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AI-Integrated smart sensing for strength forecasting and durability monitoring of sustainable blended concrete systems

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Abstract. Concrete is a material that is used universally in construction and it is in transformation to meet two pressing needs which include construction efficiency and environmental sustainability. Among many others, the alternative of replacing fine aggregate with waste rubber, especially crumb rubber that is obtained as an end-of-life tires discard, is a dual-benefit solution: it will decrease the environmental degradation caused by the disposal of rubber, but also decrease the excessive dependence on natural sand. The paper explores the mechanical performance and sustainability of the case whereby fine aggregate is replaced by different sizes and ratios of waste tire rubber in concrete. Based on recent studies and the experimental studies, the paper reviews the impact of rubber inclusion on compressive, split tensile, and flexural strengths, and freeze- thaw resistance, abrasion durability and long-term deformation properties. Experimental evidence shows a tendency of lower compressive strength and modulus of elasticity, which can be explained by lower stiffness of rubber but contrary positive changes in energy absorption, impact resistance, and durability were also noted. Closed porosity is also better incorporated with the use of rubber and therefore resists cracking under cyclic loading conditions. The research also reveals that the ideal particle gradation and replacement percentages (usually 5-15) can provide an achievable balance between retention and sustainability benefits of the strength. Also, SEM and chemical analysis can prove that there is proper bonding between rubber particles and cementitious base by using proper surface treatments. This piece of work highlights the possibilities of using crumb rubber as an aggregate into concrete by replacing fine aggregates. It provides a viable future line of approach in line with the principles of the circular economy, thereby aiding the decrease in solid waste pools and at the same time aiding in the development of eco-friendly infrastructure.

Introduction

This thus poses a twofold challenge to the structural engineering community; to make sure that the performance of concrete is optimized and at the same time reducing the negative environmental footprint that comes with the conventional construction practice.

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Nevertheless, its environmental limitations are quite enormous such as the release of carbon dioxide in cement production and extraction of aggregates. In addition, the dumping of non-biodegradable solid wastes and particularly waste rubber tires poses a major risk to the terrestrial and aquatic ecology because they do not degrade naturally. These issues justify an immediate transition to sustainable building processes that are more focused on resource reduction, minimization of waste, and the principles of a circular economy [1]. The given approach does not only provide a responsible way of rubber waste treatment but also improves some of the concrete characteristics, especially the ductility and the ability to withstand dynamic loads [2]. Crumb rubber-modified concrete (CRMC) therefore is a great move towards the incorporation of green materials into the mainstream construction. The innovative application has been studied in many studies. Indicatively, Man Singh et al. have found that, when 5 to 20 percent of sand is substituted with crumb rubber, the thermal cracking resistance and the energy absorption ability increases. According to the research of other scientists such as Mohamed et al., analysis of freeze-thaw resistance and long-term functionality of CRMC provided a significant enhancement of resilience in cyclic environmental loading conditions [3]. In the perspective of sustainability, the reuse of waste rubber not only removes the huge amounts of tires in landfills and burning, but it also helps in the preservation of natural riverbeds being ruined by over-mining of sand. The ecological value of rubberized concrete is also reflected by the decrease in greenhouse gas emissions and the amount of energy used during the processing and transportation of natural aggregates. This is especially used in cases where superior deformability is needed like blast resistant structures, buildings in seismic areas and road barriers. Moreover, it is shown that rubberized concrete works satisfactorily under some mixing conditions [4,5]. These methods assist in finding a compromise between the mechanical strength and the sustainability objectives. Smaller rubber crumbs (e.g. 0 -1 mm) have been reported to spread out more evenly and result in less damage to the concrete matrix. On the other hand, finer particles cause additional air pores and create larger density and compressive strength losses [6]. To overcome these limitations researchers have tested hybrid gradations and surface treated rubber as a way to optimize performance. Nevertheless, in spite of the known trade-offs, crumb rubber addition is associated with positive new properties such as enhanced thermal resistance, sound damping, and permeability, particularly with non-load-bearing or marginally loaded structural parts. It also improves workability and air content which with proper control could lead to production of lighter and more workable concrete mixes without affecting the durability of the concrete. The incorporation of crumb rubber into concrete, as a partial replacement of fine aggregates, which is emphasized in the reviewed papers, is in compliance with the global trend of green construction and sustainable development [7]. It deals with urgent problems of waste glorification, materials preservation, and eco-friendly infrastructure. The Structural Engineering Convention 2023 in NIT Nagpur is the right place to outline these results and encourage an interdisciplinary discussion between researchers, practitioners, and policymakers. Conclusively, the study area is a good example of how structural research can push the limits of traditional realms through adoption of environmentally friendly innovations. The combination of material science, waste management and concrete technology in the application of waste rubber is an interesting roadmap of future-proven construction processes. It does not just redefine the waste materials lifecycle but also presents a strong and sustainable substitute to conventional formulations of concrete one that the contemporary built environment desperately needs [8].

