Sustainable Concrete Development Using Fly Ash and Scrap Tire Rubber

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Abstract: The construction industry is one of the largest contributors to global carbon dioxide emissions due to extensive cement consumption. To address this environmental challenge, the present study investigates the feasibility of producing green concrete by incorporating fly ash as a partial cement replacement and scrap tire rubber as a coarse aggregate substitute in M25 grade concrete. Experimental investigations were conducted on mixes with fly ash replacements of 20%, 25%, and 30% and scrap tire replacements of 10%, 20%, and 30%. The performance of the modified concretes was evaluated in terms of workability, compressive strength, flexural strength, and split tensile strength at 7, 14, and 28 days of curing. The results indicate that the inclusion of fly ash improved the workability and contributed to long-term strength development due to its pozzolanic activity, while higher proportions of scrap tire reduced strength because of poor bonding at the interfacial transition zone. The optimum mix was observed at 25% fly ash and 20% scrap tire replacement, which achieved compressive strength of 26.0 MPa at 28 days, slightly higher than the control mix (24.9 MPa), along with an improvement of 13–14% in flexural strength and 11–14% in split tensile strength. However, beyond 30% replacement of either material, strength reductions became significant. This study demonstrates that the combined use of fly ash and waste tires can produce a sustainable and structurally viable concrete, contributing to reduced cement consumption, waste tire management, and mitigation of CO_2 emissions in the construction sector.

Keywords: *Fly Ash, Scrap Tire, Green Concrete, Compressive Strength, Sustainable Construction*.

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I. INTRODUCTION

Concrete is the most widely consumed construction material globally, surpassed only by water in terms of overall usage. Despite its versatility and strength, one major concern lies in the production of Portland cement—the principal binding agent in concrete—which is an energy-intensive process responsible for approximately 5–8% of worldwide carbon dioxide (CO_2) emissions. As infrastructure demand continues to rise, lowering the environmental footprint of cement-based materials has become a critical challenge in civil engineering and sustainability research.

One promising pathway to address this issue is the development of green concrete, which utilizes industrial by-products and waste materials to partially replace cement and natural aggregates, thereby conserving resources and reducing emissions. Among the various supplementary cementitious materials, **fly ash**, a by-product of coal-fired power plants, has received significant attention due to its pozzolanic activity, ability to refine pore structure, and potential to improve long-term strength and durability.

Similarly, the disposal of **scrap tires** has emerged as a serious environmental concern, with more than one billion tires discarded annually worldwide. These non-biodegradable materials pose ecological hazards when stockpiled or incinerated, as they release toxic pollutants. Recycling waste tires into construction applications, particularly as partial replacements for coarse aggregates in concrete, provides a sustainable waste management strategy. Beyond environmental benefits, rubber inclusion can improve ductility, impact resistance, and energy absorption capacity of concrete.

However, despite these advantages, studies indicate that tire rubber often reduces compressive and tensile strength due to poor adhesion and weak bonding at the interfacial transition zone (ITZ). Conversely, fly ash has been shown to enhance mechanical properties and durability through secondary hydration reactions. While each material individually has been extensively studied, there is relatively limited research on their **combined application in structural-grade concrete**. Furthermore, the optimal replacement levels that ensure strength, workability, and sustainability are not yet well established, particularly for

M25 grade concrete, which is widely used in Indian structural applications.

To bridge this gap, the present study explores the combined effect of fly ash (20–30% replacement of cement) and scrap tire rubber (10–30% replacement of coarse aggregates) in M25 concrete. The work specifically focuses on evaluating workability, compressive strength, flexural strength, and split tensile strength to identify an optimum mix that satisfies both mechanical performance and sustainability objectives.

II. OBJECTIVES

- To investigate the strength of green concrete by utilizing various materials on existing variations.
- To analyze the workability, compressive strength, flexural strength and split tensile strength of concrete by using 20%, 25%, 30% proportion of fly ash and10% 20% 30% proportion of scrap tires on M_{25} grade.
- To decrease carbon dioxide emission from the concrete and cement sector.
- Solving the problem of disposal of scrap tire and fly ash.
- To compare the expected variations to the ones that are already in place.

III. LITERATURE REVIEW

➢ *Fly Ash in Concrete*

The incorporation of fly ash as a supplementary cementitious material has been widely researched due to its pozzolanic reactivity and capacity to enhance durability. Kanthe et al. (2018) investigated binary and ternary blends of fly ash and rice husk ash in cement mortar, reporting that up to 30% replacement resulted in notable strength improvements and reduced material costs by nearly 20%. Similarly, Agarwal et al. (2018) demonstrated that cement substitution with 30–35% fly ash and waste glass significantly lowered CO_2 emissions while maintaining comparable strength levels. These findings confirm fly ash as an effective and sustainable partial cement replacement.

➢ *Scrap Tire Rubber in Concrete*

The reuse of waste tire rubber in concrete has attracted attention as a sustainable waste management solution. Siddique and Naik (2004) summarized early investigations, noting that while rubber aggregates generally reduced compressive strength, they enhanced ductility and impact resistance. More recently, Khan et al. (2022) evaluated concrete incorporating both scrap tires and fly ash in M20 mixes. Their results revealed strength reductions with higher tire contents but improved durability when fly ash was included. This highlights the potential of combined use, though research on structural-grade concrete remains limited.

