste accumulation, and presents challenges due to its non-biodegradable nature. The widespread use of plastic materials and their composites is driven by factors such as affordability, lightweight characteristics, water resistance, expandability, and strength, leading to the generation of an estimated 400 million tons of plastic waste annually. One innovative approach to addressing this waste issue involves repurposing residual polymer materials in concrete to enhance its ductility properties. Recycling presents a viable solution to the problem of mounting plastic waste.
Concrete, as the most utilized construction material globally, carries significant environmental implications, particularly regarding the release of carbon dioxide and harmful gases during cement production. To mitigate the carbon footprint associated with cement production, it is feasible to substitute cement with supplementary materials or industrial by-products, such as fly ash (F.A.), ground granulated blast furnace slag (GGBS), and silica fume (S.F.). By replacing cement with GGBS, the occurrence of thermal cracks, shrinkage cracks, voids, and permeability can be minimized, while simultaneously improving workability and durability owing to its fine particle size.

Awham *et al*. (2018) conducted a study on the utilization of PET as flake aggregate, exploring concentrations of 1%, 3%, 5%, 7%, and 10% by weight of cement. Their findings revealed that the addition of 1% PET led to a remarkable 58% increase in compressive strength and a 23% increase in flexural strength. Moreover, a 3% PET ratio resulted in a notable 25.59% enhancement in flexural strength. Additionally, the incorporation of 1% PET yielded a significant 130% increase in splitting tensile strength [1].

Hamsa *et al*. (2020) employed PET fibers in beams measuring 150 x 200 x 1400 mm, observing a reduction in the workability of fresh concrete. However, their study highlighted improvements in flexural strength and ductility with the use of PET fibers, albeit with decreases in ultimate load and compressive strength. Notably, the inclusion of 1.5% PET in concrete led to increases in both compressive and flexural strength [2].

Dora Foti (2012) utilized long strips of circular PET material to enhance the malleability characteristics of cement, surpassing steel-welded wire mesh. Introducing PET fibers and strips into concrete resulted in improved structural durability, reduced production costs, and mitigated the risk of steel corrosion-related structural deterioration, while concurrently addressing the issue of plastic waste [4]. Jahidul et al. (2016) investigated the replacement of coarse aggregate with PET, employing various mix proportions of 20%, 30%, 40%, and 50%.

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They found that the highest strength was achieved with a 20% PET replacement, resulting in a compressive strength 9% higher than that of regular concrete with a water-cement ratio of 0.42. Their research indicated that lower percentages of PET and a reduced water-cement ratio contributed to improved concrete strength [5]. Abdulkader *et al*. (2022) examined the addition of plastic fibers (at concentrations of 0.75%, 1.25%, and 1.75%) in beams measuring 100 x 150 x 1100 mm. They observed that compressive strength increased in beams with 0.75% and 1.25% plastic fibers by 5% and 2.5% respectively, while flexural strength and elastic modulus improved, except for the beams containing 1.75% fibers. Their research suggested that strength and elastic modulus decrease with higher percentages of plastic fibers [3].

Nabajyoti *et al*. (2013) conducted a study examining the replacement of natural aggregates with PET aggregates of varying sizes and proportions (5%, 10%, and 15%). Their findings revealed that as the percentage of plastic aggregate increased, the strength, elasticity modulus, and density of the resulting concrete decreased. Moreover, the size and shape of the PET aggregate impacted the water-cement ratio and slump of the concrete [6]. In their investigation, Richie et al. (2020) explored the incorporation of PET as a replacement for fine aggregate in concrete, using quantities of 5%, 10%, and 15%, with different curing durations (3, 7, 14, and 28 days). The study demonstrated that the workability and flexural strength of the concrete were improved. Notably, concrete containing 5% PET exhibited sustained high compressive strength even after 28 days of curing [7]. Pavia and Condren compared the durability of concrete made with GGBS (Ground Granulated Blast Furnace Slag) to that of ordinary Portland cement (OPC) concrete when exposed to silage effluent. Their study concluded that the GGBS composites displayed superior toughness compared to the OPC composites [8].

Various researchers, including Oliveira and Castro-Gomes [9], Subramani and Rahman [10], Choi *et al*. [11], and Jo *et al*. [15], have investigated the incorporation of PET fibers or aggregates in concrete mixtures, focusing on optimizing percentages, evaluating creep behavior, and achieving improved tensile strength, crack resistance, and ductility. Fly ash's global acceptance in concrete has provided rheological improvements and long-term performance advantages, albeit with potential reductions in early-age strength [20]. In a study by Borg, the inclusion of PET fibers in concrete led to a significant reduction in compressive strength with higher PET fiber content [21]. Bamigboye explored the feasibility of producing roof tiles from PET waste and river sand [22].
The current body of literature predominantly centers on the replacement of aggregates with PET, with minimal attention given to combining PET substitution with aggregates. Previous research has highlighted the enhanced strength and flexural properties achieved through 1% PET replacement with aggregates. This study seeks to thoroughly examine the structural behavior and strength of beams by integrating different proportions of GGBS and fly ash as partial cement replacements, alongside the inclusion of PET in the concrete mix. Furthermore, the study will assess the behavior of PET fiber-reinforced RC beams in conjunction with GGBS and fly ash.

