Laboratory Optimization and Environmental Assessment of Rubber Concrete Using Simultaneous Incorporation of Rubber powder and Rubber Fibers

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ABSTRACT

Annually, thousands of tons of rubber tires are produced, consumed, and discarded within the country. In recent decades, researchers have investigated the use of rubber fibers or rubber crumbs in concrete and their effects on its mechanical properties. However, the simultaneous utilization of both these materials as substitutes for sand and gravel in concrete has not been thoroughly explored. In this research, this research gap is addressed by examining the results of slump tests on rubber concrete specimens with water-to-cement ratios of 0.45, 0.50, and 0.55, incorporating rubber crumb and rubber fibers up to 25%. The test results indicate a reduction in compressive strength with increasing rubber content. By using different water-to-cement ratios, various rubber concrete proportions, and the SIMAPro software, it was determined that the combination of rubber crumb and rubber fibers leads to approximately a 40% reduction in carbon dioxide emissions in the environment. The optimal condition for all ratios is achieved by adding 4% rubber crumb and rubber fibers.

KEYWORDS: **Compressive strength, slump, rubber powder, rubber fibers, rubber concrete**

1. Introduction

The rapid expansion of the automotive industry has brought about a plethora of environmental challenges, particularly in the realm of waste management. Disposal of used car tires in landfill sites has become a critical issue, given their composition of rubber, which takes centuries to decompose. Consequently, this has led to a slew of undesirable environmental repercussions, including mosquito infestations, the release of hazardous chemicals, and the looming threat of fires, all of which endanger the inhabitants of adjacent regions. In response, there has been a recent surge in the utilization of discarded car tires as a constituent in concrete, giving rise to what is known as rubber concrete (RuC). This relatively new material boasts distinct attributes, such as exceptional energy absorption and high flexibility.

The amalgamation of rubber crumb and rubber fibers into concrete formulations offers two principal advantages: firstly, it mitigates the annual accumulation of landfill waste, and secondly, it substitutes the use of natural aggregates in conventional concrete production with recycled materials. On a global scale, an estimated one billion used tires are generated annually [1]. Given the excessive depletion of natural resources and the mounting construction and demolition waste output, our environment and ecosystems find themselves exposed to a burgeoning threat [2].

The core objective of present research is the concurrent incorporation of rubber crumb and rubber fibers into concrete mixtures. We seek to determine their impact on critical factors such as compressive strength, slump, failure mode, the identification of the optimal percentage, and the comprehensive analysis of their life cycle using the CIMAPro software. This study centers on a meticulous examination of the laboratory-based inclusion of rubber crumb and rubber fibers as substitutes for a proportion of coarse and fine aggregates. In pursuit of these laboratory experiments, a diverse range of percentages, spanning from 0 to 8% for rubber crumb and 0 to 16% for rubber fibers, were incorporated for varying water-to-cement ratios of 0.45, 0.50, and 0.55. Additionally, for each specific water-to-cement ratio, a control specimen devoid of rubber was employed as a reference concrete sample.

2. Materials and Mix Proportions

Within the scope of this research, Type 2 cement with an apparent density of 3150 Kg/m³ was chosen, alongside sand with an apparent density of 2650 Kg/m³. Coarse aggregates, characterized by a maximum size of 19 mm, were carefully selected in adherence to ASTM C125 standards. The formulation of concrete mixtures adhered to the guidelines stipulated by the ACI standard. The water-to-cement weight ratios were meticulously adjusted to 0.45, 0.50, and 0.55, respectively.

