

EVALUATION OF BEHAVIOR ON UNTREATED CRUMB RUBBER CONCRETE

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Abstract

Modern progress hinges on environmental and natural resource preservation. With the rapid production of next-generation cars, crumb rubber output is expected to rise. Unfortunately, burning and disposing of crumb rubber in landfills harms the environment. This investigation explores the potential use of crumb rubber in concrete, specifically as a fine aggregate. Concrete of M30 grade will be utilized for this study. Future steps involve creating cube, cylinder, and prism specimens, each cast with a unique mix proportion. After a 28-day curing period, these samples will undergo mechanical tests for compressive, flexural, and split tensile strength. Additionally, the density, permeability, and water absorption of CR concrete will be assessed. These findings will determine the optimal crumb rubber content and the overall efficiency of the concrete.

Keywords: Crumb rubber; Density; Efficiency; Fine aggregate; Landfills and burned; Mechanical properties; Optimum quantity; Permeability; Tensile strength; Water absorption

Introduction

Disposing of discarded tires is a challenging task each year due to their lengthy lifespan and non-biodegradable nature, contributing to landfill issues and negative environmental effects. One strategy to reduce landfill waste is using tire crumb rubber (CR) instead of natural aggregate concerning Hameed and Sekar (2008). Tire recycling, part of vehicle recycling, involves repurposing tires no longer suitable for automotive use due to wear or irreparable damage, such as punctures. Thin steel wires are removed from tires to create CR, which is a powdered or small piece of tire according to Hameed and Sekar (2009). This study aims to utilize waste tires as a sand alternative in varying

percentages. The project uses M30 concrete grade, with primary goals to replace sand with CR at different proportions: 0%, 5%, 10%, 15%, 20%, and 25%. Specimens in the form of cubes, cylinders, and eventually, prisms will be cast using specific mix proportions. After casting, the specimens are placed in a curing chamber for 28 days. Subsequently, they will undergo tests for flexural, split tensile, and compressive strength.

Wisnukhorn *et al.* (2023) examine the impact of adding crumb rubber aggregate and waste PET on the microstructure and strength characteristics of concrete modified with NRL. The study investigates the combination of PET and crumb rubber at 10%,

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20%, and 30% aggregate replacement ratios. NRL addition resulted in a lower compressive strength for the NRL-modified concrete compared to regular concrete. After 28 days, the compressive strengths of NRL10WP, NRL20WP, and NRL30WP were 8.3%, 15%, and 28.5% lower than NRL-modified concrete, respectively. Conversely, NRL-modified concrete exhibited a flexural strength approximately 3.3% greater than regular concrete. Despite the reduction in flexural strength with the replacement ratios of PET and CR aggregate, NRL10WP's flexural strength met Thailand's minimum standard of $f_f \sim 4.2$ MPa for rigid pavement, as required by the Department of Health. Microstructural analysis indicated that the NRL additive formed a film network that inhibited the development of hydration products, reducing compressive strength. However, this film network acted as a bridge mechanism, enhancing particle adherence in the concrete matrix and improving flexural strength.

Ganjian *et al.* (2009) evaluated the effectiveness of using used tires in mix proportions of 5%, 7%, and 10% as an alternative for cement and aggregate. The study found: (i) As the percentage of rubber in concrete increased, compressive strength fell. However, at a 5% rubber replacement in aggregate or cement, the reduction in compressive strength was minimal (less than 5%) with no significant changes in other concrete parameters. The most significant reduction occurred with 7.5% and 10% rubber replacement. (ii) Tensile strength decreased as the percentage of rubber substitution increased. Concrete with rubber chips instead of aggregates had lower tensile strength compared to concrete with rubber powder (used as a cement substitute). Tensile strength decreased by approximately 30-60% when 5-10% of the aggregate was replaced with chipped tire rubber, compared to using rubber powder in the same percentages for cement. (iii) Flexural strength also decreased with rubber substitution, though at different rates for different grades. The decrease was around 29% for coarse aggregates and 37% for cement replacements. (iv) Substituting rubber in concrete mixtures increased water absorption and improved water permeability depth when coarse aggregate was replaced, but decreased water absorption when cement was replaced.