➢ *Alternative Industrial By-Products*

A variety of other waste materials have also been explored as cement replacements. Admute and Nagarka (2017) showed that silica fume replacement at 5–15% improved concrete strength and sustainability, although excessive replacement caused performance losses. Ibrahim et al. (2018) studied alkali-activated binders and emphasized the influence of activator molarity and curing on strength development. Beyond material performance, Kono et al. (2018) conducted a multi-country sustainability assessment, highlighting that the adoption of green concrete must also consider environmental and social trade-offs across the supply chain.

➢ *Computational Approaches in Green Concrete*

Recent studies have also applied machine learning techniques to predict and optimize the properties of green concrete. Iqbal et al. (2019), for example, employed Gene Expression Programming (GEP) to forecast compressive and tensile strengths of mixes containing industrial by-products, demonstrating that computational models can reduce experimental workload and guide mix optimization with high accuracy.

➢ *Critical Gaps*

The literature consistently indicates that fly ash improves mechanical strength and sustainability, while tire rubber enhances ductility but weakens compressive performance. However, very few studies have comprehensively investigated the **combined effects of fly ash and tire rubber in structural-grade concrete (M25 and above)**. In particular, the optimum replacement levels that balance strength, durability, and workability are still not well defined in the Indian context. Addressing these gaps, the present study evaluates M25 green concrete incorporating 20–30% fly ash and 10–30% scrap tire rubber, aiming to determine optimal proportions that meet both performance and sustainability criteria.

Author & Year	Materials Used	Mix/Method	Main Findings	Relevance to Present Study
Khan et al. (2022) (5)	Fly ash + scrap tires (M20)	Partial replacement of cement & aggregates	Strength decreased with higher tire content; FA improved durability	Supports combined use; but limited to M20 grade
Iqbal et al. (2019) (6)	Foundry sand + GEP modeling	Predictive modeling	ML models accurately predicted compressive/tensile strength	Shows potential of computational optimization
Ibrahim et al. (2018) (7)	Alkali-activated binders	Varying SH molarity	Higher SH molarity (14M) increased strength by 24%	Highlights influence of binder chemistry
Kono et al. (2018) (8)	Green concrete in 6 countries	Hotspot analysis	Social & environmental trade-offs in sustainability	Indicates global sustainability challenges

Kanthe et al. (2018) (9)	Fly ash + rice husk ash	10–30% replacement	30% blend improved strength; reduced cost by ~20%	Confirms FA as effective SCM
Agarwal et al. (2018) (10)	Fly ash + glass powder	30–45% replacement	CO_2 emissions reduced by 35%; strength maintained	Reinforces SCMs for emission reduction
Admute et al. (2017) (11)	Silica fume + brick waste	5–20% replacement	5–15% silica improved strength; >20% reduced	Shows SCMs need optimization
Siddique & Naik (2004) (12)	Scrap tire rubber	Review	Lower compressive strength; better ductility & energy absorption	Confirms rubber benefits + limitations

The literature consistently emphasizes that while fly ash improves workability and strength, tire rubber reduces compressive strength due to poor bonding. Very few studies have systematically examined the combined effect of both materials at varying replacement levels in M25 grade structural concrete, particularly in the Indian context. This study addresses that gap by experimentally evaluating mechanical and workability performance of green concrete mixes incorporating both fly ash (20–30%) and scrap tire rubber (10–30%), with the goal of determining optimum proportions for sustainable applications.

