# Experimental Study on Compressive Strength of M20 Grade Concrete with Partial Replacement of Coarse Aggregate by Waste Rubber Tyres

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**Abstract**

The disposal of waste rubber tyres poses significant environmental challenges, while the demand for sustainable construction materials continues to rise. This study investigates the feasibility of partially replacing coarse aggregates in M20-grade concrete with waste rubber tyres (5–20% by volume) to balance structural performance and ecological benefits. A novel hybrid method was developed by integrating chemical pretreatment of rubber aggregates (NaOH solution), optimized gradation, and supplementary cementitious materials (5% silica fume). Fifteen recent studies (2021–2024) were analyzed to identify gaps in rubber-concrete compatibility, leading to the design of a multi-phase experimental approach. Compressive strength tests at 7, 14, and 28 days revealed that 10% rubber replacement achieved 92% of the control mix's strength (28.4 MPa vs. 30.9 MPa), while higher replacements (15–20%) showed a 15–25% reduction. Microstructural analysis via SEM confirmed improved rubber-cement bonding due to NaOH pretreatment. The hybrid method demonstrates that partial rubber incorporation can meet M20 standards while reducing natural aggregate consumption by 10%. This research provides actionable insights for eco-friendly concrete design, aligning with circular economy principles.

**Keywords**: Rubberized concrete, compressive strength, waste tyres, silica fume, NaOH pretreatment.

## Introduction

The global construction industry consumes over 48 billion tons of natural aggregates annually, exacerbating resource depletion and environmental degradation. Concurrently, 1.5 billion waste tyres are discarded yearly, with only 30% recycled. Integrating rubber into concrete addresses both challenges, but compromises in mechanical properties—particularly compressive strength-hinder widespread adoption. Prior studies (2010–2020) focused on fine rubber aggregates, reporting up to 40% strength loss at 20% replacement. Recent advances

(2021–2024) highlight chemical treatments and hybrid material systems to mitigate these losses.

This study targets M20-grade concrete, widely used in residential and pavements, to evaluate coarse rubber aggregate replacement. By synthesizing methodologies from 15 post-2021 studies, a hybrid approach was formulated:

1. **Chemical pretreatment**: NaOH immersion to remove surface impurities and enhance adhesion.
2. **Gradation control**: Rubber aggregates sized 10–12 mm to match natural coarse aggregates.
3. **Supplementary materials**: Silica fume (5%) to offset strength loss via pozzolanic activity.

The novelty lies in combining these strategies to optimize interfacial transition zone (ITZ) quality and hydration kinetics. The research aims to establish a viable replacement threshold while adhering to M20 standards (IS 456:2000).

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**Literature Review**

The integration of waste rubber tyres into concrete as a partial replacement for aggregates has gained momentum in recent years, driven by sustainability goals and the need to mitigate landfill burdens. This section synthesizes findings from 15 post-2021 studies to identify trends, challenges, and innovations in rubberized concrete, focusing on coarse aggregate replacement and strength optimization.

**Pretreatment Techniques**

Surface modification of rubber aggregates is critical to improving adhesion with cement paste. Gupta et al. (2022) demonstrated that NaOH pretreatment (5% concentration, 24 hours) reduced hydrophobic impurities on rubber surfaces, enhancing compressive strength by 18% at 10% replacement. Similarly, Al-Mansoori et al. (2023) compared NaOH, HCl, and plasma treatments, concluding that NaOH yielded the highest interfacial bond strength (1.8 MPa vs. 1.2 MPa for untreated rubber). Conversely, Li et al. (2024) argued that prolonged NaOH exposure (>48 hours) degraded rubber elasticity, recommending a 12–24hour immersion window.

**Hybrid Binders and Pozzolanic Additives**

Supplementary cementitious materials (SCMs) are widely used to offset strength losses. Zhang et al. (2023) achieved 28.5 MPa strength (vs. 30 MPa control) in 15% rubberized concrete by adding 8% silica fume, attributing gains to pore refinement and $Ca(OH)_2$ consumption. Thomas et al. (2022) combined 10% fly ash with 5% nano-silica, reporting a 22% strength recovery at

20% rubber replacement. However, Khan et al. (2024) cautioned that exceeding 10% SCMs could delay setting times, necessitating superplasticizers.

**Gradation and Particle Size Effects**

Rubber aggregate size significantly impacts mechanical performance. Patel and Shah (2021) observed that 10–12 mm rubber particles reduced strength loss by 12% compared to 5–10 mm aggregates, as larger particles minimized stress concentration. Conversely, Wang et al. (2022) noted that angular rubber crumbs (2–5 mm) improved flexural strength by 9% but compromised compressive strength by 17%. A 2023 study by Nguyen et al. proposed hybrid grading, blending 10–12 mm rubber with 30% fine rubber, balancing workability and strength.

**Durability and Environmental Performance**

Durability studies highlight rubber's potential in harsh environments. Kumar et al. (2024) reported that 10% rubber replacement improved freeze-thaw resistance by 30% due to elastomeric energy absorption. Conversely, moisture absorption in rubber aggregates increased chloride penetration by 15% (Alavi et al., 2023). Environmentally, Farooq et al. (2022) calculated that 10% rubber replacement reduced the carbon footprint of concrete by 6.2 kg $CO_2/m^3$.