Mashaan and Karim (2013) reported that as the crumb rubber content in the mix increases, the softening point value also rises. This increase in the percentage of asphalt to resin, possibly due to the higher rubber content, improved the stiffening qualities and reduced the modified binder's sensitivity to temperature changes. The rubberized asphalt binder's flexibility and ability to withstand rutting at elevated temperatures were evaluated.

A higher amount of crumb rubber significantly improved ductility and elastic recovery.

Wakchaure and Chavan (2014) examined the impacts on concrete parameters, including compressive and flexural strength, in M25 grade concrete when fine aggregate was partially substituted with crumb rubber at 0.5%, 1%, 1.5%, and 2%. Glass fibre was added to the cement at ratios of 0.4% and 0.5% to compensate for the strength lost when using tire crumb rubber particles. The findings demonstrate that while there is no discernible change in the properties of the concrete at fine aggregate proportions of 0.5% and 1%, there is a considerable shift at 1.5% and 2% when waste tire crumb rubber particles are substituted.

Al-Tayeb *et al.* (2017) examined the effects on the long-term performance of concrete under low-impact mid-point bending loads by substituting some of the sand with waste fine rubber. Samples were created with 5% and 10% sand replacement by volume. The study found that ordinary concrete experienced an average compressive stress of 37 MPa over 28 days. When 5% and 10% volumes of fine crumb rubber replaced the sand, the compressive pressure was reduced by 14% and 22%, respectively. Over time, the change in tip load showed an increase in peak amplitude by 5% and 7% when fine crumb rubber replaced 5% and 10% of the sand volume, respectively. Rubber in concrete promotes impact load absorption and ductility, with its high plastic energy capacity leading to increased tip load and bending load.

Methodology

Material property

Ordinary Portland Cement (OPC) of grade 53, with a specific gravity of 3.15, is utilized as per IS 12269-2013 standards. Locally available sand, classified as grading zone II, has a specific gravity of 2.65, a fineness modulus of 2.51, and a bulk density of 1850 kg/m³. Crushed granite coarse aggregate, known for its superior interlocking shape, is used to enhance strength, complying with IS 383-1987 standards. The largest size of coarse aggregate is 20 mm with a specific gravity of 2.7. All specimens are prepared using water available on the construction site, which has a pH of 6, meeting the requirements of IS 456:2000. The concrete's water content is reduced and its compressive strength is increased using Superplastic 430 super plasticizers as per IS 9103-1999.

Crumb rubber

Crumb rubber, a small portion of tire material used in automobiles after removing the thin steel

wire, is one of the ingredients in concrete Xiao *et al.* (2012). Figure 1 illustrates the hydrophobic action of UCR. To varying degrees, fine aggregate is replaced with crumb rubber with a specific gravity of 1.15 and a fineness modulus of 2.18. Figure 2 Demonstrates the Grain size distribution for UCR