2. MATERIAL PROPERTIES AND MIX QUANTITIES

PET is a versatile polymer possessing both amorphous and semi-crystalline characteristics, commonly utilized as a waterproofing material, notably in the form of lightweight, colorless plastic bottles for beverages. In this study, PET bottles sourced from landfills and dump yards were mechanically cut into small flake-like pieces. These PET flakes were then combined with cement, fine and coarse aggregates, and ground granulated blast furnace slag (GGBS) as a substitute material, along with water to form a fiber. The PET used in this investigation exhibits a specific gravity ranging from 1.38 to 1.40 and a density of 1.

For the experimental setup, OPC 53 grade cement was employed, characterized by a specific gravity of 3.15 as per the density bottle technique. The components, including aggregates, were bound together using cement. Fine aggregates, with particle sizes less than 4.75 mm, were categorized as fine aggregates, possessing a specific gravity of 2.52. Coarse aggregates, sized larger than 4.75 mm, were classified as coarse aggregate, with a specific gravity of 2.71. In this study, cement was partially replaced with ground GGBS up to 50% and fly ash up to 30%, with increments of 10%. PET fiber was fixed at 1% by volume of the concrete based on existing literature. Following Indian standards (IS:10262 - 2019) and considering material properties, conventional M30 concrete and PET concrete were prepared. The mixed proportions, incorporating limited replacements of Ordinary Portland Cement by 0% to 50% GGBS and 0% to 50% fly ash with a 10% increment, were determined. Table-1 presents the quantities of the mix for one cubic meter of concrete.

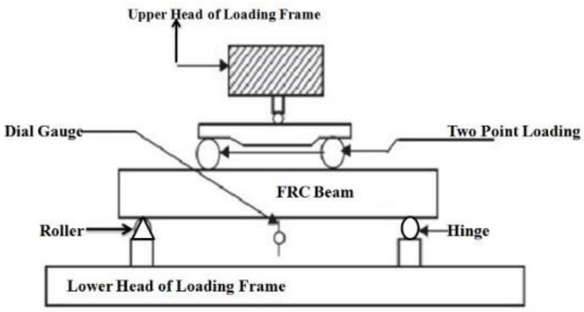

Figure-1. Typical loading condition for flexural test.

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Table-1. Mix quantities for (kg/m^3).

Mix Designation	Percent of Replacement	Cement	Fine Aggregates	Coarse Aggregates	GGBS	Fly ash
PG0	Conventional	413.3	728.58	1058.77	0	0
PG1	10%	371.99	707.07	1040.19	41.33	0
PG2	20%	330.67	707.07	1040.19	82.66	0
PG3	30%	289.33	707.07	1040.19	123.99	0
PG4	40%	247.99	707.07	1040.19	165.33	0
PG5	50%	206.66	707.07	1040.19	206.66	0
PG 6	10%	371.99	707.07	1040.19	0	41.33
PG 7	20%	330.67	707.07	1040.19	0	82.66
PG 8	30%	289.33	707.07	1040.19	0	123.9
PG 9	40%	247.99	707.07	1040.19	0	165.33
PG 10	50%	206.66	707.07	1040.19	0	206.66
Water- 186 Lt, W/C – 0.45, and PET (1%) – 18.2 kg/m3						

3. EXPERIMENTAL INVESTIGATION

The focus of the present study lies in evaluating the mechanical properties and flexural attributes of beams. Results indicate that the ideal replacement ratio for GGBS and fly ash is capped at 30%. The flexural performance of beams reinforced with PET fibers was investigated by varying longitudinal and cross-sectional dimensions. This comprehensive assessment encompassed various analyses, including load versus deflection, stress-strain behavior, load normalization curve, and moment normalization curve. Testing involved applying two-point loading on the beams, as depicted in Figure-1, offering a visual depiction of the overall load configuration in the experimental setup.