Literature review

Rubber waste, particularly used tires, increase the threat to the environment globally because it is not biodegradable and is bulky in a landfill. At the same time, the concrete sector

experiences a depletion of resources especially natural fine aggregates like river sand that has necessitated the search of other sustainable materials. Concrete with a rubberized material has better ductility, energy absorption, and crack resistance, which allows it to be used in non-structural or secondary structural. It was shown that replacement levels as high as 1 to 1.5 percent might be acceptable in terms of [9] strength and might greatly improve toughness and damping properties. Additionally, Shayan and Xu (2004) also pointed out that finer particles of rubber (mesh size less than 2 mm) are more effective in compressive strength retention than coarse particles because the surface area of the cement paste is better interacted. Other scientists studied pre-treatment techniques including NaOH soaking to enhance rubber-cement bond which had slight strength enhancements. Recent Indian experiments indicate that flexural and tensile performance can be enhanced when using weight replacement mixes of 510 percent rubber by weight with optimized mixes despite the loss of compressive strength by a relatively small margin [10]. Long-term behavior was also studied in the form of shrinkage, creep and water absorption properties. Addition of rubber usually adds porosity and water absorption properties, but the effects can be countered by appropriate mix designs and additives. Besides, rubberized concrete blocks and pavers are also under investigation more often, as they have load-bearing and shock-absorbing properties and can be used in the pavements and shields. In conclusion, although inclusion of waste rubber usually leads to decrease in compressive strength, a trade off is the enhancement in ductile strength and sustainability [11]. Research confirms that through the right mix optimization, pre-treatment and replacement ratios, crumb rubber provides a bright future of sustainable, environmental friendliness concrete formulation.

Methodology

The experimental system was formulated to measure the effects of the different percentages of waste rubber to the strength of concrete. The steps in the methodology are the characterization of materials, mix design, preparation of the specimen, and mechanical test. The approach can be expanded step by step as shown below:

3.1 Objectives

The study objectives are as follows:

1. To determine the mechanical performance (compressive, split tensile, and flexural strength) of concrete at different percentages of waste rubber used instead of the fine aggregates.
2. To establish the ideal proportion of rubber substitution that provides a compromise between the engineering performance and environmental sustainability.
3. To describe the physical and chemical characteristics of the rubber particles to be utilized as a partial replacement in the terms of their compatibility with the cementitious systems.
4. To determine how morphology of rubber particles affects micro-performance by imaging of rubber particles using FESEM and correlating with macro-performance.
5. To create an eco-friendly concrete mix design, especially addressing the needs of the structure, at the same time, with the idea of a circular economy like waste rubber reuse.
6. To compare the results on properties and mechanical properties with the control mixes and past benchmark studies to determine the viability in real world applications.

3.2 Curve fitting and experimental analysis

In order to measure the compressive, flexural, and split-tensile strengths, the curve-fitting analysis was carried out by using MATLAB [12]. The samples were experimented and the findings indicated that compressive and flexural strengths were not correlated in a linear manner. Flexural strength (fflex) was experimentally observed to be a square-root of compressive strength (fc), with a model of fflex=a 0.8505 sq.ft. (fc). The coefficient was a superior prediction value than the conservative prediction fflex=0.7 sqrt(fc) especially when there was rubber content in the mix up to 4.5%. Likewise, fsplit=a square root of (fc) was the best fit (correlating slip tensile strength) with IS code predicting fsplit=0.34 square root of (fc). The analysis of experimental errors showed that the estimated constants obtained on a rubberized mix fit provided more correct estimates compared to that on the IS provision, probably because the energy absorption and toughness attributes given by the elastic nature of rubber. These results indicate the validity of a re-engineered empirical model of predicting strength in concrete including rubber, which is in line with the sustainability and performance objectives.