Figure 1. illustrates the hydrophobic action of UCR

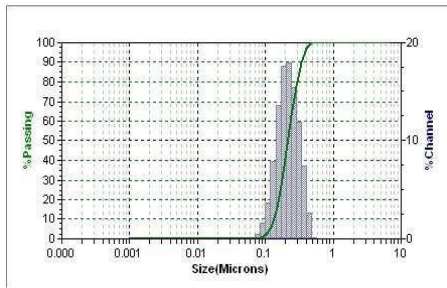


Figure 2. Demonstrates the Grain size distribution for UCR

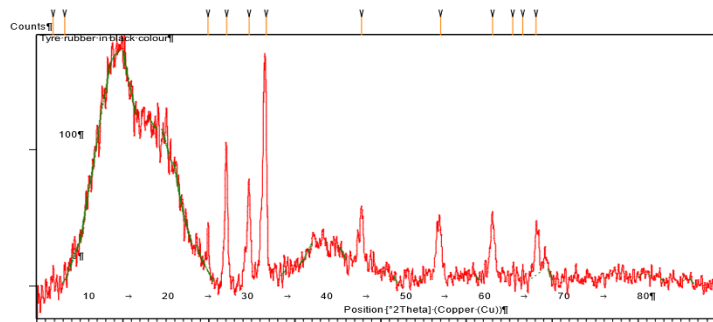


Figure 3. Graphical information about the UCR

X-ray diffraction

The material's structure is determined using this pattern. Figure 3 gives graphical information about the UCR. The material's atomic structure, composition, crystallinity, particle shape density, and viscosity, among other characteristics, are given in the table. Table. 1 Clarifies the measured Information about UCR. Table 2 Demonstrate the Crumb Rubber Pattern list of the angles and intensities.

Mix proportions

The mix proportions of various replacement percentages and resultant quantities were determined using IS 10262: 2019's mix design process. For fine aggregate replacement in M30 grade, crumb rubber (CR) was used as a percentage substitute. With the water content held constant at 197 kg/m³, all mix proportions were created with a slump range starting at 10 mm. A consistent water-to-cement ratio of 0.40 was employed for all mixtures. CR was used to replace fine aggregate in varying weights from 0% to 25%. The next stage involves substituting CR for fine aggregate based on weight determinations, with replacement ratios of 0%, 5%, 10%, 15%, 20%, and 25%. Table. 3 Listed the mixed Proportion of UCR used in the concrete mix.

Table 1. Clarifies the measured Information about UCR

Distribution	Intensity	Run Time	256 Sec	Fluid	Water	Reflected Pwr (Mv):	142
Progression	Standard	Rum#	1 Of 1	Fluid Ref Index:	1.333	Loading Index	0.058
Up Edge (Um):	6.54	Particle	B	Above Residual	0	Conc Index:	0.1224
Low Edge (Um):	0.0008	Transparency	Absorbing	Below Residual	0	Viscosity (Cp)	0.8350
Residuals	Enabled	Part Ref. Index	N/A	RMS Residual	1.525%	Cell Temp©	27.88
#Channel Mode:	52 Full	Particle shape Density	Irregular I 7G/Ce	Nano Ring Opt	Enabled	Nanotracer Type	Nano.Ultra
Filter Resolution	Std. Norm	Db Record	1837	Recalc status	Original	Serial Number	U2475e

Table 2. Demonstrate the Crumb Rubber Pattern List

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Rel.Int. [%]
11.8319	8.47	0.2362	7.47980	6.29
13.1972	10.01	0.2362	6.70886	7.43
29.346	35.66	0.2362	2.98503	26.48
32.0592	100.88	0.3149	2.79189	74.92
34.6700	73.97	0.3149	2.58740	54.93
36.6467	134.65	0.2755	2.45225	100.00
47.8172	40.83	0.3149	1.90224	30.33
56.9535	37.00	0.5510	1.61689	27.48
63.0076	49.07	0.5510	1.47532	36.44
65.4182	11.16	0.3149	1.42667	8.29
66.5555	12.47	0.1574	1.40503	9.26
68.0895	34.98	0.5760	1.37593	25.98

Table 3. Listed the mixed Proportion of UCR

Mix	Replaced UCR%	Sand (Kg)	Rubber (Kg)
UCR-0	0	709.0	0
UCR-1	5	673.5	35.5
UCR-2	10	638.1	70.9
UCR-3	15	602.6	106.4
UCR-4	20	567.2	141.8
UCR-5	25	531.7	177.3

Mechanical Test Procedure

Compressive and split tensile strength

A hardened concrete cube measuring 15 cm × 15 cm × 15 cm will undergo a compression test to assess its crushing strength as discussed in Gupta *et al.* (2016). The strength is noted at 28 days. According to IS 516-1959, the ultimate strength is determined when the specimens can no longer bear any more stress. Cylindrical specimens, 15 cm in diameter and 30 cm in height underwent split tensile tests at 28 days. Figure 4 shows the compressive strength of UCR, according to IS 5816-1999, these specimens are evaluated using compression testing equipment.