3.1 Preparation of specimens

This research considered various types of concrete samples, all prepared according to specific mix design proportions and left to harden. After 24 hours of casting, the samples underwent curing. Beams were tested after 28 days of curing, while cubes, cylinders, and prisms were tested on both the 7th and 28th days of curing. After 28 days of curing, the entire beams were coated with whitewash to observe crack patterns during load application. The samples included standard Cubes (150 mm x 150 mm x 150 mm), Prisms (100 mm x 100 mm x 500 mm), and Cylinders (150 mm diameter x 300 mm height). Additionally, there were six beams: Beam 1 (1500 mm x 150 mm x 150 mm) made of conventional concrete, Beam 2 (1500 mm x 150 mm x 150 mm) made of GGBS with PET concrete, Beam 3 (1500 mm x 150 mm x 150 mm) made of fly ash with PET concrete, Beam 4 (1500 mm x 230 mm x 230 mm) made of conventional concrete, Beam 5 (1500 mm x 230 mm x 230 mm) made of GGBS with PET concrete, and Beam 6 (1500 mm x 230 mm x 230 mm) made of fly ash with PET concrete. Deflections were observed using a dial gauge with a least count of 0.001. High-yield strength deformed (HYSD) steel bars were employed as tension reinforcement in structural elements, yielding positive outcomes for reinforced structures. Specifically, 8 mm diameter bars were used as stirrups in beams, while longitudinal reinforcement for beams consisted of two 10 mm diameter bars at the top and 12 mm diameter bars at the bottom, by specifications outlined in IS 1786. A total of 66 specimens (cubes, prisms, and cylinders) and 6 beams were cast and cured for durations of 7 and 28 days.

Table-2. Mechanical properties of specimen.

Studies	Specimen name and size	Testing age	Equipment
Compressive strength	Cube (150 x 150 x 150 mm$^)$	7,28	2000 kN Compression Testing Machine
Splitting Tensile strength	Cylinder (150 mm Dia x 300 mm Length)	7,28	2000 kN Compression Testing Machine
Bending strength	Prism (500 x 100 x 100 mm^3)	7, 28	100 kN Beam Testing Machine

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Table-3. Flexural properties of beams with different cementitious blending.

S. No	Sample ID	Dimensions (mm)	Remarks
1	Beam 1	1500 × 150 × 150	conventional
2	Beam2	1500 × 150 × 150	PET with GGBS
3	Beam 3	1500 × 150 × 150	PET with fly ash
4	Beam 4	1500 × 150 × 230	conventional
5	Beam 5	1500 × 150 × 230	PET with GGBS
6	Beam 6	1500 × 150 × 230	PET with fly ash

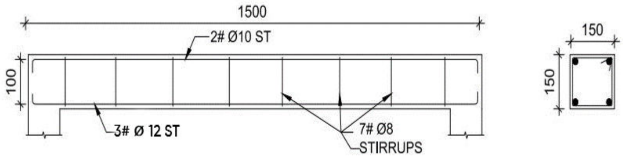

Figure-2. Beam 1-3 for flexural test specimen.

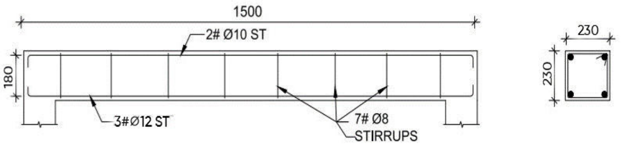

Figure-3. Beam 4 - 6 for the flexural test specimen.

4. RESULTS AND DISCUSSIONS

4.1 Mechanical Properties

To ascertain the mechanical properties (by IS: 516-1959), strength evaluations were conducted on varying replacement levels of GGBS (PG0 - 0%, PG1 - 10%, PG2 - 20%, PG3 - 30%, PG4 - 40%, and PG5 - 50%) and fly ash (PG0 - 0%, PG6 - 10%, PG7 - 20%, PG8 - 30%, PG9 - 40%, and PG10 - 50%) with 1% PET in M30 grade concrete. These assessments were performed at both 7 and 28 days.

Analysis of the results depicted in Figures 5, 7, 9, 10, 11, and 12 revealed a consistent increase in strength from 10% to 30% replacement levels, with 30% replacement yielding the highest strength for both GGBS and fly ash. However, at 40% GGBS and 50% replacement levels, the strength exhibited a decline relative to the 30% replacement threshold. Notably, among all replacement levels, 50% of replacement exhibited the lowest strength.

For the strength tests, a 2000kN compressive testing machine was employed. The machine applied load at a rate of approximately 140 kg/cm2 per minute until the specimen failed. A prism measuring 100 x 100 x 500 mm was utilized in the setup, with two steel rollers ensuring consistent load application.

Figure-4. Compressive strengths of concrete cube.