IV. MATERIALS AND METHODOLOGY

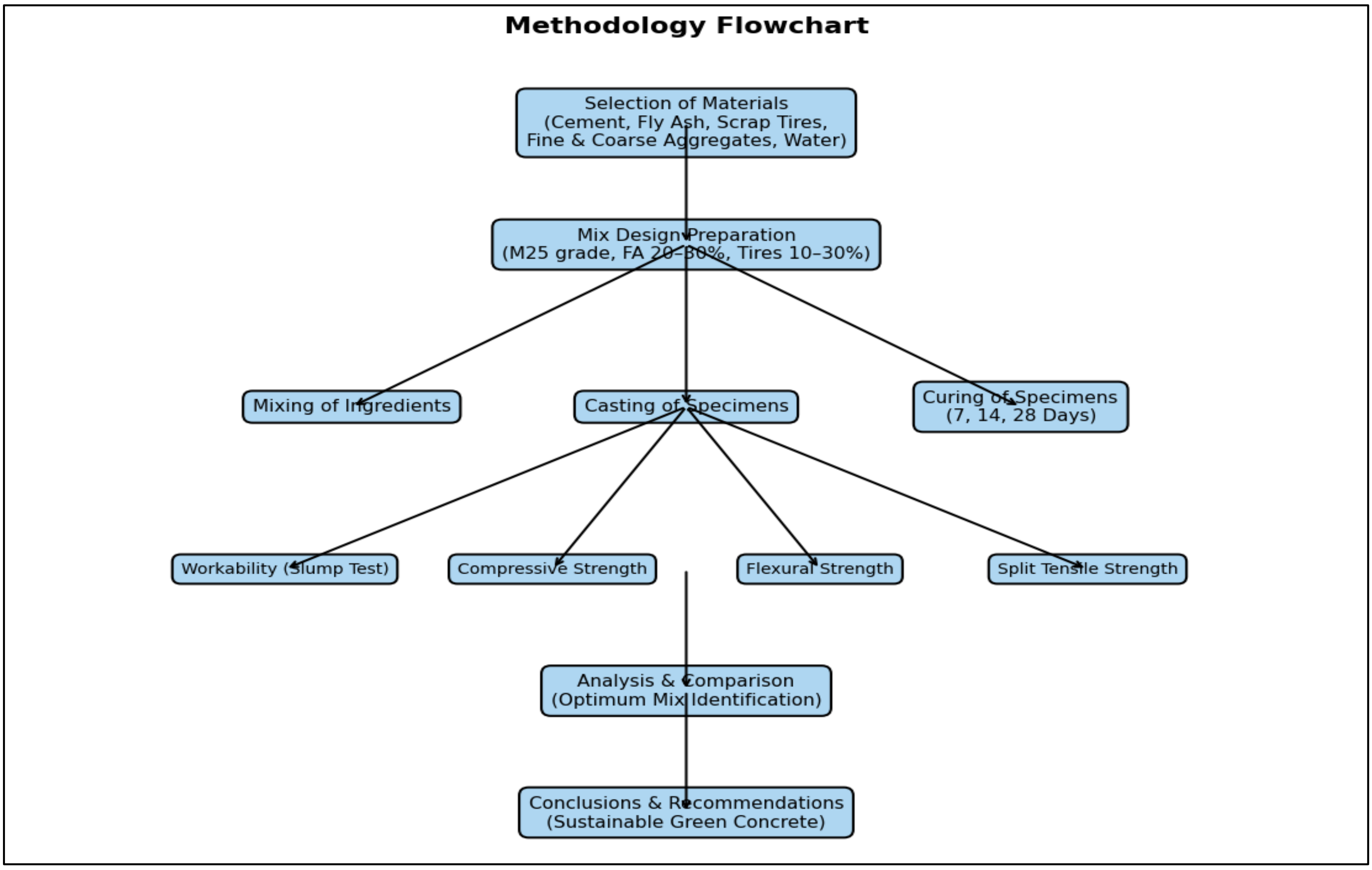

Fig 1 Flowchart of Methodology

The methodical approach used in this study to examine the performance of green concrete that incorporates fly ash and scrap tire rubber is depicted in the methodology flowchart. Ordinary Portland Cement (OPC), fly ash, scrap tire rubber, natural aggregates, and water were selected in compliance with pertinent Indian Standards at the start of the process. The next step is Mix Design Preparation, wherein M25 grade concrete mixes were created with different replacement percentages of scrap tires (10–30%) for coarse aggregates and fly ash (20–30%) for cement. In order to achieve consistent workability and strength development, the following step, mixing of ingredients, makes sure that all materials are properly homogenized, either mechanically or manually. When casting specimens, such as cubes, cylinders, and beams for various strength tests, the concrete was mixed and then poured into standard molds. (13-17)In order to fully develop hydration and pozzolanic reactions, these specimens were then placed under water for 7, 14, and 28 days during the Curing process. Following curing, the specimens were subjected to property testing. In accordance with IS codes, workability was evaluated using the slump test, compressive strength by cube testing, flexural strength by beam testing, and split tensile strength by cylinder testing. To ascertain the effect of fly ash and tire rubber replacements on workability

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and strength, the gathered test data was processed in the Analysis and Comparison stage. The outcomes were compared with the control mix. The best mix proportions that strike a balance between sustainability advantages and mechanical performance were highlighted in the conclusions and recommendations that followed. This encouraged the use of waste materials in environmentally friendly construction. (18-20).

➢ *Cement*

Ordinary Portland Cement (OPC) of 43 Grade was used as the primary binder. The cement conformed to IS 269:2015 specifications, and its chemical composition was determined in accordance with IS 4031 (Part 2–15). Table 1 presents the oxide composition, including CaO (63.17%), SiO_2 (19.98%), Al_2O_3 (5.17%), and Fe_2O_3 (3.27%), among others.

Table 1 Shows Chemical Composition of Cement

OXIDES	**CONTENT%**
CaO	63.17
SiO2	19.98
Al2O3	5.17
Fe2O3	3.27
MgO	0.78
SO3	2.39
L.S.F	0.86
I.R	1.46
L.O.I	1.88
All Alkalis	0.9

➢ *Coarse Aggregate.*

Locally sourced coarse aggregates with a nominal size of 20 mm were used. These aggregates met the grading and quality requirements of IS 383:1970. A sieve analysis was carried out on a 15 kg sample, and the gradation results are shown in Table 2.

Table 2 Shows Sieve Analysis of Coarse Aggregates

Sieve size (mm)	**Weight retained (gm)**	**% Retained**	**Cumulative % Retained**	**% Passing**	**Limits as per BIS 383:1970**
40	0	0	0	100	100
20	316	2.1	21	97.9	85-100
10	12,834	85.56	87.65	12.34	0-20
4.75	1745	11.65	99..30	0.7	0-5

➢ *Fine Aggregate*

Natural river sand with a maximum size of 4.75 mm was utilized as the fine aggregate. The sand complied with IS 383:1970 specifications. A sieve analysis was conducted on a 1.5 kg sample, with results presented in Table 3, confirming that the sand falls within Zone II grading requirements.