**Figure 4. shows the compressive strength of UCR**

Flexural test

The experimental test aims to establish the beam specimens' maximum load-carrying capacity. Each specimen is loaded twice, with the load at

failure recorded. Figure 5 shows the flexural strength of UCR according to ASTM C78. Flexural strength is measured at 28 days on a beam specimen measuring 10 × 10 × 50 cm.

**Figure 5. shows the flexural strength of UCR****Figure 6. Shows the curing of the specimen**

Water Absorption Test

The equipment used is a water cup with a graded tube, which has an interior radius of 40 mm and a height of 300 mm. Figure 6 Shows the curing of the specimen for 7 and 28 days after curing which

is examined for a water absorption test. The water level decrease is measured over ten minutes. The Water Absorption Factor (WAF) is calculated in $\text{ml/m}^2/\text{s}$.

Density

The ratios of the components used in making concrete affect its density. Due to its large specific surface area, crumb rubber can replace a small percentage of natural aggregate with a significant volume, made as lightweight concrete (Lv *et al.*, 2015).

Permeability of concrete

The TC-330 device was used to determine the concrete's permeability coefficient. Tests were conducted on two similar specimens at a pressure of 7 kgf/cm^2 , which were removed from the pressure tank after 24 hours. The difference between the initial and final values, divided by the tank area, determined the extent to which moisture filled the pores and capillaries. The specimen's discharge (Q) was then used to calculate the permeability coefficient.

Reading and conversation

Compressive Strength

The outcome represents the compressive stiffness of the specimen. Strength diminishes as crumb rubber (CR) content increases, Figure 7 demonstrates the compressive strength of UCR concrete in 7 & 28 days. Including more CR leads to a decline in compressive strength due to the hydrophobic nature of rubber, which causes improper bonding between the aggregate and CR. Segregated CR may induce more porosity, resulting in a further decline in compressive strength with increased CR content.

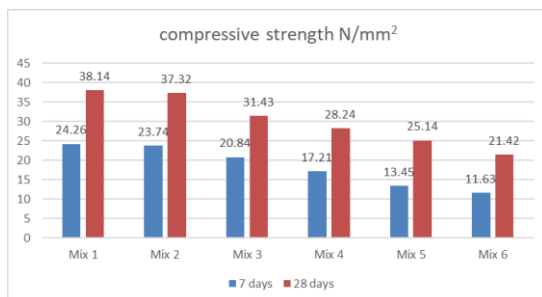


Figure 7. Demonstrates the compressive strength of UCR concrete in 7 & 28 days

Split Tensile Strength

With the addition of crumb rubber (CR), tensile strength gradually decreases. Figure 8 shows

the split tensile strength of UCR concrete in 7 & 28 days and how CR reduces concrete strength and increases porosity. However, CR's elasticity has the potential to arrest micro-cracks in the concrete.

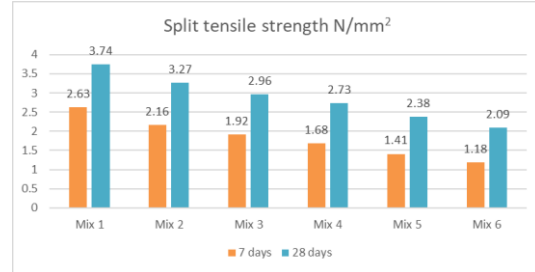


Figure 8. Shows the split tensile strength of UCR concrete in 7 & 28 days

Flexural Strength

A flexural strength investigation of the conventional and CR replacement mix was conducted. Figure 9 Represents the flexural strength of UCR concrete in 7 & 28 days. Strength deteriorates as CR content gradually rises. The flexural strength decreases by 5%, 17%, 25%, 35%, and 44% with CR contents of 5%, 10%, 15%, 20%, and 25%, respectively. During testing, the mode of failure of the specimen becomes more ductile as the CR content increases.

