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Assessment of Flexural and Compressive Strengths in Concrete Utilizing Replacement of Coarse Aggregates with Rubber

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Abstract*: Employing waste rubber as a substitute for natural aggregate in concrete presents a promising environmentally conscious solution. The primary objective of this research is to assess the concrete's performance concerning its compressive and flexural strengths when coarse aggregate is partially replaced with recycled rubber. Seven distinct mixes were formulated, encompassing varying degrees of crumb rubber replacing coarse aggregate: 0%, 5%, 15%, 25%, 50%, 75%, and 100% by volume. The rubberized concrete underwent evaluation based on slump, compressive strength, flexural strength, density, and the influence of slight seawater exposure. Notably, the rubberized concrete blends exhibited enhanced workability and reduced density compared to the control mixture. As the proportion of coarse rubber content increased, there was a noticeable decline in compressive, tensile, and flexural strengths. Impressively, the rubberized concrete formulations displayed commendable performance even after a mere 28-day curing period in seawater conditions. The outcomes of this study provide a comprehensive understanding of the implications of integrating recycled rubber into concrete, particularly for various road construction projects prone to regular slight seawater infiltration. This approach is applicable up to a 25 percent volume replacement of rubber particles, underscoring its feasibility and effectiveness.*

Keywords: rubber, concrete, seawater, flexural, compressive

I. INTRODUCTION

Enhancing concrete properties through the incorporation of suitable materials is a widely explored avenue in concrete research. The inherent brittleness of concrete, coupled with its relatively lower load-bearing resilience in comparison to other materials, has led to the investigation of utilizing discarded tire particles as a potential alternative aggregate in concrete. This approach aims to mitigate or address these limitations. By introducing elastic and adaptable tire-rubber particles, the attributes of concrete can be enhanced [1][2][3]. The proper management and disposal of waste tires pose significant environmental challenges in numerous countries. Accumulating discarded tires is not only environmentally risky, but it also presents potential hazards like fires and the propagation of pests such as rodents, insects, and flies [4][5][6].

The imperative to recycle used tires has led researchers to explore the integration of rubber as a partial substitute for traditional aggregates in concrete formulations, with the aim of foreseeing concrete attributes across diverse applications [7][8]. Numerous investigations have pointed out that elevating the proportion of rubber in fresh rubberized concrete tends to diminish its workability [9–13]. The consistency of rubberized concrete, as indicated by its slump, experienced a reduction as the rubber content increased. This reduction was particularly noticeable when employing larger tire chips compared to smaller crumb rubber particles, and it was especially pronounced when using higher ratios of rubber particle substitution [10][19].

Multiple researchers have substantiated a consistent reduction in the density of rubberized concrete, attributing this phenomenon to the comparatively lower relative density of rubber in contrast to conventional aggregates [10][14][15–18]. The replacement of either coarse or fine aggregates with chipped tire fragments or crumb rubber, across varying levels of substitution, led to diminished compressive strengths in both scenarios. However, the reduction in compressive

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strength associated with the replacement of coarse aggregates was more pronounced than that observed in the case of fine aggregate replacement [10][20].

This study's fundamental objective is to assess the compressive and flexural strengths of concrete that integrates recycled rubber, ranging from 0% to 100% in volume, as a substitute for coarse aggregates at varying levels of replacement (5%, 15%, 25%, 50%, 75%). Parameters such as slump, compressive strength, flexural strength, and density were scrutinized. Additionally, the research aims to establish the optimal proportion of rubber replacement in relation to the volume of coarse aggregates, specifically applicable for road construction projects frequently exposed to slightly seawater intrusion.

II. MATERIALS AND METHODS

2.1. Materials

2.1.1. Cement: Ordinary Portland Cement (OPC) was acquired from a local construction supply, possessing a specific gravity. The OPC adheres to the Type IP Portland cement specifications stated in ASTM C150-05 (2005) (Specification for Portland Cement).

2.1.2. Fine Aggregates: Fine aggregates were sourced from a local supplier and obtained from a quarry, featuring a maximum size of 4.76 mm.

2.1.3. Coarse Aggregates: Coarse aggregates consisted of crushed stone with a maximum size of 0.75 inches or 19 mm.

2.1.4. Mixing Water: The water used for concrete mixing was potable and drawn from water supply sources. The water-cement ratio stood at 0.50.

2.1.5. Rubber Tire Chips: Rubber tire chips with a maximum size of 0.50 inches or 12.7 mm, devoid of steel wires, were incorporated.