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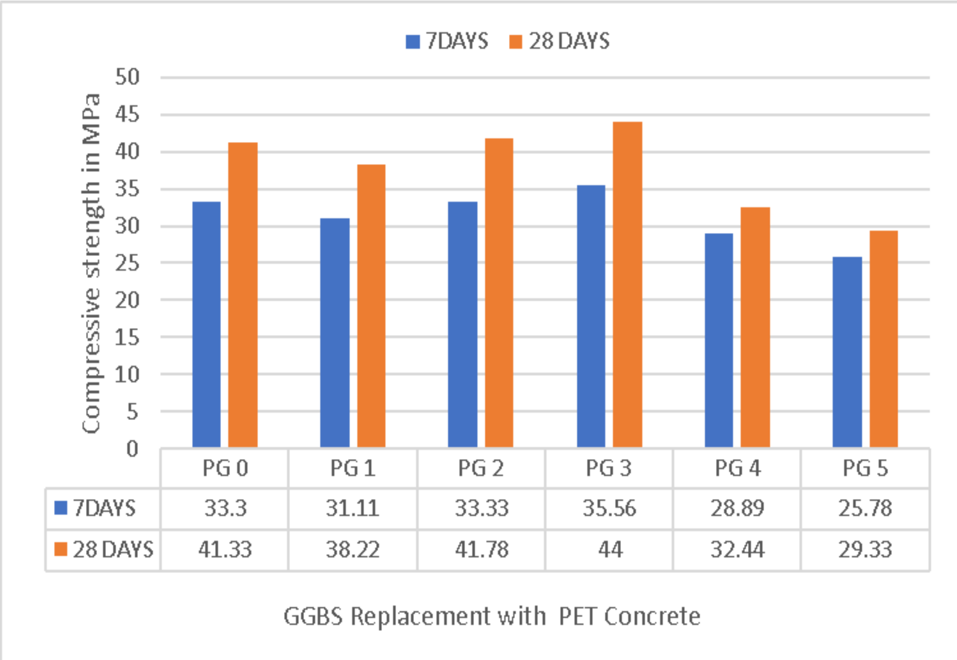

Figure-5. GGBS with PET Concrete compressive strength after 7 and 28 Days.

Observing Figure-5, it was noted that the compressive strength consistently increased from 10% to 30% replacement levels for GGBS (10% - 38.22 MPa, 20% - 41.78 MPa, and 30% - 44 MPa), with 30% replacement achieving the highest strength. However, at 40% (32.44 MPa) and 50% (29.33 MPa) replacement levels, 50% replacement exhibited the lowest strength among all levels. Specifically, GGBS replacement at 30% demonstrated significantly higher strength compared to conventional concrete.

Figure-6. Splitting tensile strength of concrete cylinder.

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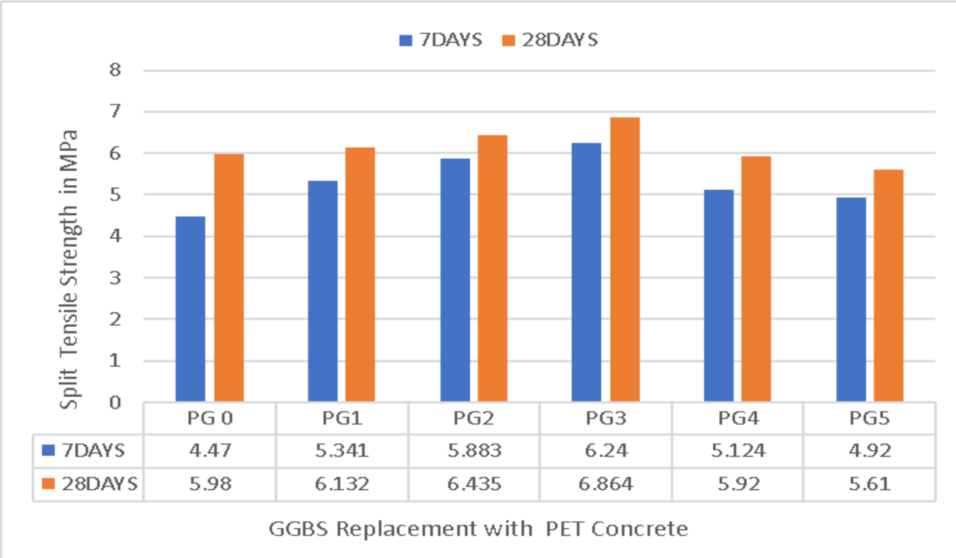

Figure-7. GGBS with PET concrete splitting tensile strength after 7 and 28 Days.

Examining Figure-7, it was noted that the splitting tensile strength consistently increased from 10% to 30% replacement levels for GGBS (10% - 6.132 MPa, 20% - 6.435 MPa, and 30% - 6.864 MPa), with 30% replacement achieving the highest strength. However, at 40% (5.92 MPa) and 50% (5.61 MPa) replacement levels, 50% replacement exhibited the lowest strength among all levels. Specifically, GGBS replacement at 30% demonstrated a 12.8% higher strength compared to conventional concrete.