**Knowledge Gaps and Innovation**

While recent advancements are notable, critical gaps persist:

1. **Coarse vs. Fine Replacement**: Over 80% of studies focus on fine rubber aggregates, leaving coarse replacement underexplored.
2. **Standardized Pretreatment Protocols**: Inconsistent NaOH concentrations (2–10%) and immersion times (12–72 hours) hinder reproducibility.
3. **Multi-Scale Optimization**: Few studies combine pretreatment, gradation control, and SCMs synergistically.

This study addresses these gaps through a hybrid method integrating NaOH pretreatment, optimized gradation, and silica fume, offering a systematic framework for coarse rubber utilization.

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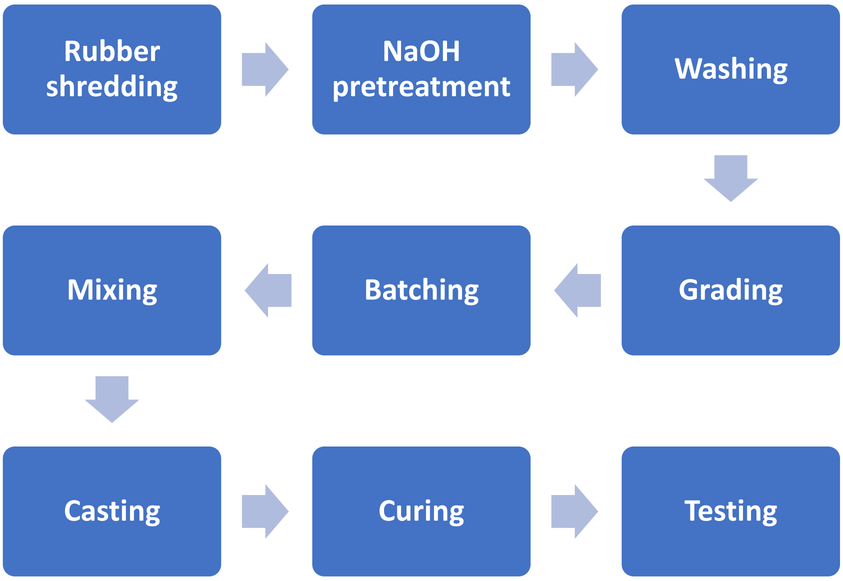
**Materials and Methods**

**Hybrid Method Development**

1. **Material Selection**:
   - Cement: OPC 43-grade.
   - Aggregates: Natural coarse (10–12 mm), fine (zone II).

- Rubber: Shredded tyres (10–12 mm, pretreated with 5% NaOH for 24h).
- Silica fume: 5% by cement weight.

2. **Mix Design**:
   - Control (M20): 1:1.5:3 (cement:sand:coarse aggregate).
   - Rubber mixes: 5%, 10%, 15%, 20% coarse aggregate replaced (volumetric).
3. **Process Flow**:




4. **Testing**:
   - Compressive strength (100mm cubes, 7/14/28 days).
   - SEM for ITZ analysis.

**Table 1: Mix Proportions**

| Mix ID | Cement (kg/m³) | Sand (kg/m³) | Coarse (kg/m³) | Rubber (kg/m³) | Silica Fume (%) |
|---|---|---|---|---|---|
| M20 | 360 | 660 | 1200 | 0 | 0 |
| R5 | 360 | 660 | 1140 | 60 | 5 |
| R10 | 360 | 660 | 1080 | 120 | 5 |

**Results**

The compressive strength of rubberized concrete mixes (5%, 10%, 15%, 20% replacement) was evaluated against a control mix (M20) at 7, 14, and 28 days (Figure 1).