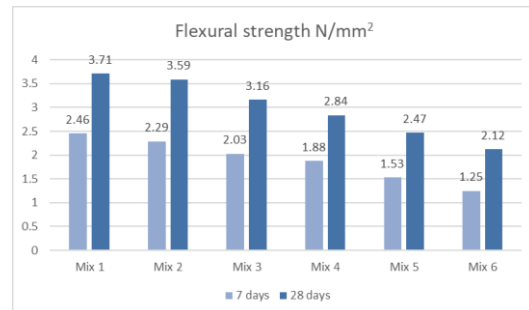


Figure 9. Represent the flexural strength of UCR concrete in 7 & 28 days

Deflection characteristics of UCR

The failure loads around the specimen's center and the deflection of the beams, as measured on the dial gauge with different quantities of untreated crumb rubber, were analyzed in reference by Shridevi *et al.* (2023). As the proportion of rubber material increased, the beams' ductility and the average load at which the first crack formed both changed. Figure 10 shows the deflection characteristics of UCR concrete. The 0% and 5% crumb rubber-reinforced samples broke directly at their centers, whereas the 15% and 20% crumb rubber-reinforced concrete failed 90-100 mm away from the center on either side. Crumb rubber

reinforced concrete can withstand greater distortion as the load increases, providing an essential warning before final failure. According to the test results, deflection increased with 15% and 20% crumb rubber content.

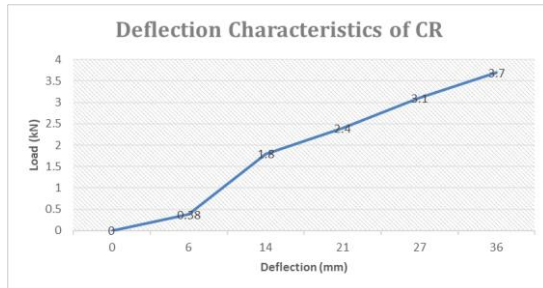


Figure 10. Shows the deflection characteristics of UCR concrete

Water Absorption Test

As a consequence of the improper alignment of the rubber components, voids are created when untreated crumb rubber is added to the concrete specimen. Figure 11 Demonstrates the water absorption test for UCR concrete. As the percentage of crumb rubber rises, the existence of voids may become more pronounced. A crumb rubber content of 5% to 25% significantly improves water absorption capacity.

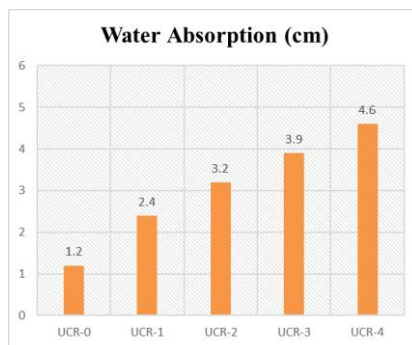


Figure 11. Demonstrate the water absorption test for UCR concrete



Figure 12. Illustrated the permeability test for UCR concrete

Permeability of concrete

The porosity in the CR concrete allows water to permeate through the material. Figure 12 Illustrated the permeability test for UCR concrete. Permeability increases with the quantity of voids about the CR content. In areas where CR is present, the permeability is low, and the ductility is high.

Relationship between water absorption and permeability

Water absorption is directly proportional to the permeability of water flow through CR concrete. The separation of crumb rubber causes the porosity, which is the primary reason for this relationship. Figure 13 illustrates the relationship between water absorption and permeability and shows that high permeability results from the interconnected pores in the CR concrete. Long-term water absorption can lead to the corrosion of reinforcement bars and may be affected by freezing and thawing conditions, inducing cracks. Proper arrangement of CR in the specimen can arrest these micro-cracks.