2.2 Methods

The following methods were adopted in this research were as follows:

2.2.1 Mixture proportion: The table shows the quantities of cement, sand, coarse, and rubber cuts per design mix. The mix required a 0.50 water-cement ratio. The control mix, M0 was used as the basis for preparing the other mixes: Mix M5, tire rubber cuts replaced 5% of the coarse volume; Mix M15, tire rubber cuts replaced 15% of the coarse volume; Mix M25, tire rubber cuts replaced 25% of the coarse volume; Mix M50, tire rubber cuts replaced 50% of the coarse volume; Mix M75, tire rubber cuts replaced 75% of the coarse volume and Mix M100, tire rubber cuts replaced 100% of the coarse volume.

2.3 Laboratory tests

Specific Gravity and Water Absorption of Fine and Coarse Aggregates: The assessment of aggregates' specific gravity and water absorption adhered to ASTM C 128-79 guidelines, which are employed as the standard criteria for determining the specific gravity and absorption of fine aggregates. The specific gravity and percentage absorption of fine aggregates were measured at 2.68 and 3.63%, respectively. Meanwhile, the specific gravity and percentage absorption of coarse aggregates were recorded as 2.65 and 3.43%.

TABLE 1: MIX DESIGN OF CEMENT, SAND, COARSE AND TIRE RUBBER CUTS

Mix Design	**Cement (m^3)**	**Sand (m^3)**	**Coarse (m^3)**	**Tire Rubber Cuts (m^3)**
Mix M0	0.01059	0.0221	0.0335	0
Mix M5	0.01059	0.0221	0.2928	0.00331
Mix M15	0.01059	0.0221	0.2498	0.00654
Mix M25	0.01059	0.0221	0.02279	0.00955
Mix M50	0.01059	0.0221	0.01623	0.0164
Mix M75	0.01059	0.0221	0.00812	0.0247
Mix M100	0.01059	0.0221	0	0.03237

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- Cement Specific Gravity Determination: The specific gravity assessment of cement in both the control and designed concrete mixtures adhered to ASTM C150 guidelines (Standard Specification for Portland Cement). The specific gravity value obtained for the cement was 3.15.
- Sieve Analysis: The standard procedure outlined in ASTM C136 was employed for conducting the sieve analysis on both fine and coarse aggregates. Fine aggregates in the concrete mix consisted of sand that passed through a 4.76 mm sieve.
- Aggregates' Unit Weight: The unit weight of aggregates in compacted or loose conditions was established according to ASTM C 29-78 (Standard Method of Test for Bulk Density (Unit Weight) and Voids in Aggregates).
- Mixing Protocol: To ensure consistency, ASTM C305-82 (Standard Criterion for Cement Pastes and Mortars for Plastic Consistency) required a thorough mixing of cement, water, and aggregates. The strength of the sample is influenced by the even distribution and blending of these constituents.
- Curing Method: The procedures outlined in ASTM C140-91 (Standard Test Methods for Sampling and Testing) were followed. The test specimens were stored at room temperature for a period ranging from 20 to 48 hours prior to removal. Subsequently, the specimens were placed in a curing tank maintained at room temperature. Curing durations included 7, 14, and 28 days for exposure to a mixture of water and seawater.
- Compressive Strength Testing: The average compressive strength of concrete specimens was determined within the standard curing periods of 7 days, 14 days, and 28 days, while being subjected to a combination of water and seawater. The testing procedure adhered to ASTM C39-86.
- Flexural Strength Testing: Flexural strength assessment of the specimen was carried out using the ASTM C 293 method (Standard Test Method for Flexural Strength of Concrete Using Simple Beam with Center-Point Loading).

III. RESULTS AND DISCUSSION

Table 2 displays the fluctuation in slump values across different compositions of the new concrete mixtures. Among these, the control mix M0 exhibits the highest slump, while mix M100 shows the lowest value, as indicated in the table. The slump values show an upward trend from Mix M5 to Mix M25, but a decrease is observed from Mix M50 to Mix M100. Despite these variations in slump, as depicted in Figure 1, the rubberized concrete samples exhibited satisfactory workability, ensuring ease in handling and proper placement.