Table 3 Shows Sieve Analysis of Fine Aggregates

Sieve size	**Weight retained (gm)**	**% Retained**	**Cumulative % Retained**	**% Passing**	**Limits for zone II as per BIS 383:1970**
10 mm	0	0	0	100	100
4.75 mm	27	1.8	1.8	98.2	90-100
2.36 mm	7	0.46	2.46	97.74	75-100
1.18 mm	343	28.93	31.19	68.81	55-90
600 microns	270	18	49.19	50.81	35-59
300 microns	427	28.46	77.65	22.35	8-30
150 microns	263	17.53	95.18	4.82	0-10

➢ *Scrap tires.*

Shredded waste tires with an average particle size of approximately 20 mm and a specific gravity of 1.15 were used as a partial replacement for coarse aggregates. The material was selected due to its availability and potential for sustainable waste management.

- *Water*

Potable water with a pH of around 7 was used for mixing and curing, in compliance with IS 456:2000 guidelines.

- *Fly Ash:*

Class F fly ash obtained from a nearby thermal power plant was incorporated as a cement replacement material. Its chemical composition included SiO_2 (35–60%), Al_2O_3 (15–30%), Fe_2O_3 (5–20%), and CaO (1–20%), as shown in Table 4.

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Table 4 Shows Chemical Composition of Fly-Ash

Component	Typica Range (%by weight)
(LOI)	0.5-10
(K_2O)	0.1-3
(Na_2O)	0.1-2
(SO_3)	0.1-5
(MgO)	0.5-5
(CaO)	1-20
(Fe_2O_3)	5-20
(Al_2O_3)	15-30
(SiO_2)	35-60

➢ *Mix Design and Casting*

Concrete mixes were designed for M25 grade in accordance with IS 10262:2019. Fly ash replaced cement at levels of 20%, 25%, and 30%, while scrap tire rubber substituted coarse aggregates at levels of 10%, 20%, and 30%. A control mix with no replacements was also prepared for comparison. After proportioning, materials were dry-mixed to ensure uniform blending, followed by the addition of water to achieve the target slump. The fresh concrete was placed into standard molds (150 mm cubes, 150 × 300 mm cylinders, and 100 × 100 × 500 mm beams) in three layers, each compacted using a vibrating table.

Curing and Testing

All specimens were demolded after 24 hours and then cured in clean water at 27 ± 2 °C for 7, 14, and 28 days. After curing, the following tests were conducted as per IS codes:

- *Workability:*
  Assessed by the slump cone test (IS 1199:1959).

- *Compressive Strength*
  Measured on 150 mm cubes in accordance with IS 516:1959.

- *Flexural Strength:*
  Determined on beam specimens (100 × 100 × 500 mm) following IS 516:1959 guidelines.

- *Split Tensile Strength:*
  Evaluated on 150 × 300 mm cylinders using the same standard.

V. RESULT AND DISCUSSION

This section presents the results of workability, compressive strength, flexural strength, and split tensile strength of M25 grade green concrete mixes incorporating varying proportions of fly ash and scrap tire rubber. The results are compared with the control mix and analyzed in relation to material behavior.

Table 5 Shows Slump Value of Different Concrete Mixes.

Proportions ratios	Slump value (mm)	
Cement: fly Ash	**Coarse aggregates: scrap tires**	**M_{25} mix design**
100:00	100:00	76
	90:10	68
	80:20	61
	70:30	49
80:20	100:00	78
	90:10	70
	80:20	63
	70:30	54
75:25	100:00	88
	90:10	77
	80:20	64
	70:30	52
70:30	100:00	89
	90:10	81
	80:20	73
	70:30	61