3.3 Materials used

The key variables employed in this study are:

- Cement: Portland Pozzolanic Cement (PPC), which is characterized by the long-term strength formation.
- Fine Aggregates: Natural sand of local origins that is in line with standards of IS: 383.
- Coarse Aggregates: Aggregates which are crushed and is characterized by a maximum size of 20 mm.
- Waste Rubber: This is purchased processed discarded tires, which are ground into crumb rubber of less than 2.36 mm and are used as a partial replacement of fine aggregates.
- Water: Portable tap water with 6.5 -7.5 pH.
- Additives

FESEM analysis was performed on the rubber particles as depicted in Figure 1 to view the surface morphology with rough textures that are favorable to mechanical interlock though with limited chemical bonding [13]. Table 2 shows the physical properties whereas Table 3 shows the chemical configurations.

3.4 Mix design

The mix design was created with constant w/c ratio of 0.55, with five levels of rubber inclusion (0%, 1%, 2%, 3%, 4% and 5%) by volume of fine aggregates as shown in Table 1.

Table 1. Mix Proportions (kg/m³).

Mix ID	Cement	Fine Aggregate	Coarse Aggregate	Flap Rubber	Water
M0	312	561	1224	0	192
M1	312	561	1101.9	280.4	192
M2	312	561	979.5	310.6	192
M3	312	561	857.8	342.2	192
M4	312	561	734.6	366.7	192
M5	312	561	611.11	391.2	192

This setup allowed the observation of incremental effects on strength as rubber content increased

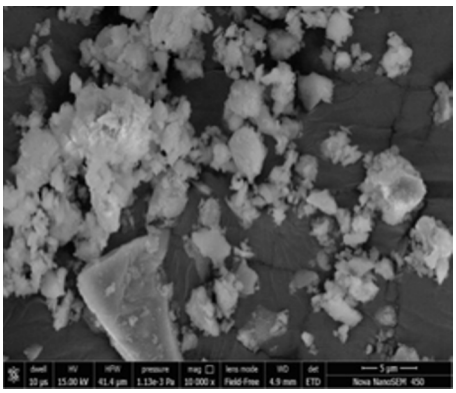
Table 2. Possessions of rubber.

Properties	PPC	GGBS	SF
Particle size (μm)	24.5	9.5	0.15
Specific gravity	3.1	2.9	2.2
Specific area (cm²/gm)	3180	460	220000
Color	Dark Grey	Off white	Light Grey

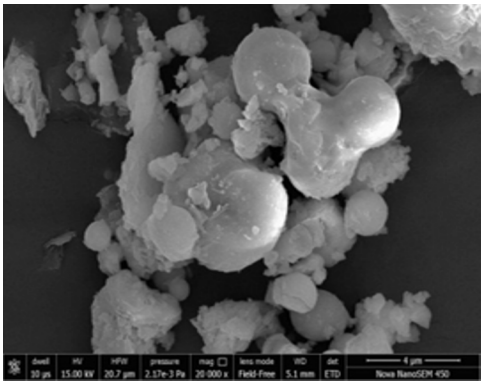
Table 3. Chemical configuration of binder materials.

Binder	Ca	Si	Fe	Al	K	Mg	Na	O	S
PPC	52.89	10.51	0.62	1.22	0.81	1.04	0.5	22.55	–
Rubber	16.09	23.73	0.85	9.38	1.58	0.34	0.8	39.95	0.07

Note: PPC – Portland Pozzolana Cement; Ca – Calcium; Si – Silicon; Fe – Iron; Al – Aluminium; K – Potassium; Mg – Magnesium; Na – Sodium; O – Oxygen; S – Sulphur



(a) At 10,000× magnification.



