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Experimental Investigation of Mechanical Durability and structural Properties of Crumb Rubber Concrete with Partial Replacement of Coarse Aggregate

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ABSTRACT

This study examines the incorporation of recycled waste-tyre crumb rubber as a partial replacement for natural coarse aggregate in concrete. The source thesis reports experimental series with low rubber contents (0–3%) and a principal series containing 0%, 5%, 10%, 15%, 20% and 25% replacement. For the principal series, workability, 7- and 28-day compressive strength, splitting tensile strength, flexural response, acid-exposure strength, elevated-temperature response, sorptivity-related measurements and rapid chloride permeability were examined. Reinforced concrete beams were also assessed through load–deflection and cracking observations. The highest reported 28-day compressive strength was 35.56 MPa at 15% rubber replacement, compared with 32.89 MPa for the control (an increase of approximately 8.1%). At 20% and 25% replacement, the corresponding strengths declined to 24.08 and 17.60 MPa. Splitting tensile strength peaked at 3.04 MPa at 15% replacement, whereas the reported flexural strength peaked at 26.0 MPa at 10%. The acid-exposure tables generally showed the highest residual strengths at 15% rubber content, while rapid chloride permeability test charge increased as rubber content increased. These findings indicate that moderate crumb-rubber replacement can be promising in the reported mix system but entails a property-specific trade-off; further validation, especially of inconsistent source measurements, is needed before structural application.

Keywords: crumb rubber concrete; waste tyres; coarse aggregate replacement; compressive strength; acid resistance; RCPT; reinforced concrete beams.

1. Introduction

Concrete production requires substantial natural aggregate, while disposal of end-of-life tyres remains an environmental challenge. The conversion of waste tyres into crumb rubber offers a potential aggregate substitute and a pathway for material recovery. Compared with mineral aggregates, rubber particles have lower density, high deformability and a different interface with cement paste. Their incorporation can therefore change fresh-concrete behaviour, strength, toughness and transport properties. The performance depends on particle size and shape, replacement fraction, mix design and treatment of the rubber surface [1–6].

The source thesis investigates crumb rubber primarily as a partial replacement for coarse aggregate. Its stated objectives include comparing mechanical properties and workability, resistance to hydrochloric and sulphuric acid exposure, temperature effects, chloride penetration and reinforced concrete beam response. This article concentrates on the numerical results in the coherent 0–25% replacement series, and treats the smaller-dosage trials as supplementary findings because the source reports them in separate chapters with different baselines.

2. Previous Research and Study Rationale

Prior research reviewed in the thesis shows that rubber substitution frequently reduces density and, at sufficiently high dosages, compressive strength. Eldin and Senouci examined rubber particles as concrete aggregate, while Toutanji and Khatib and Bayomy documented the influence of replacement content on mechanical performance [1–3]. Segre and Joeke studied tyre-rubber particles in cement paste, and Siddique and Naik reviewed their application and associated performance trade-offs [4–5]. The literature also identifies improved deformability and impact-related behaviour as potential benefits, although they do not automatically imply higher compressive or flexural strength [5–7]. The rationale of the thesis is to assess whether a useful balance can be obtained using recycled tyre rubber in a conventional concrete mixture and whether resulting beams exhibit acceptable cracking and deflection characteristics.

3. Materials and Experimental Method

The thesis describes ordinary Portland cement (53 grade), natural sand, crushed coarse aggregates (nominal sizes of 20 mm and 12.5 mm), water and processed tyre crumb rubber. Recorded specific gravities include approximately 3.1 for cement, 2.7 for fine aggregate, 2.9 for coarse aggregate and 1.2 for rubber. The principal concrete series was described as M25 grade, with 0%, 5%, 10%, 15%, 20% and 25% rubber replacement of coarse aggregate. Replacement basis is described inconsistently across the source chapters as weight and volume; consequently, the percentages here are reproduced as reported and cannot be interpreted as a fully reproducible volumetric mixture specification.

Cube specimens were evaluated for compressive strength at 7 and 28 days; splitting tensile and flexural properties were also measured. Separate specimens were exposed to 5% and 10% hydrochloric acid (HCl) and sulphuric acid (H₂SO₄). Temperature-exposure tests at 200 °C and 400 °C, a water-uptake/sorptivity-related test and rapid chloride permeability testing (RCPT) were reported. Reinforced concrete beams with different replacement rates were subjected to load testing, with load–deflection and crack-width comparisons presented graphically in the thesis. Full specimen counts, statistical variability, some exposure durations and all beam reinforcement details were not consistently available in the source, limiting independent replication.

4. Results and Discussion

4.1 Mechanical properties

Table 1 transcribes the principal 0–25% replacement series. The 28-day compressive strength increased from the control value to a maximum at 15% rubber content, then decreased markedly at higher replacement ratios. Seven-day strengths showed a comparable trend. The splitting tensile test also peaked at 15%, while the highest reported flexural result occurred at 10%.

Replacement (%)	7-day compressive (MPa)	28-day compressive (MPa)	Splitting tensile (MPa)	Reported flexural (MPa)
0	25.78	32.89	2.75	24.0
5	25.83	34.22	2.83	24.8
10	25.89	34.87	2.9	26.0
15	26.15	35.56	3.04	25.6
20	16.14	24.08	2.87	24.6
25	9.81	17.6	2.76	22.8

Table 1. Mechanical test values transcribed from the main replacement series in Chapter 5. The flexural values are reproduced verbatim, but the source does not provide sufficient clarity to confirm their test geometry or interpretation; they should be verified before publication.