Figure-8. Bending strength of concrete prism.

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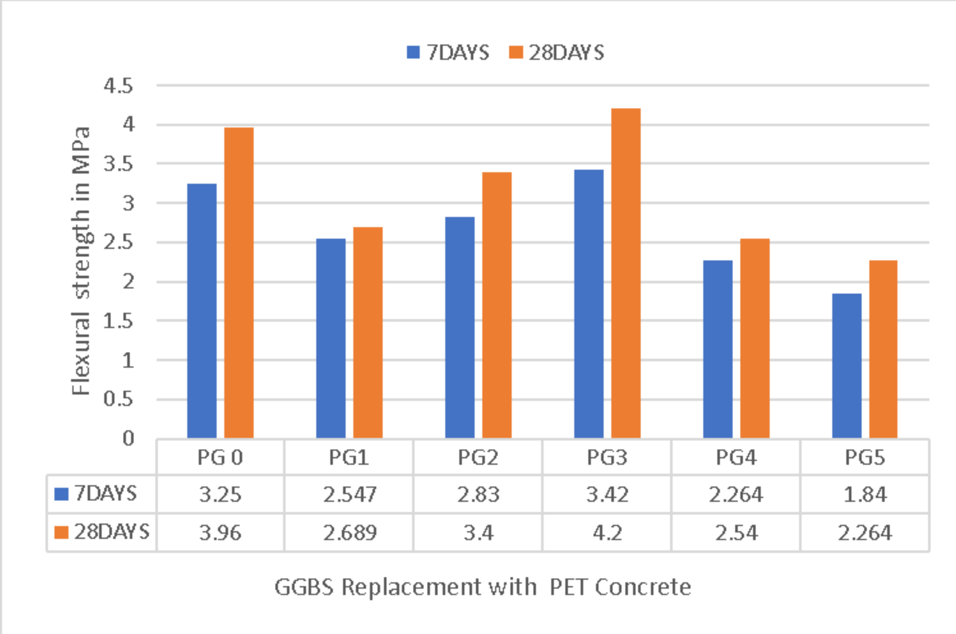

Figure-9. GGBS with PET concrete bending strength after 7 and 28 Days.

Analyzing Figure-9, it was observed that the bending strength consistently increased from 10% to 30% replacement levels for GGBS (10% - 2.689 MPa, 20% - 3.4 MPa, and 30% - 4.2 MPa), with 30% replacement achieving the highest strength. However, at 40% (2.54 MPa) and 50% (2.264 MPa) replacement levels, 50% replacement exhibited the lowest strength among all levels. Specifically, GGBS replacement at 30% demonstrated a 5.7% higher strength compared to conventional concrete.

From Figure-10, it was observed that the compressive strength consistently increased from 10% to 30% replacement levels for fly ash (10% - 35.33 MPa, 20% - 39.41 MPa, and 30% - 41.68 MPa), with 30% replacement achieving the highest strength. However, at 40% (38.46 MPa) and 50% (34.23 MPa) replacement levels, the strength decreased compared to the 30% replacement level. Among all the replacement levels, 50% of replacement exhibited the lowest strength. Specifically, fly ash replacement at 30% demonstrated a 1.2% higher strength compared to conventional concrete.