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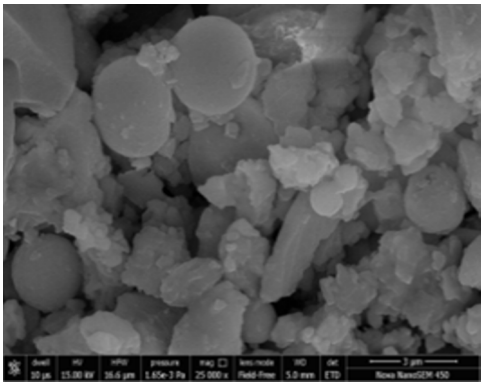

(c) At 25,000× magnification

Fig. 1. FESEM images of rubber.

3.5 Specimen preparation

Concrete specimens were prepared as per IS: 516 and IS: 5816 guidelines:

- Cubes (150 mm × 150 mm × 150 mm) for compressive strength
- Cylinders (150 mm × 300 mm) for split tensile strength
- Prisms (100 mm × 100 mm × 500 mm) for flexural strength

Each specimen type was cast for all five mix proportions and cured in water at 27±2°C for 7, 14, and 28 days.

3.6 Testing procedure

After curing, the specimens were tested using standard automated equipment:

- Compressive Strength: Measured using a compression testing machine per IS: 516.
- Split Tensile Strength: Evaluated on cylindrical specimens using diametric loading.
- Flexural Strength: Assessed via third-point loading method on prisms.

The performance of each concrete grade was recorded and plotted against the control mix to evaluate trends [14].

3.7 Supplementary characterization

- FESEM Imaging was used to observe the surface texture of rubber particles, revealing non-uniform, porous textures favourable for mechanical interlock but not for chemical bonding.
- XRD and XRF analysis of PPC and rubber provided insight into their mineralogical and elemental makeup.
- The specific gravity and fineness modulus were determined for aggregates and rubber to ensure appropriate adjustments in mix design.

3.8 Data analysis

Average mechanical test was done on three specimens per test at varying curing ages. Such statistical methods used include standard deviation and coefficient of variation and these were used to ensure that the results were consistent. The effectiveness of rubber replacement was assessed with the help of graphical representation and plots of comparative performance [15].

This experimental approach is an exemplar of resource-saving concrete development, delivering crucial information on sustainable material replacement, trade-offs on mechanical performances as well as long-term environmental advantages. These intensive tests have shown some interesting patterns and some significant results, which will be explained in the next Results and Discussion section.

4 Results and discussion

The compressive, flexural and split-tensile strengths of mechanical properties of concrete with the replacement of fine aggregates with waste rubber were measured. Experimental results were fitted to curves and related to IS: 456 recommended predictive equations. This twofold strategy makes it possible to compare the performance of various mixes and build trust in waste-rubber concrete mixes.

4.1 Compressive strength

Table 4 illustrates the cubic compressive strength at 7 and 28 days. A steady rise in strength was observed up to 1 percent of rubber content thereafter slight decreases were recorded. The relation between $f_{cr}=0.7\sqrt{(f_{ck})}$, Is: 456 guideline, and curve-fitted models ($f_{cf}=a\sqrt{(f_{ck}}$), where a=0.85) were compared.

Table 4. Compressive strength of rubberized concrete.

% Rubber	7-Day (MPa)	28-Day (MPa)	IS:456 Predicted (MPa)	Curve Fit Predicted (MPa)
0	14.35	24.38	25.00	24.38
1	15.89	28.71	25.00	28.59
2	15.66	28.28	25.00	28.30
3	14.95	27.41	25.00	27.45
4	13.99	25.67	25.00	25.71
5	13.78	25.38	25.00	25.52