TABLE 2: SLUMP TEST RESULTS

Mix Design	**Slump, cm**
M0	5.2
M5	2.5
M15	3.2
M25	3.4
M50	2.7
M75	2.4
M100	2.1

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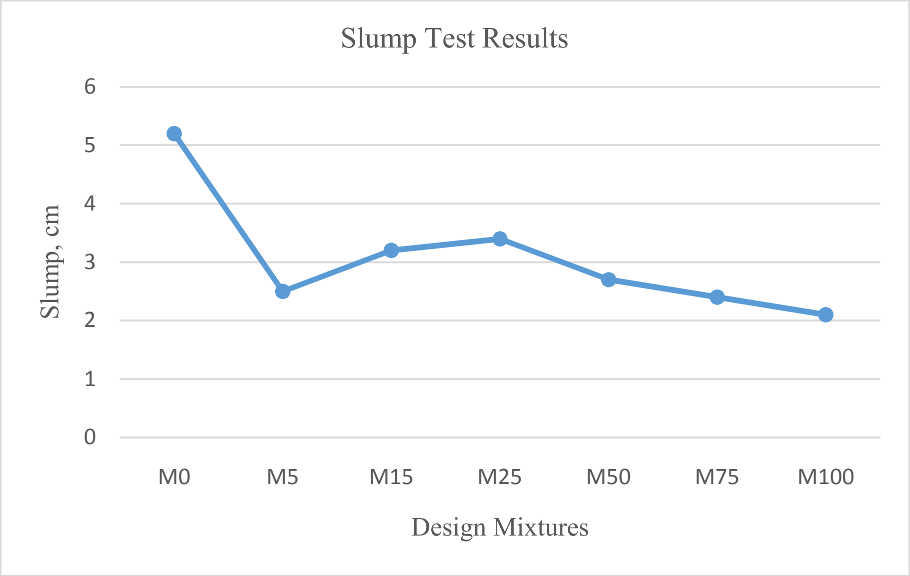

Figure 1. Property of Concrete, Slump

As evidenced by the data presented in Table 3 and illustrated in Figure 2, there is a noticeable decline in the unit weight of concrete from Mix M0 to Mix M100. This reduction in unit weight is a direct consequence of the increment in the proportion of coarse volume replaced by tire rubber. The substitution of the comparatively weightier coarse aggregates with the lighter tire rubber cuttings contributed to the overall reduction in the concrete's unit weight.

TABLE 3: QUANTITIES AND PROPERTIES OF MATERIALS

Mix Design	**Density, kg/m^3**
M0	2302.40
M5	2295.50
M15	2132.50
M25	1778.05
M50	1406.95
M75	1028.69
M100	866.33

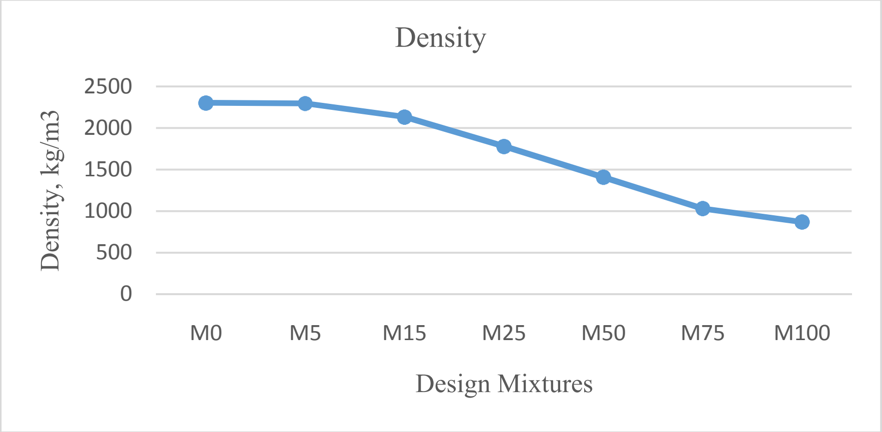

Figure 2. Property of Concrete, Unit Weight

The outcomes of the compressive strength tests conducted at 7, 14, and 28 days, where a portion of coarse aggregate was replaced with rubber, are presented in Table 4 and depicted in Figure 3. As the proportion of rubber replacing the coarse aggregate increases, a substantial decline in compressive strength becomes evident. The strength exhibited decreases from Mix M0 to Mix M100, respectively.

TABLE 4: COMPRESSIVE STRENGTH OF SPECIMENS (fc'), MPA

Mix Design	Curing Period (water)		
	7 days	14 days	28 days
M0	26.10	27.40	32.85
M5	24.70	25.7	29.52
M15	16.30	23.10	25.85
M25	12.28	16.6	18.6
M50	7.81	10.85	12.30
M75	5.20	8.12	9.4
M100	4.50	5.95	7.2