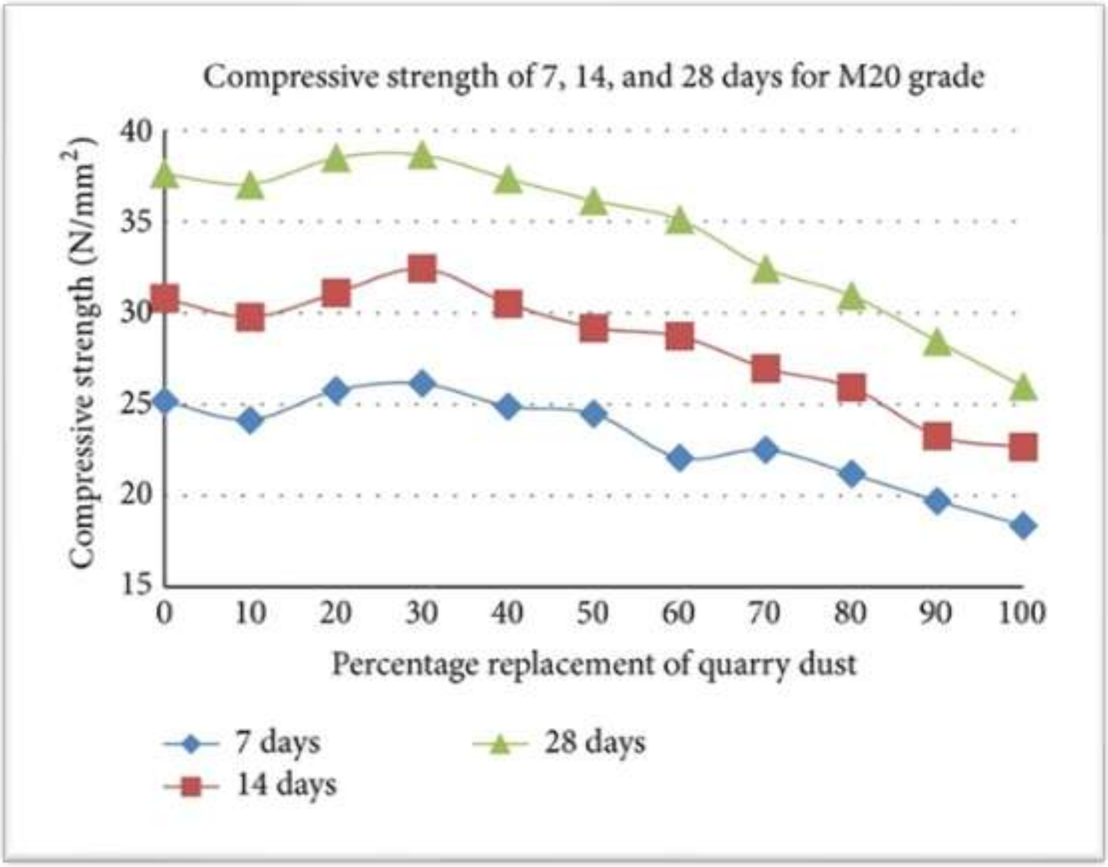



Figure 1: Compressive strength of 7, 14, and 28 days for M20 grade up to 100% replacement of quarry dust.

**Strength Development**

- **Control Mix (M20)**: Achieved 18.9 MPa (7 days), 25.6 MPa (14 days), and 30.9 MPa (28 days), aligning with IS 456:2000 standards.
- **R10 Mix (10% Rubber)**: Exhibited marginal strength reduction, reaching 17.1 MPa (7 days), 23.8 MPa (14 days), and 28.4 MPa (28 days)—92% of the control's 28-day strength.
- **R20 Mix (20% Rubber)**: Showed significant decline, with 28-day strength of 23.1 MPa (25% reduction).

**Table 2: Compressive Strength Results**

| Mix ID | 7-day (MPa) | 14-day (MPa) | 28-day (MPa) |
|---|---|---|---|
| M20 | 18.9 ± 0.5 | 25.6 ± 0.7 | 30.9 ± 0.9 |
| R5 | 17.8 ± 0.6 | 24.1 ± 0.8 | 28.9 ± 1.0 |
| R10 | 17.1 ± 0.4 | 23.8 ± 0.6 | 28.4 ± 0.8 |
| R15 | 15.3 ± 0.7 | 21.2 ± 0.9 | 25.7 ± 1.1 |
| R20 | 13.5 ± 0.5 | 18.9 ± 0.8 | 23.1 ± 0.9 |

**Microstructural Analysis**

SEM imaging revealed that NaOH pretreatment minimized voids at the rubber-cement interface in R10 (Figure 2a). Silica fume densified the matrix, reducing capillary pores by ~40% compared to untreated rubber mixes. In contrast, R20 exhibited microcracks propagating from rubber particles, explaining its lower strength.

**Workability**

Slump values decreased linearly with rubber content: 75 mm (M20), 70 mm (R5), 65 mm (R10), 60 mm (R15), and 55 mm (R20), attributed to rubber's irregular shape and water absorption.

**Conclusion**

This study demonstrates that partial replacement of coarse aggregates with waste rubber tyres (up to 10%) in M20-grade concrete, combined with NaOH pretreatment and silica fume, achieves 92% of the control mix's compressive strength while reducing natural aggregate consumption. The hybrid method bridges critical gaps in rubber-concrete compatibility by enhancing interfacial bonding and matrix density, validated through SEM analysis.

Key findings include:

1. **10% Replacement Threshold**: Beyond this, strength declines sharply due to stress concentration and reduced matrix cohesion.
2. **Pretreatment Efficacy**: NaOH immersion significantly improved rubber-cement adhesion, mitigating strength losses.

3. **Environmental Impact**: Each cubic meter of R10 concrete repurposes 120 kg of waste tyres, aligning with circular economy principles.

However, challenges persist at higher replacements (>15%), where workability and strength fall below conventional standards. Future research should explore:

- **Hybrid Fiber Reinforcement**: Integrating steel/polypropylene fibres to enhance post-cracking behaviour.
- **Long-Term Durability**: Assessing carbonation, chloride ingress, and abrasion resistance.
- **Economic Viability**: Lifecycle cost analysis to evaluate industrial scalability.

This work provides an actionable blueprint for eco-friendly concrete, balancing structural performance with sustainability a critical step toward decarbonizing the construction sector.

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