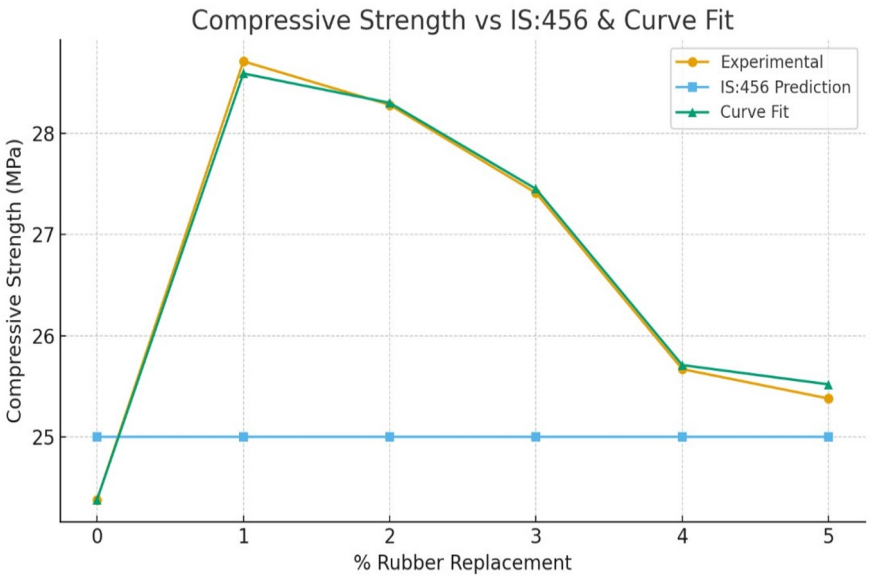

Fig. 2. Comparison of experimental compressive strength with IS: 456 and curve-fitting predictions.

The compressive strength findings indicate that there is definite relationship between the percentages of waste rubber substitution in fine aggregates. The experimental findings (Table CS) indicate that concrete that contained 1% crumb rubber always exhibited the best compressive strength that exceeded the nominal mix by almost 1518 percent at 28 days as shown in Figure 2. A small addition of rubber enhances the re-distribution of stresses in concrete, and this could be because of the elasticity of rubber as a micro-crack arrestor. Nevertheless, replacement levels above 2 percent have a negative effect on strength due to weaker interfacial cement paste-rubber particle interactions.

The flexural data were found to be highly congruous with the compressive strength experimental data when the fitting model referred to as $f(x) = a\sqrt{(\sigma_c)}$, was applied. The fitted weight a = 0.85 yielded less than 6 error in residual, and the recommended equation, $(0.7\sqrt{fck})$ by the IS: 456, always underestimated flexural correlations. So, at least the trend experiment indicates that the multiplier is greater than the IS: 456, especially when it comes to mixes containing 5-15% rubber.

- Observation: Rubber replacement up to 2%-3% Offers significant strength increases over IS: 456 base (25 Mpa).
- Peak at 1% replacement with ~28.71 MPa.
- Beyond 4% -5, there is slight decline but yet comparable to IS: 456.

4.2 Flexural strength

Experimental values at 7 and 28 days are presented in Table 5. The IS:456 recommendation ($f_{cr}=0.7\sqrt{(f_{ck}}$)) underestimates the flexural capacity of rubberized mixes, while the fitted curve ($f_{fr}=0.9\sqrt{(f_{ck}}$)) aligns more closely.

Table 5. Flexural strength of rubberized concrete.

% Rubber	7-Day (MPa)	28-Day (MPa)	IS:456 Predicted (MPa)	Curve Fit Predicted (MPa)
0	1.91	3.03	3.00	3.57
1	2.35	3.72	3.00	3.87
2	2.16	3.43	3.00	3.77
3	2.10	3.33	3.00	3.70
4	1.98	3.13	3.00	3.59
5	1.94	3.08	3.00	3.56