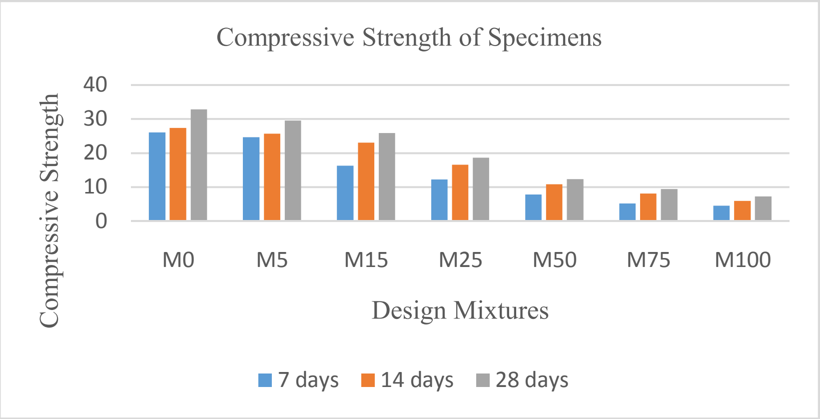

Figure 3. Compressive Strength of Concrete (water curing)

The results of the 28-day compressive strength assessment for concrete samples subjected to curing in both water and a mixture of water and seawater are detailed in Table 5 and illustrated in Figure 4. Following a 28-day exposure period to seawater, a notable enhancement in the compressive strength of rubberized concrete specimens was observed for Mixes M5, M15, and M25. There was a slight increase for Mix M50, while a marginal reduction was noted for Mixes M75 to M100. This variation could potentially be attributed to the interaction between the water mixture and the seawater in combination with the concrete mix.

TABLE 5: COMPRESSIVE STRENGTH OF SPECIMENS (fc'), MPA

Mix Design	28 days (water)	28 days (mixture of water and seawater)	Difference
M0	32.85	28.35	-4.5
M5	29.52	32.65	3.13
M15	25.85	27.89	2.04
M25	18.6	21.79	3.19
M50	12.30	13.04	0.74
M75	9.5	8.75	-0.75
M100	7.2	5.23	-1.97

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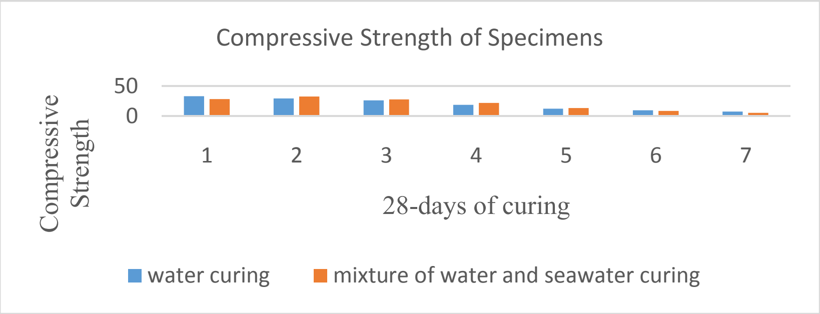

Figure 4. Compressive Strength of Concrete

Table 6 and Figure 5 below show the flexural strength of the specimens. The results showed that the flexural strength decreased as the rubber content in the mixture decreased. A considerable difference was seen for Mix M5, M15 and M25. As shown in the results, percent replacement of coarse aggregates is acceptable up to 25% with a strength of 4.46 MPa.

TABLE 6: FLEXURAL STRENGTH OF SPECIMENS (fc'), MPA

Mix Design	**Curing Period (water)**		
	7 days	**14 days**	**28 days**
M0	7.32	9.65	11.87
M5	6.42	7.98	9.48
M15	5.08	6.15	7.18
M25	1.95	3.76	4.46
M50	1.49	2.98	3.45
M75	1.35	2.62	2.98
M100	0.98	2.14	2.53