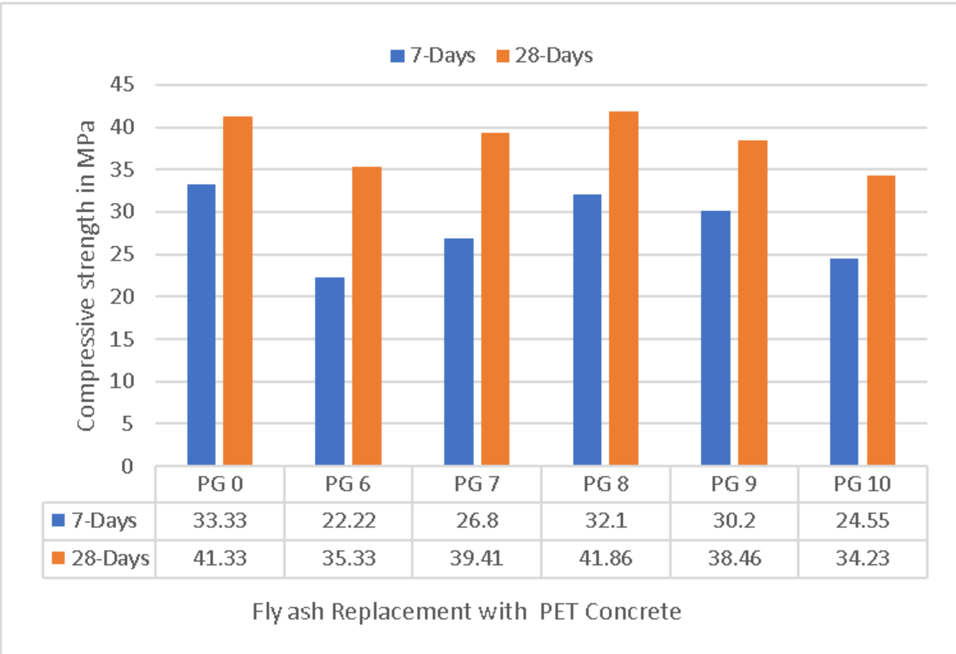

Figure-10. Fly ash with PET concrete compressive strength after 7 and 28 Days.

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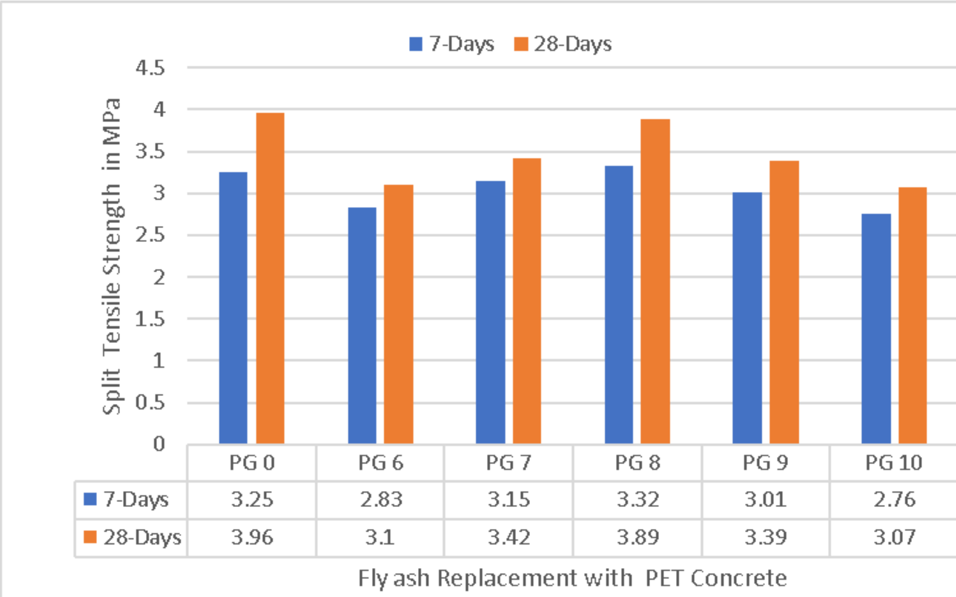

Figure-11. Fly ash with PET concrete splitting tensile strength after 7 and 28 days.

Examining Figure-11, it was observed that the splitting tensile strength consistently increased from 10% to 30% replacement levels for fly ash (10% - 3.1 MPa, 20% - 3.42 MPa, and 30% - 3.89 MPa), with 30% replacement achieving the highest strength. However, at 40% (3.39 MPa) and 50% (3.07 MPa) replacement levels, the strength decreased compared to the 30% replacement level. Among all the replacement levels, 50% of replacement exhibited the lowest strength. Specifically, fly ash replacement at 30% demonstrated a 1.76% lower strength compared to conventional concrete.