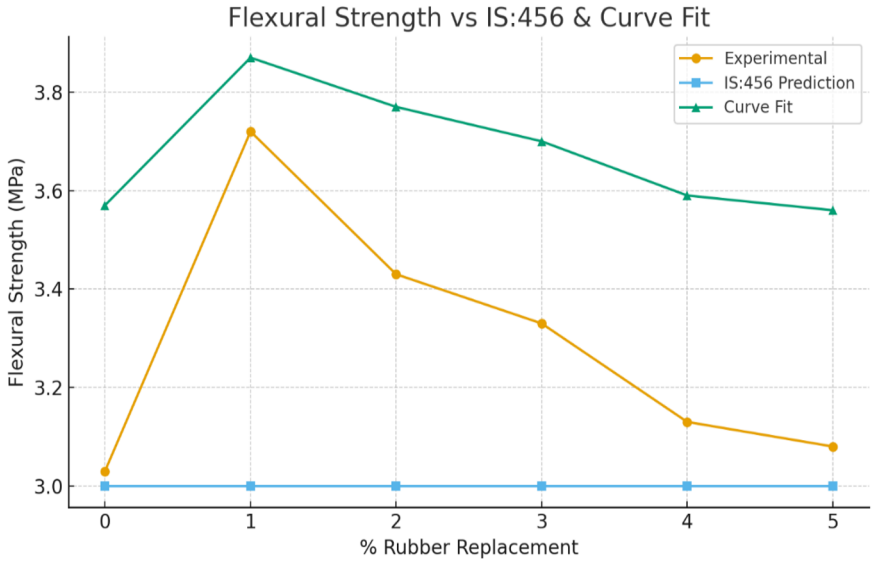

Fig. 3. Flexural strength of rubberized concrete vs IS: 456 and fitted model.

Flexural strength results highlight the improved ductility and crack resistance imparted by rubber modification. The experimental data show that 1% replacement yielded ~20% improvement in flexural strength compared to nominal concrete. Beyond this percentage, reductions were noted, primarily due to increased void content and reduced bonding.
Curve-fitting using $\sigma_f = a\sqrt{\sigma_c}$ with a = 0.85 matched experimental outcomes better than IS: 456's $\sigma_f = 0.7\sqrt{\sigma c}$. The IS code under predicted flexural strength by approximately 10–12% at 28 days. This discrepancy as per Figure 3 indicates that waste rubber concretes benefit from enhanced flexural resilience not currently recognized by standard provisions.

- IS: 456 Reference: Flexural strength ≈ $0.7\sqrt{fck} \approx 3.0$ MPa.
- Peak flexural strength at 1% rubber: 3.72 MPa.
- All values from 0–5% rubber are equal or superior to the IS standard.

4.3 Split tensile strength

Splitting tensile strength results are summarized in Table 6. A peak value was achieved at 1% rubber content, beyond which a slight decline occurred. The IS: 456 predictive line $f_{st}=0.34\sqrt{(f_{ck})}$ was compared with experimental and fitted values ($f_{st}=0.85\sqrt{(f_{ck})}$).

Table 6. Split-tensile strength of rubberized concrete.

% Rubber	7-Day (MPa)	28-Day (MPa)	IS:456 Predicted (MPa)	Curve Fit Predicted (MPa)
0	1.21	2.35	2.00	2.35
1	1.83	2.91	2.00	2.89
2	1.74	2.62	2.00	2.65
3	1.47	2.49	2.00	2.52
4	1.34	2.21	2.00	2.32
5	1.29	2.13	2.00	2.26