Relative to the control, the reported 28-day compressive-strength changes were +4.0%, +6.0%, +8.1%, –26.8% and –46.5% at 5%, 10%, 15%, 20% and 25% replacement respectively. This non-monotonic behaviour differs from the commonly reported decline at increasing rubber dosage and requires confirmation through independent repeats and detailed mix documentation. The source also records a slump reduction from 80 mm for nominal concrete to 50 mm for a rubber-containing mixture in an earlier experimental series, but that result is not explicitly resolved by replacement percentage and should not be applied to every mix.

4.2 Chemical resistance and elevated-temperature response

Table 2 summarizes the acid-exposure compressive strengths reported for the main series. At each of the four acid conditions, the maximum tabulated strength occurs at 15% replacement. However, the recorded 5% HCl strengths exceed the corresponding pre-exposure 28-day compressive strengths for several mixes; the source does not fully clarify the testing chronology or comparability of these specimens. Accordingly, the acid results should be treated as strength measurements after specified exposure rather than evidence of a quantified improvement in acid resistance.

Replacement (%)	5% HCl (MPa)	10% HCl (MPa)	5% H ₂ SO ₄ (MPa)	10% H ₂ SO ₄ (MPa)
0	33.33	32.44	25.87	19.26
5	35.66	32.65	26.72	20.06
10	36.12	33.37	26.92	21.22

Replacement (%)	5% HCl (MPa)	10% HCl (MPa)	5% H ₂ SO ₄ (MPa)	10% H ₂ SO ₄ (MPa)
15	36.58	34.88	27.49	22.43
20	34.89	32.45	24.87	18.19
25	32.46	31.81	22.53	15.61

Table 2. Compressive strength values following acid-exposure conditions, as reported in Chapter 5.

For the 200 °C temperature condition, the thesis reports strengths of 33.09, 34.46, 35.25, 36.45, 34.89 and 32.46 MPa from 0% to 25% replacement. The corresponding values at 400 °C are 32.94, 34.24, 35.08, 36.12, 32.20 and 30.67 MPa. Comparisons with ambient-age strength should be made cautiously because source details for exposure duration, cooling method and subsequent testing are incomplete.

4.3 Water transport and chloride permeability

The source reports paired values at 1 min and 24 h under a section labelled sorptivity (for example, 1023 and 1033 for conventional concrete; 934 and 938 for 15% replacement). However, it does not consistently establish their physical units, specimen geometry or the conversion into a sorptivity coefficient. A comparable standardized sorptivity coefficient therefore cannot be calculated reliably from these entries alone.

Replacement (%)	RCPT charge (coulombs)
0	2029.05
5	2360.25
10	2422.8
15	2461.05
20	2481.3
25	2494.35

Table 3. RCPT charge values reported in Chapter 5.

RCPT charge rose progressively from 2029.05 C in control concrete to 2494.35 C at 25% replacement, an increase of approximately 22.9%. These measurements do not support an unqualified conclusion that increasing rubber content improved chloride-penetration resistance. Interpretation should consider the electrical nature of RCPT and the absence of repeatability and uncertainty estimates.

4.4 Reinforced concrete beam response

Chapter 6 of the thesis illustrates specimen casting, loaded beams, load–deflection graphs and crack-width comparisons for conventional and rubberized reinforced concrete beams. Its narrative identifies favourable behaviour for 5%, 10% and 15% rubber replacement under a stated 25 kN load. However, the underlying numerical load–deflection coordinates, reinforcement schedule and tabulated ultimate loads are not supplied in a sufficiently consistent machine-readable form to calculate ductility indices, stiffness or percentage changes with confidence. Thus the structural findings are retained as qualitative observations rather than converted into unsupported quantitative claims.

5. Conclusions

- The reported 28-day compressive strength of the main mix series increased from 32.89 MPa for conventional concrete to 35.56 MPa at 15% crumb rubber replacement (+8.1%).
- Increasing replacement above 15% corresponded to substantial compressive-strength loss: 24.08 MPa at 20% and 17.60 MPa at 25%.
- Splitting tensile strength reached a maximum of 3.04 MPa at 15% replacement, whereas the highest reported flexural-strength value occurred at 10%.
- The acid-exposure and high-temperature series often retained the highest measured strengths around 15%, but incomplete procedural information prevents strong comparative durability claims.
- RCPT charge increased with rubber content, demonstrating that the studied mixtures did not improve this indicator of chloride-penetration resistance.
- The beam observations suggest potential for modified cracking and deflection behaviour, but quantitative structural validation is necessary before design recommendations can be made.

6. Limitations and Recommendations

This manuscript is a condensed adaptation of the supplied thesis, not a new experimental study. The thesis contains distinct 0–1%, 1.5–3% and 0–25% series, different baseline values between chapters, and inconsistencies concerning mix grade, replacement by mass versus volume, some acid results and flexural-test reporting. The principal 0–25% data series is therefore foregrounded without pooling incompatible experiments. Before journal submission, the authors should verify laboratory notebooks and raw test sheets; document batch proportions, rubber gradation, pretreatment and substitution basis; add specimen count, standard deviations and test standards; clarify acid and thermal exposure protocols; and provide calibrated numerical beam curves. Claims about cost and environmental life-cycle benefits should be tested using cost and life-cycle inventories rather than inferred solely from waste diversion.

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