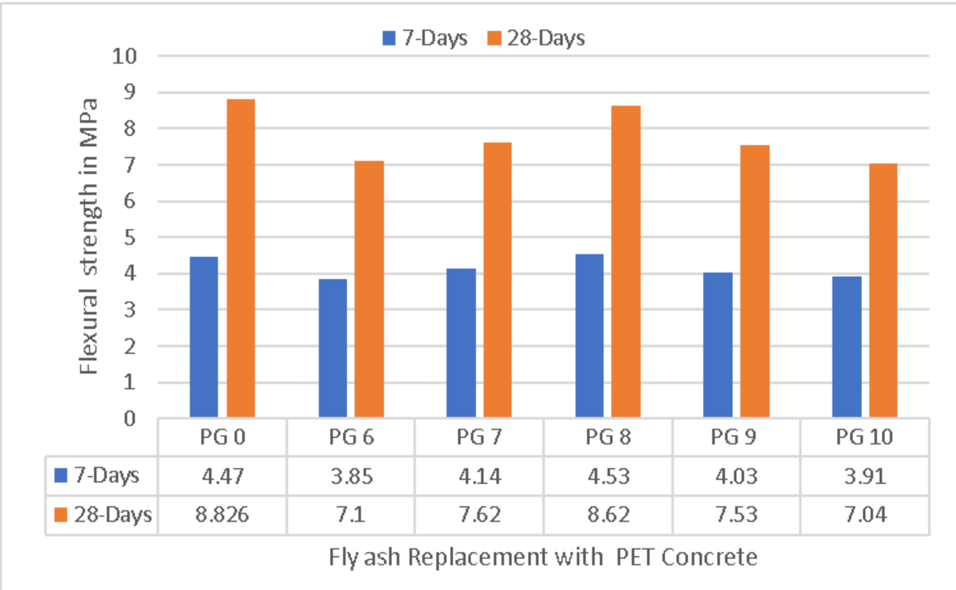

Figure-12. Flyash with PET concrete bending strength after 7 and 28 days.

Examining Figure-12, it was noted that the bending strength consistently increased from 10% to 30% replacement levels for GGBS (10% - 7.1 MPa, 20% - 7.62 MPa, and 30% - 8.62 MPa), with 30% replacement achieving the highest strength. However, at 40% (7.53 MPa) and 50% (7.04 MPa) replacement levels.

4.2 Flexural Behaviour of R. C Beams

After examining the mechanical properties, it was concluded that the optimal replacement ratio for both GGBS and fly ash was up to 30%. Subsequently, flexural studies were conducted using this 30% replacement ratio. Beam samples were simply supported on a rigid steel frame, utilizing a two-point loading setup for the tests. In

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all instances, beam failure commenced at mid-span, near the point of loading application.

Experimental investigations recorded the first cracking load and the ultimate capacity of the test beams. As illustrated in Figure 8, the ultimate load capacities and corresponding deflections of the beams are as follows: Beam 1 - ultimate load capacity of 122.2 kN with a deflection of 14.63 mm, Beam 2 - ultimate load capacity of 216.9 kN with a deflection of 10.92 mm, Beam 3 - ultimate load capacity of 119.8 kN with a deflection of 14.52 mm, Beam 4 - ultimate load capacity of 80 kN with a deflection of 6.03 mm, Beam 5 - ultimate load capacity of 190.2 kN with a deflection of 2.95 mm, and Beam 6 - ultimate load capacity of 60.8 kN with a deflection of 6.4 mm. It was observed from the curves that the load-deflection behavior initially follows a linear and elastic pattern, transitioning to nonlinear behavior leading to eventual beam failure. Flexural cracks, upon reaching the neutral axis, began to incline and persisted until beam failure.

Figure-13. Beam 1-3 tested on loading frame.

Figure-14. Beam 4 - 6 tested on loading frame.

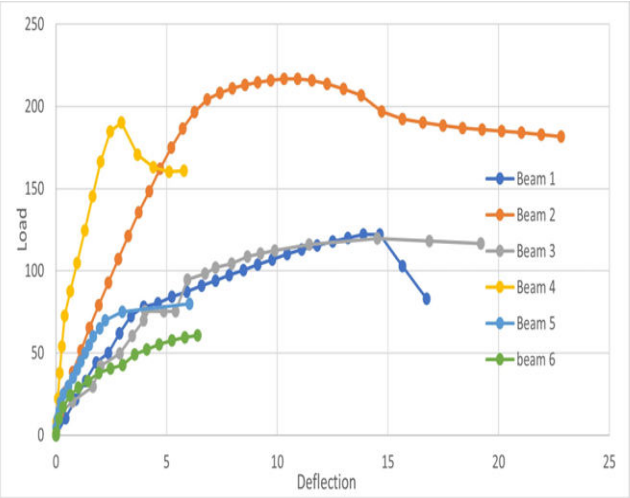

Figure-15. Applied load with mid span deflection for beams.

4.3 Stress-Strain Behavior

The stress-strain behavior describes how a material reacts to applied stress and undergoes deformation. Analyzing Figure-16, it becomes evident that the stress-strain behavior exhibited a linear relationship up to specific stress values for each beam. Specifically, Beam 1 reached stress of 0.00543 N/mm², Beam 2 reached 0.0096 N/mm², Beam 3 reached 0.00532 N/mm², Beam 4 reached 0.0040 N/mm², Beam 5 reached 0.003594 N/mm², and Beam 6 reached 0.00115 N/mm². These stress levels corresponded to strains as follows: Beam 1 - 0.009753, Beam 2 - 0.00728, Beam 3 - 0.0096, Beam 4 - 0.00151, Beam 5 - 0.00196, and Beam 6 - 0.00427.