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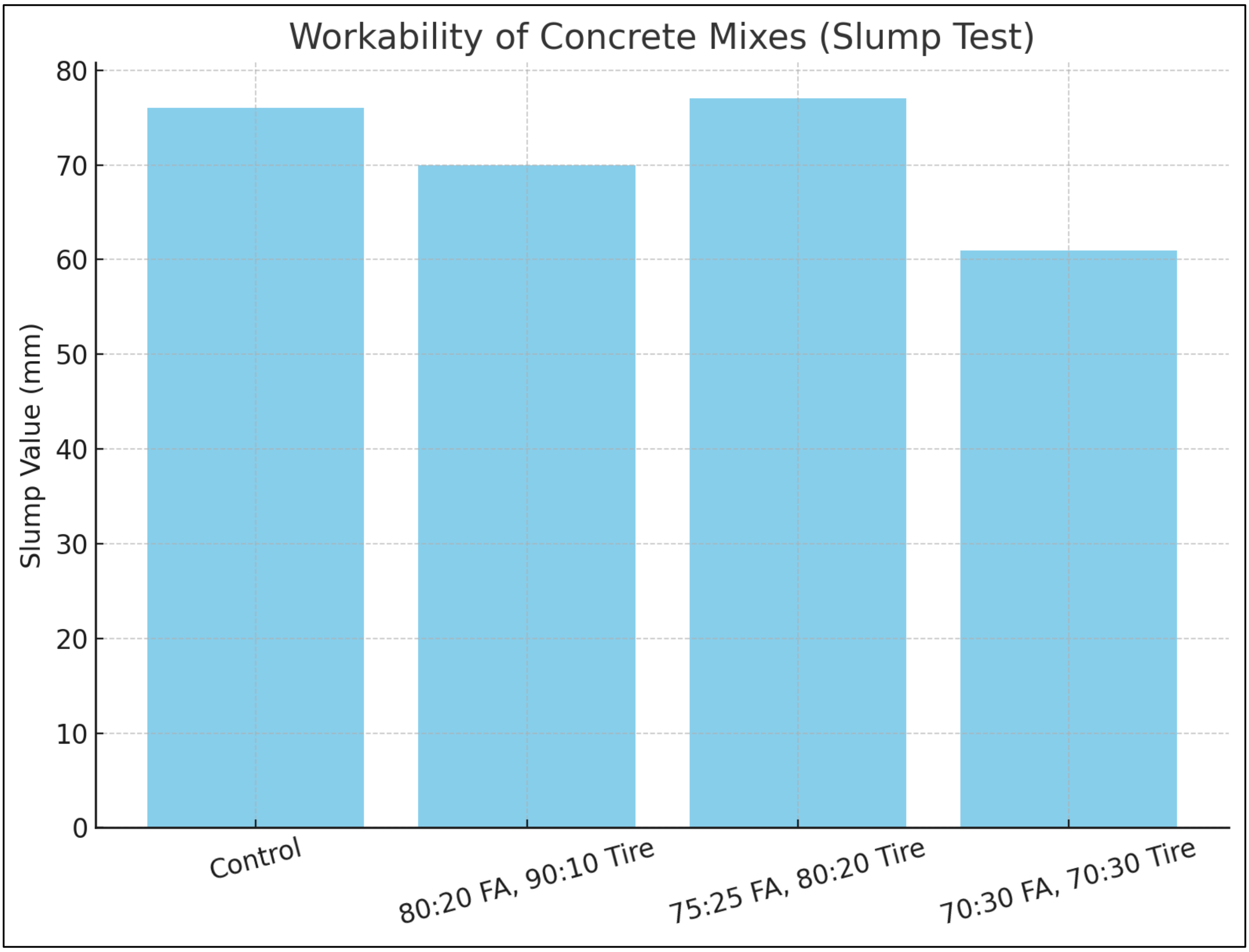

Fig 2 Workability of Concrete Mixes

The slump test results (Table 5, Figure 2) demonstrated that workability decreased as the proportion of scrap tire rubber increased. For the control mix, the slump was 76 mm, which reduced to 49 mm at 30% tire replacement. This reduction can be attributed to the irregular surface texture and hydrophobic nature of rubber particles, which hinder proper cohesion with the cement paste.

In contrast, the inclusion of fly ash improved the workability of fresh mixes. The maximum slump value of 88 mm was observed with 25% fly ash, reflecting the spherical particle shape of fly ash that promotes better flow ability and particle packing.

Interpretation: Fly ash enhances workability due to its micro-filler effect and smooth particle morphology. Scrap tire rubber decreases slump because of poor wettability and angularity. The combined influence indicates that fly ash can partially compensate for the loss of workability caused by rubber aggregates.

➢ *Compressive Strength*

The compressive strength of all mixes was evaluated at 7, 14, and 28 days (Table 6, Figure 3). The optimum strength was obtained for the mix containing 25% fly ash and 20% tire rubber, which achieved 26.0 MPa at 28 days—slightly higher than the control mix (24.9 MPa). Beyond 30% replacement of either material, strength reductions were significant.

- *Interpretation*

a) Fly Ash Contribution: Long-term strength gains are due to secondary hydration reactions, where fly ash reacts with calcium hydroxide to form additional calcium silicate hydrate (C–S–H), leading to pore refinement.
b) Effect of Tire Rubber: Rubber reduces compressive strength because of weak adhesion at the interfacial transition zone (ITZ) between hydrophobic rubber and cement paste.
c) Balanced Mix: The 25% fly ash + 20% tire rubber mix provided an optimal balance, where the strength-enhancing effect of fly ash offset the reduction associated with rubber, resulting in a net improvement.

Table 6 Shows Compressive Strength of Concrete

Proportions		Compressive strength (MPa)		
Cement: fly-ash	Coarse aggregates: scrap tires	7 days	14 days	28 days
100:00	100:00			
	90:10	16.5	19.8	23.98
	80:20	15.5	`18.63	23.32
	70:30	14.2	17.8	21.97
80:20	100:00	17.2	20.8	25.4
	90:10	16.8	20.2	25.1
	80:20	16.1	19.03	24.5
	70:30	14.o9	18.65	22.9
75:25	100:00	17.6	21.33	26.00
	90:10	17.01	20.04	25.91
	80:20	16.89	19.5	25.67
	70:30	16.25	18.01	24.03
70:30	100:00	16.01	18.59	23.3
	90:10	15.20	18.21	22.5
	80:20	14.39	17.43	21.97
	70:30	13.98	16.99	20.75