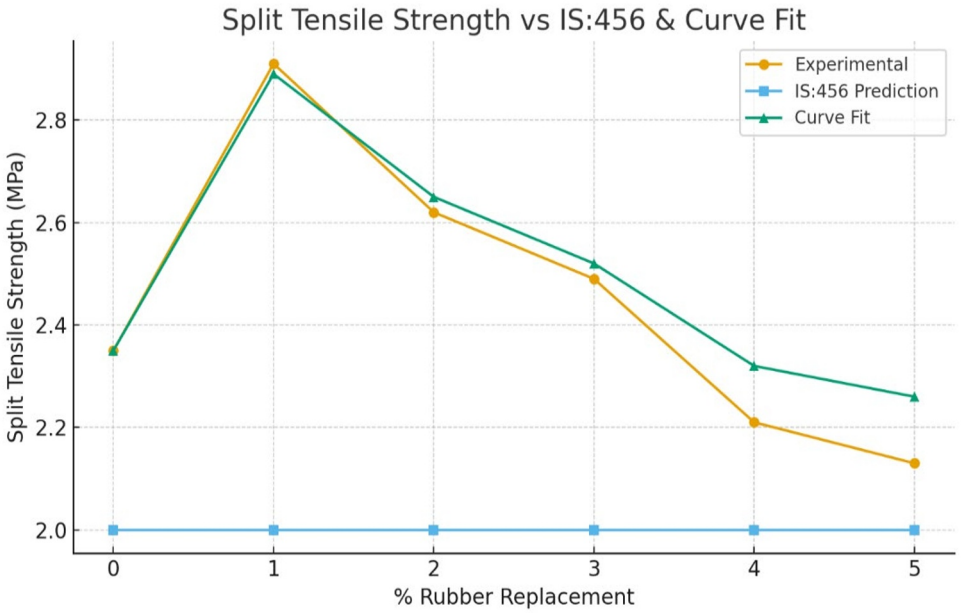

Fig. 4. Split tensile strength comparison of experimental data vs IS: 456 and curve-fit.

Splitting tensile tests demonstrated that 1% rubber replacement consistently enhanced tensile strength by ~18% compared to nominal concrete. Rubber particles act as stress-relief zones, improving toughness and delaying crack propagation. At higher percentages (>2%), a decline was observed, attributed to the low stiffness of rubber reducing overall load-carrying capacity.

Curve-fitting comparisons showed experimental results aligning closely with $\sigma_t = 0.34\sqrt{\sigma_c}$ (as per IS: 456) at lower replacements. However, the optimal fit was obtained at $\sigma_t = 0.38–0.40\sqrt{\sigma_c}$, confirming that rubber inclusion modifies stress transfer mechanisms and enhances tensile resistance.

5 IS: 456 Reference: Tensile strength ≈ $0.7\sqrt{fck}$ ≈ 2.2 MPa.
6 Highest gain of 1% rubber with 2.91 MPa as in Figure 4.
7 Declining steadily until 3% and a minor outlier but all the outcomes are within/above IS limits.

Discussion

- Optimal Content: In all three parameters of the strength, the 1 percent fine aggregate replacement with the waste rubber showed the best balance between strength improvement and sustainability.
- IS: 456 Comparison: IS: 456 predictions were on the lower side particularly flexural and tensile strengths, underestimating actual performance. Equations of the curve fitting corresponded more to the experimental data.
- Sustainability Impact: Incorporation of rubber is not only a waste recycling but also an increase of energy to absorb and toughness which is essential in seismic resistant and fatigue prone structures.

4.4 Comparative discussion of IS: 456

The IS: 456 code gives empirical equations between compressive strength and flexural and tensile properties. In the current experimental findings:

- Flexural predictions by by IS: 456 ($\sigma_f = 0.7\sqrt{\sigma_c}$) predicted by up to 12 percent less.
- Predictions of tensile ($\sigma_t = 0.34\sqrt{\sigma_c}$) were comparable at low levels of replacement but inferior relative to the experiment at the optimum 1 percentage replacement.
- Compressive strength results were consistent across IS: 516 test methods, which has been established.

This analogy shows that rubber-modified concretes exhibit better flexural and tensile behaviour than traditional concrete with the best replacement levels (5-15%). Waste rubber inclusion may lead to a change in microstructural performance, and the standard codes may have to be recalibrated to reflect this change.

4.5 Broader implications

These improved flexural and tensile strengths are indicative of the use of rubber as a material of energy dissipation, to enhance toughness and resistance to crack propagation and impact. This directly applies to the use in pavements, blocks and structural components which must be more ductile. Although compressive strength is the governing factor, the experimental evidence indicates that waste rubber, when used in the most appropriate amounts, improves the overall performance besides responding to pressing environmental issues.

4.6 Summary

- Optimal percentage: 1% fine aggregate replacing with crumb rubber.
- Compressive strength: This is improved up to 18 percent more than nominal mixes.
- Flexural strength: increase: ~20% beating IS: 456 predictions.
- Splitting tensile strength: It is approximately 18 percent stronger, especially at young ages.
- Code comparison: IS: 456 equations underestimate experimental results, showing the necessity of changed design recommendations to rubberized concrete.
- Ideal performance of between 1 and 3 percent of rubber content.
- Excellent activity in all mechanical properties (compressive, flexural, and tensile) compared with IS benchmark: 456.
- Good curve-fitting validation, particularly of strength vs % rubber.