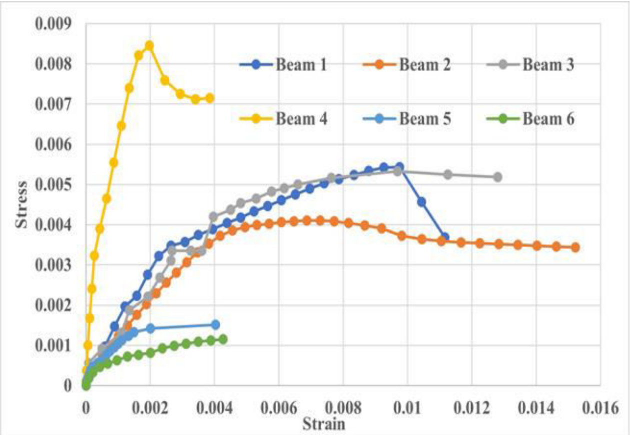

Figure-16. Stress-strain behavior for beams.

4.4. Normalization Curves

Figure-17 depicts the correlation between normalized lateral displacement (Δ/H) and normalized lateral load, where each lateral displacement is divided by the depth of the beam. This normalized lateral load is calculated by multiplying the concrete compressive strength with the concrete area (f_{ck}*b*d). It's important to note the substantial influence of shear force in this relationship.

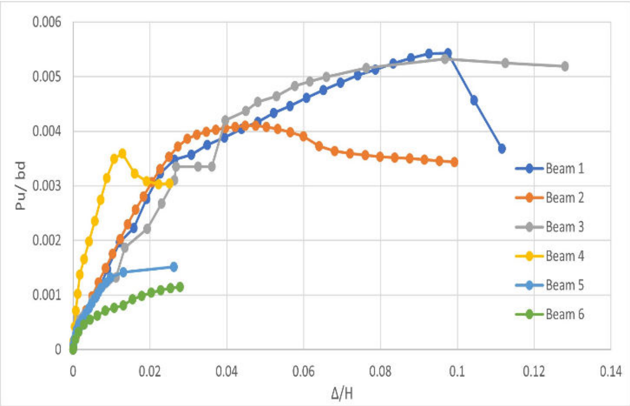

Figure-17. Load normalization curves for beams.

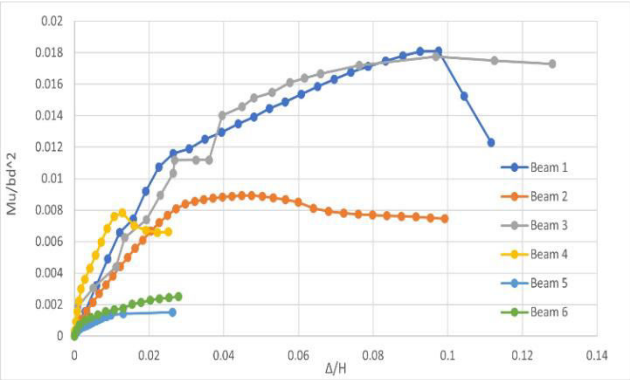

Figure-18. Moment normalization curves for beams.

Among the beams examined, beam 3 showed a notably higher ratio, whereas beam 6, lacking both shear and flexural reinforcement, displayed a lower shear force ratio. Additionally, Figure-18 illustrates the relatively larger contribution of the shear force ratio in beam 1 compared to other beams. Conversely, beam 5, also lacking both shear and flexural reinforcement, exhibited a low shear force ratio.

5. CONCLUSIONS

- To summarize, this study delved into the impact of incorporating GGBS and Fly Ash into PET concrete at varying replacement levels, focusing on their mechanical and flexural properties. At a GGBS replacement level of 30% and 1% PET content, M30-grade concrete demonstrated the highest compressive strength of 44 MPa, along with a splitting tensile strength of 6.864 MPa and a bending strength of 4.2 MPa.

- Conversely, when 10% of cement was replaced with Fly Ash and 1% PET, the mechanical properties of M30-grade concrete were comparatively lower.

- Beyond a 30% GGBS replacement in PET concrete, the mechanical properties, particularly the strength characteristics, were adversely affected. In comparison to Fly Ash substitution, the utilization of GGBS yielded superior mechanical properties.

- Regarding flexural behavior, Beam 2 (1.5m x 0.15m x 0.15m) with GGBS and PET concrete exhibited the highest strengths in load versus deflection and stress versus strain curves.

- The peak values of load normalization and moment normalization curves for Beam 3 (1.5 meters by 0.15 meters by 0.15 meters) composed of PET concrete and fly ash indicated favorable flexural behavior of the beam.

- The examination underscored the varied shear force ratios among the beams, underscoring the impact of reinforcement presence on structural behavior and emphasizing the necessity for meticulously planned designs to enhance load-bearing capacity.

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