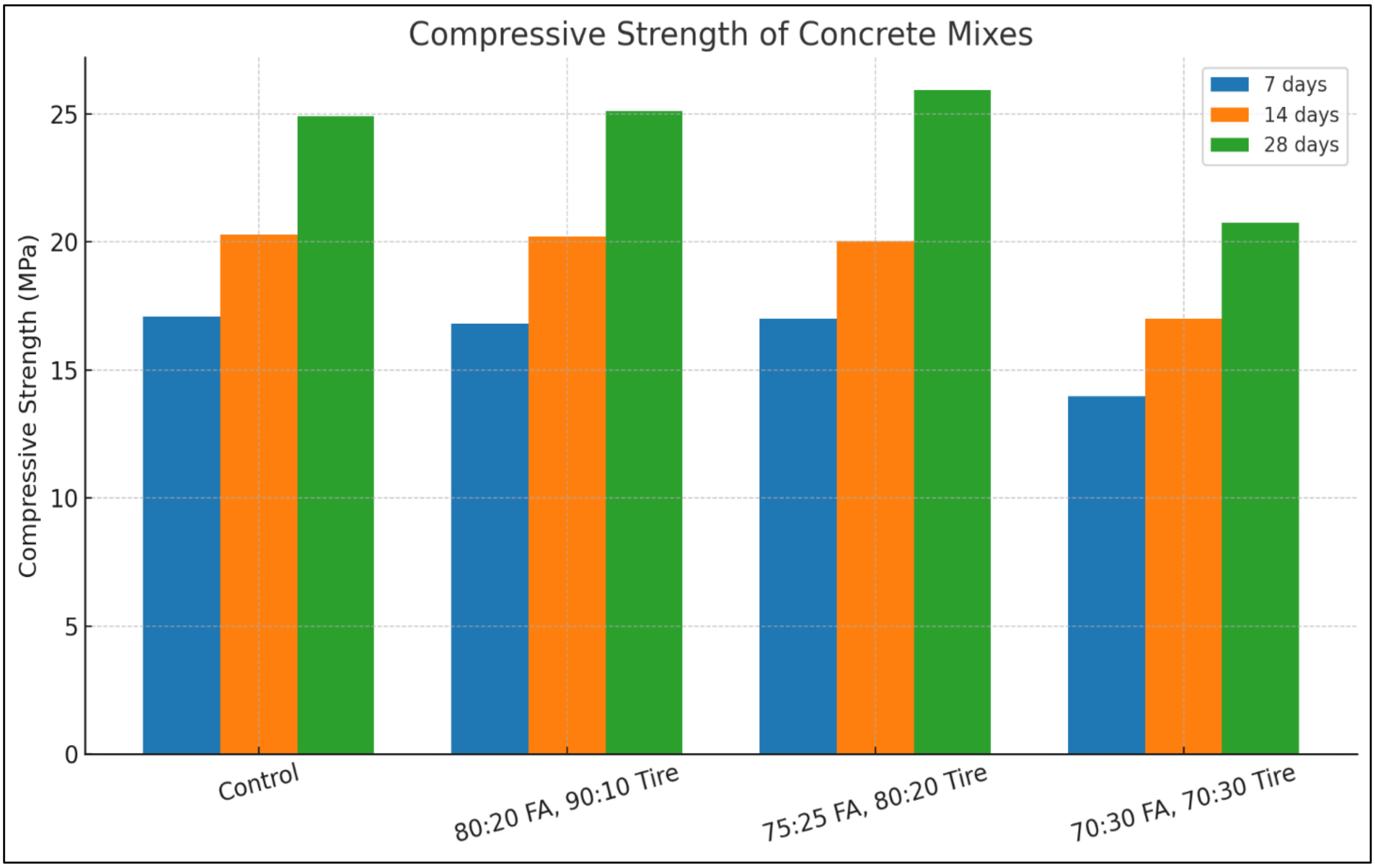

Fig 1 Compressive Strength of Different Concrete Mixes

➢ *Flexural Strength*

Flexural strength results (Table 7, Figure 4) indicated that the optimum mix (25% fly ash + 20% rubber) exhibited a 13–14% improvement compared to the control, reaching 3.97 MPa at 28 days versus 3.48 MPa for the reference mix. However, when rubber replacement exceeded 30%, strength dropped considerably.

- *Interpretation*

a) Scrap tire rubber enhances ductility and energy absorption, which benefits flexural behaviour.
b) Fly ash contributes to improved microstructure and stiffness, counteracting the softening effect of rubber.
c) Excessive rubber content decreases stiffness, leading to a reduction in load-bearing capacity.

Table 7 Shows Flexural Strength of Concrete

Proportions		Flexural strength (MPA)	
Cement: fly Ash	**Coarse aggregates: scrap tires**	**7 days**	**28 days**
100:0	100:00	2.84	3.486
	90:10	2.76	3.42
	80:20	2.59	3.33
	70:30	2.48	3.19
80:20	100:00	2.62	3.6
	90:10	2.58	3.49
	80:20	2.5	3.42
	70:30	2.39	3.37
75:25	100:00	3.09	3.86
	90:10	2.002	3.92
	80:20	3.21	3.97
	70:30	2.89	3.79
70:30	1 00:00	2.71	3.316
	90:10	2.64	3.192
	80:20	2.37	3.068
	70:30	2.26	2.915