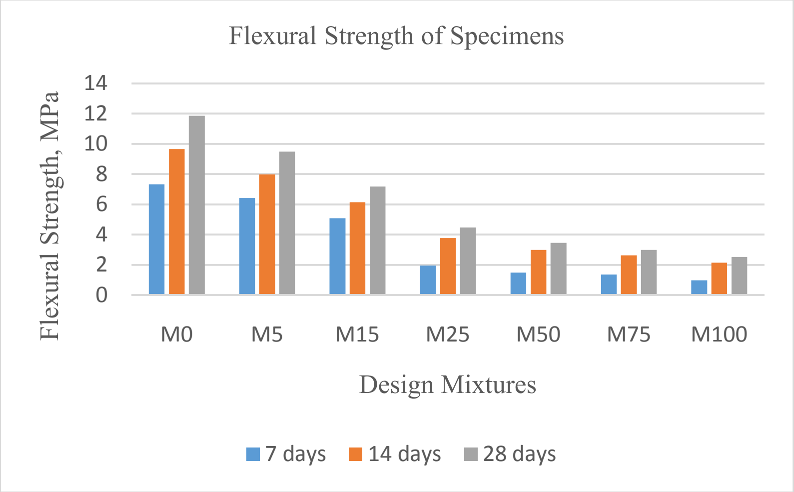

Figure 5. Flexural Strength of Specimens

The analysis of the flexural strength of concrete subjected to complete immersion in both water and a mixture of water and seawater is detailed in Table 7 and visualized in Figure 6. Mixes M5, M15, and M25 exhibited an upsurge in flexural strength, whereas Mixes M50, M75, and M100 displayed a decline in flexural strength after 28 days of complete immersion in the water-seawater mixture. Notably, Mix M25, with a strength of 4.63 MPa, emerged as a viable recommendation for roads prone to frequent water intrusion.

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TABLE 7: FLEXURAL STRENGTH OF SPECIMENS (fc'), MPA

Mix Design	**28 days (water)**	**28 days (mixture of water & seawater)**	**Difference**
M0	11.87	13.21	1.34
M5	9.48	9.59	0.11
M15	7.18	7.65	0.47
M25	4.46	4.63	0.17
M50	3.45	2.89	-0.56
M75	2.98	2.13	-0.85
M100	2.53	1.87	-0.66

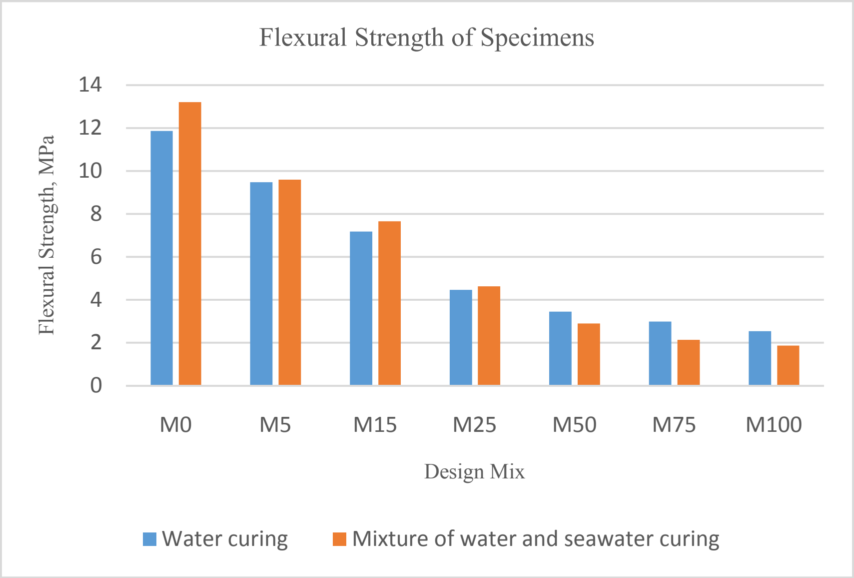

Figure 6. Flexural Strength of Specimens

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- Irrespective of the extent of coarse aggregate replacement with rubber particles, the compressive strength displayed a decrease as the rubber content proportion increased during both water and seawater curing. Notably, on the 28th day of curing with a water-seawater mixture compared to water alone, a slight upturn in compressive strength was observed for replacement levels of 5%, 15%, and 25% of rubber in coarse aggregates. This indicates the potential viability of utilizing rubberized concrete with up to 25% replacement levels for roadways frequently exposed to seawater intrusion.
- The density of concrete showed a consistent reduction with the augmentation of rubber cuttings replacing coarse particles in terms of volume.
- The study revealed fluctuating outcomes in slump measurements, indicating variable workability of the concrete mixtures.
- Investigation into flexural strength demonstrated that substituting 5%, 15%, and 25% of coarse rubber for coarse aggregates by volume led to increased flexural strength after 28 days of seawater curing. However, replacing 50%, 75%, and 100% of the volume with rubber caused a decrease in flexural strength.
- For road construction prone to minor saltwater infiltration, it is feasible to incorporate 25% rubber in the concrete mix as a substitute for coarse aggregates.

5.2 Recommendation

The conducted assessments were confined to the evaluation of compressive and flexural strengths, focusing solely on coarse rubber particles as a partial substitute for coarse aggregates. However, there exists a need for further exploration regarding impact of heat exposure and the impact of prolonged seawater exposure on rubberized concrete during extended curing durations. In order to comprehensively ascertain the performance of rubberized concrete, it is advisable to incorporate supplementary mechanical and chemical tests.

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