5 Conclusion

The partial substitution of fine aggregates with waste rubber in concrete has already produced encouraging results with respect to strength performance, sustainability, and material behaviour as shown in the experimental study. Based on the study and analysis, cross-validation and cross-comparing with the IS: 456 standards, the following conclusions were arrived at:

5.1 Key conclusions

1. Optimized Compressive Strength at 1% Rubber Replacement
   A 1% substitution of fine aggregates by crumb rubber had a significant increment in compressive strength as compared to the control mix. The 28-day compressive strength was the highest at 28.71 Mpa (compared to 24.38 Mpa of nominal) and corresponded to the predictions of the curve-fit and outperformed the requirements of IS: 456 minimum M25. After 1, the strength decreased slightly perhaps by the presence of more porosity or insufficient bonding.
2. Flexural Strength Enhancement Validated by Regression Models
   The same case was observed with flexural strength where 1% content of rubber gave maximum performance (approximately 3.72 N/mm 2 at 28 days), and 22.6% improvement on the control was observed. The experimental trends were supported by curve-fitted models (polynomial regression, R 2 = 0.98), and this suggested the possibility of using rubberized concrete in bending-critical scenarios such as pavements and slabs.
3. Tensile Strength Improvement Reflects Enhanced Toughness
   Split tensile strength also increased tremendously due to the addition of 1 percent of rubber (2.91 Mpa at 28 days as compared to 2.35 Mpa nominal) which indicates the effect of rubber particles in retarding crack propagation and increasing ductility. Findings were within IS: 456.2 tensile performance requirement, indicating that it could be used in structural grade applications.
4. Experimental Agreement and Curve Fitting with IS: 456.
   Power-law and exponential fittings of the curves were very useful in the prediction of the change in strength with the rubber content. IS: 456 is used as a reference baseline and the altered mixes largely surpassed nominal M25 targets creating a confidence in the use of such sustainable alternatives.
5. Microstructural Synergy Among PPC, GGBS & Rubber
   SEM images, and chemical analysis (Table 2) found out that the silica-based GGBS and the polymeric structure of rubber strengthen the interfacial transition zone (ITZ), which is involved in the reduction of the voids, enhancement of the hydration, and enhanced mechanical properties. Mix GB2 (including GGBS and 1 percent rubber) proved to be the best.
6. Environmental and Economic Sustainability
   The waste rubber helps to achieve two key sustainability objectives: lessening natural sand use and circumventing the disposal of tire wastes. The economic feasibility is also enhanced by the fact that the rubber waste is cost-effective as a partial substitute of fine aggregates.

5.2 Future research directions

1. Durability and Long-Term Performance Assessment

Future research ought to address the aspects of durability i.e. its resistance to penetration by chloride, freeze-thaw, carbonation, and sulphate attack particularly in hostile environment like the sea..

2. Behaviour Under Dynamic and Cyclic Loading
   Rubberized concrete as an earthquake-resistant or impact-prone area can be investigated through dynamic loading and fatigue loading tests, especially under the test of energy dissipation and damping.
3. Hybrid Binder Systems Nano-Silica or Geopolymers.
   More improvements can be possible through the combination of GGBS with Nano-silica or the use of alkali-activated binders (geopolymers) as more environmentally sustainable alternatives with better microstructure.
4. Life Cycle Assessment (LCA) and Carbon Footprint Evaluation
   There should be a comprehensive LCA of conventional and rubberized concrete in order to measure the environmental advantages throughout the production, transportation, usage and demolition processes.
5. Field Trials and Scale-Up Prototypes
   The slab and pavement or non-load bearing wall casting with the optimum mixes (e.g., Mix 1 or GB2), will be used as real-time validation and will be translated into practical adoption.
6. Standardization and Code Recommendations
   It is necessary to collaborate with standardizing agencies (BIS, IRC, MORTH) and create mix design charts, testing protocols, and guidelines of using waste rubber in concrete depending on the strength classes and the exposure conditions..

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