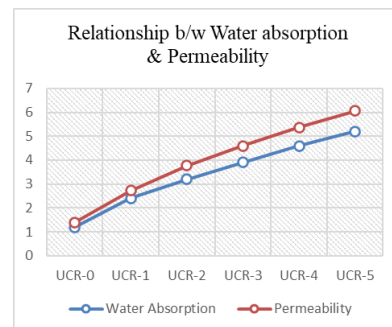


Figure 13. Illustrates the relationship between water absorption and permeability

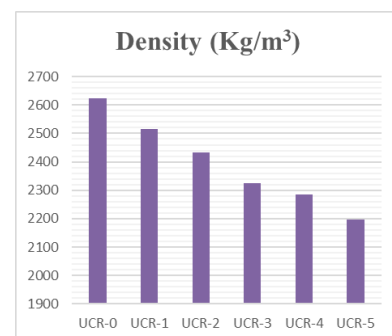


Figure 14. Shows the density of UCR

Density

Figure 14 shows the density of UCR, the density decreases, which directly impacts the overall density of the concrete due to the low density of crumb rubber.

Comparison with Results and Discussion

Mechanical properties were analyzed through the above testing procedure, and results were compared with the control mix and literature study.

1. Compressive strength and split tensile strength decreased consistently with the increment of CR content from 10% to 25%, with the strength value reducing from 17% to 45%.
2. The deflection of the specimen was high due to the ductility of CR. As the crumb rubber content increased, deflection increased. For specimens with 20% to 25% CR, the deflection was 3.1 mm to 3.7 mm, respectively.
3. Untreated crumb rubber repels water and floats on top of the specimen, causing the separation of CR and accumulation in specific areas. This segregation allows water absorption through the pores.
4. Air pores enhance sound absorption and reduce thermal conductivity. The permeability of the specimen affects the durability of the concrete.
5. Based on the readings and results, the optimal crumb rubber content was determined to be 5%.

Conclusion

This research paper analyzed the behavior of concrete with various proportions of untreated crumb rubber (UCR) and reported the following findings:

1. Crumb rubber has a low unit weight and high specific gravity, making the concrete less dense and lighter.
2. Compared to the control mix, the compressive and split tensile results show reduced strength, indicating that an increase in rubber content uniformly decreases strength.
3. Flexural strength results show that with an increasing crumb rubber percentage, deflection and flexibility also rise.
4. Beams with 0% and 5% crumb rubber had little to no ductility. However, increasing the crumb rubber content to 15% to 25% made the concrete more ductile.
5. The hydrophobic action of UCR elements causes segregation in specific areas, making the concrete highly porous.
6. Due to increased porosity and weak bonding, water absorption gradually rises with higher crumb rubber content.

7. The relationship between water absorption and permeability shows a corresponding flow rate increase in UCR concrete from 5% to 25%.
8. The research suggests that UCR concrete is most effective with a 5% replacement for non-load-bearing structures, concrete pavements, breast walls, and parapet walls.

Suggestions of the Author

In this research, compression, flexural, and split tensile strength declined with the increment of crumb rubber (CR), due to the hydrophobic action of crumb rubber. To counteract this effect, surface treatment of crumb rubber with sodium hydroxide, potassium permanganate, and sodium bisulfite under controlled conditions is used to achieve hydrophilic action regarding Ansari *et al.* (2021). This treatment may reduce segregation in the concrete, decreasing porosity, increasing bonding strength, and allowing greater usage quantities of CR. However, further investigation into the properties, behavior, and chemical action of treated crumb rubber by Zhang *et al.* (2014) will be conducted in the future. This paper only discusses the mechanical behavior of untreated crumb rubber (UCR) concrete in different proportions, while future studies will change the water-cement ratio to determine the effect of hydrophilic action and the microstructure of the concrete to understand the distribution of CR.

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