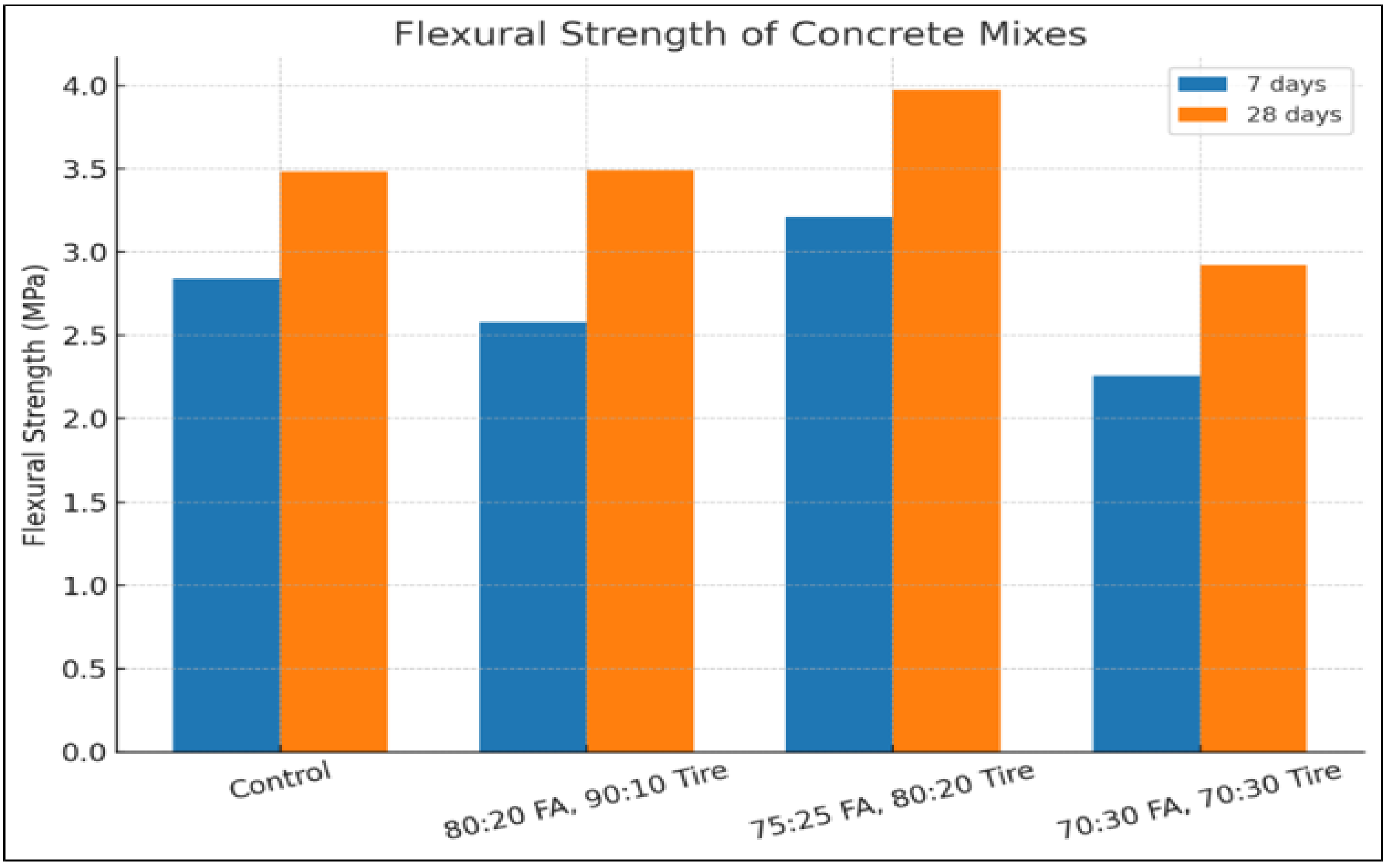

Fig-4 Flexural Strength of Different Concrete Mixes

➢ *Split Tensile Strength:*

Split tensile strength followed trends similar to compressive and flexural strengths (Table 8, Figure 5). The optimum mix (25% fly ash + 20% rubber) recorded an 11–14% improvement over the control. At 30% rubber replacement, tensile strength declined sharply.

➢ *Interpretation:*

- Rubber particles enhance tensile resistance due to their elastic nature, providing better crack bridging and energy absorption.
- Fly ash improves tensile behaviour by densifying the cement matrix and strengthening the ITZ.
- The combined effect at optimal proportions leads to improved tensile properties, while excessive rubber weakens the matrix.

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Table 8 Shows Split Tensile Strength of Concrete

Proportions		Split tensile strength (Mpa)	
Cement: fly Ash	**Coarse aggregates: scrap tires**	**7 days**	**28 days**
100:0	100:00	2.09	2.54
	90:10	2.001	2.81
	80:20	1.89	2.68
	70:30	1.7	2.59
80:20	100:00	2.3	2.87
	90:10	2.35	2.92
	80:20	2.13	2.67
	70:30	1.89	2.51
75:25	100:00	2.4	2.86
	90:10	2.31	2.81
	80:20	2.36	2.912
	70:30	2.16	2.73
70:30	100:00	1.923	2.81
	90:10	1.810	2.69
	80:20	1.65	2.40
	70:30	1.47	2.33

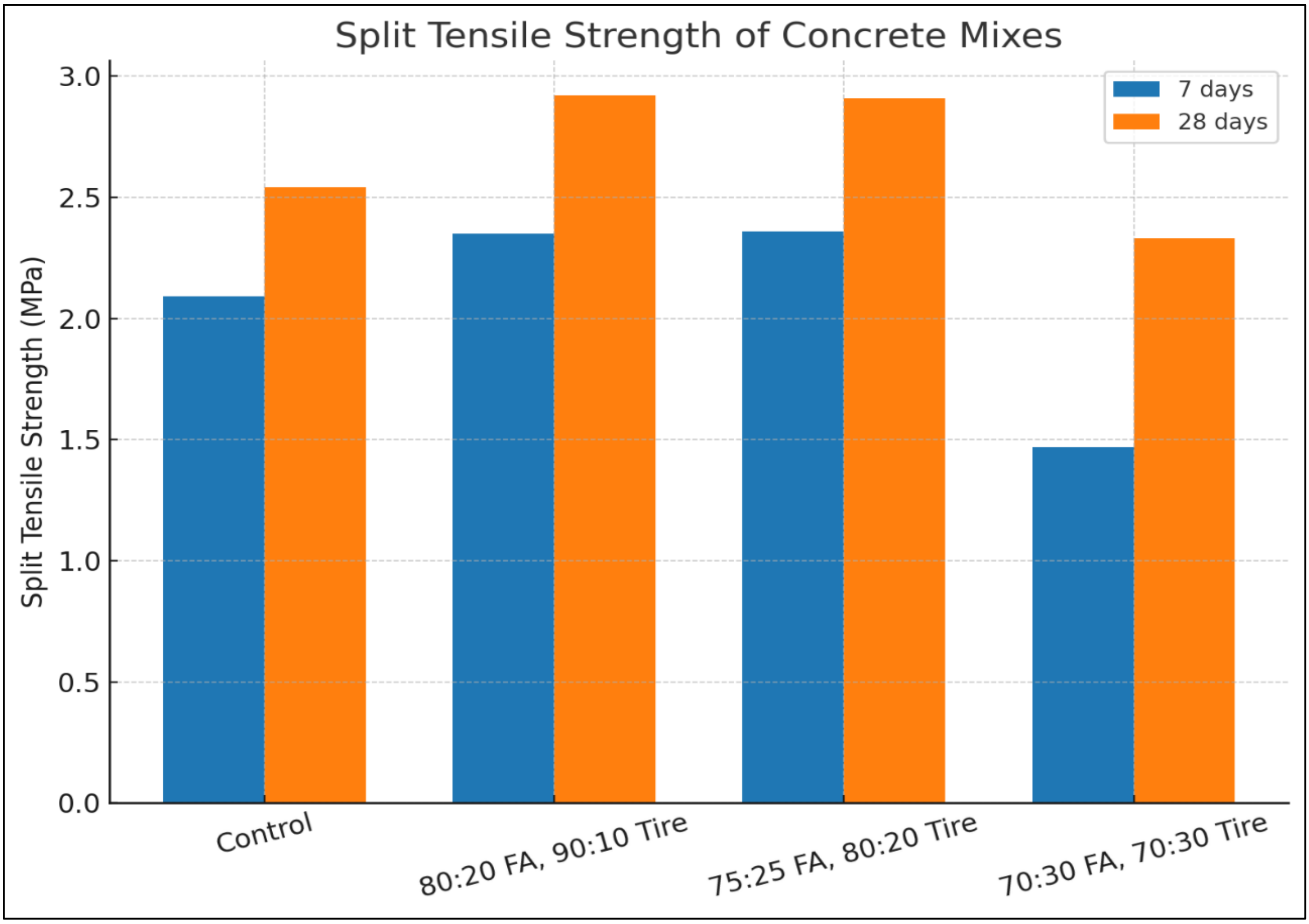

Fig 2 Split Tensile Strength of Concrete Mixes

➢ *Comparison with Literature*

The experimental findings are consistent with earlier studies. Siddique and Naik (2004) also reported that rubber lowers compressive strength but enhances ductility. The observed strength gain with fly ash aligns with the results of Kanthe et al. (2018) and Agarwal et al. (2018), who found that 20–30% fly ash replacement improves strength and reduces emissions. Importantly, this study demonstrates that combining fly ash with tire rubber can mitigate the negative strength effects of rubber alone—a finding less explored in previous research.

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VI. CONCLUSIONS

This study investigated the combined use of scrap tire rubber as a partial coarse aggregate replacement (10–30%) and fly ash as a partial cement replacement (20–30%) in M25 grade concrete. The experimental program evaluated the effects on workability, compressive strength, flexural strength, and split tensile strength at different curing ages. The major findings are summarized as follows:

- *Workability*

The incorporation of scrap tire rubber reduced workability because of its rough surface texture and hydrophobic characteristics. Conversely, the addition of fly ash improved slump values due to its fine spherical morphology, which enhances particle packing and lubrication.

- *Compressive Strength:*

At 28 days, the optimum performance was recorded for the mix containing 25% fly ash and 20% scrap tire rubber, achieving a compressive strength of 26.0 MPa, slightly higher than the control mix (24.9 MPa). However, when the replacement level exceeded 30%, compressive strength declined sharply.

- *Flexural and Tensile Strength:*

The optimum mix also exhibited an 11–14% increase in split tensile strength and a 13–14% increase in flexural strength compared to the control. This improvement highlights the beneficial role of tire rubber in enhancing ductility and energy absorption capacity.

- *Sustainability Benefits:*

The combined use of fly ash and waste tires reduces reliance on natural aggregates and cement, while simultaneously diverting large quantities of non-biodegradable waste from landfills. This approach not only promotes sustainable waste management but also contributes to lowering CO_2 emissions associated with cement production.

- *Practical Implications*

For a balance between strength, workability, and sustainability, a mix containing 25% fly ash and 20% tire rubber is recommended for structural applications. Higher tire replacement levels are not advised due to their detrimental effect on durability and strength.

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