Table 1. Laboratory Test Sample Specifications: Water-to-Cement Ratio

Sample	Sample specifications
COW_1	Control concrete sample with rubber crumb and rubber fibers, water-to-cement ratio of 0.50
$CRP_{1.5}F_{2.5}W_1$	Sample containing 1.5% rubber crumb and 2.5% rubber fibers, water-to-cement ratio of 0.55
$CRP_{2.5}F_{4.5}W_1$	Sample containing 2.5% rubber crumb and 4.5% rubber fibers, water-to-cement ratio of 0.55
$CRP_{3.5}F_{6.5}W_2$	Sample containing 3.5% rubber crumb and 6.5% rubber fibers, water-to-cement ratio of 0.50
$CRP_{4.5}F_{8.5}W_2$	Sample containing 4.5% rubber crumb and 8.5% rubber fibers, water-to-cement ratio of 0.50
$CRP_{5.5}F_{10.5}W_3$	Sample containing 5.5% rubber crumb and 10.5% rubber fibers, water-to-cement ratio of 0.45
$CRP_{6.5}F_{12.5}W_3$	Sample containing 6.5% rubber crumb and 12.5% rubber fibers, water-to-cement ratio of 0.45
$CRP_{7.5}F_{14.5}W_1$	Sample containing 7.5% rubber crumb and 14.5% rubber fibers, water-to-cement ratio of 0.55
$CRP_{8.5}F_{16.5}W_1$	Sample containing 8.5% rubber crumb and 16.5% rubber fibers, water-to-cement ratio of 0.55

3. Experimental analysis

In pursuit of our research goals, we embarked on a concrete mixing endeavor, adhering to the predetermined design parameters across various water-to-cement ratios. Subsequently, we subjected each sample to the slump test, followed by a curing period of 24 hours in a dedicated facility.

After a comprehensive 28-day curing period, the concrete samples were primed for compressive strength testing.

3.1. Slump Test

Our slump tests, in accordance with ACI 211 guidelines, yielded intriguing results. Across all water-to-cement ratios, the replacement of up to 4% of rubber crumb and rubber fibers showed minimal impact on slump, with reductions hovering around the 2.5% mark. However, as we pushed the boundaries to a 25% replacement rate with rubber crumb and rubber fibers, we witnessed a significant slump reduction, reaching 63%, 67%, and 75% for the respective ratios. This substantial drop can be attributed to the excessive rubber content and its propensity to absorb water within the concrete matrix.

3.2. Compressive Strength Test

Turning our attention to compressive strength, our findings painted a clear picture. With increasing rubber content, a consistent trend emerged—compressive strength exhibited a decline. This downward trajectory can be ascribed to the burgeoning air voids and fissures that emerged around the rubber components within the concrete. The elastic modulus of rubber-infused concrete also experienced a reduction, a phenomenon potentially linked to factors beyond mere shrinkage-induced stresses. These factors might encompass thermal effects and the unique properties of coarse aggregates, including their elastic modulus, type, and quantity.

3.3. Environmental Assessment of Recycled and Rubber Materials

As we delved into the realm of environmental evaluation, a striking pattern emerged concerning CO2 gas emissions. In rubber concrete, a tangible decline in CO2 emissions was observed. At a 25% replacement rate, we achieved a staggering 42% reduction in CO2 emissions compared to plain concrete, marking the highest reduction recorded. In the biogenic category, a modest reduction in CO2 emissions, around 2.0%, was observed in plain concrete compared to rubber concrete, specifically with a 4% rubber replacement at a water-to-cement ratio of 0.50. However, the most significant reductions occurred in rubber concrete with 25% replacement, showcasing a remarkable 44% decrease compared to plain concrete. At a water-to-cement ratio of 0.45, with the incorporation of 4% rubber, a substantial 5.3% reduction in fossil CO2 emissions was achieved. Notably, this reduction intensified with higher rubber content.

In the present exploration of the impact of rubber crumb and rubber fibers on fracture mode, a noteworthy outcome surfaced—increased proportions of these materials in the samples led to a narrowing of crack widths.

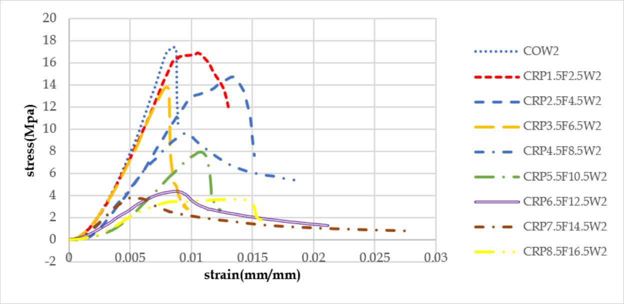

Figure 1. Stress-Strain Curve with Control and Rubber Concrete Samples (Water-to-Cement Ratio of 0.50)

This figure illustrates the stress-strain relationship for various concrete samples, including the control sample and those incorporating rubber crumb and rubber fibers. The data points provide insight into the material's mechanical behavior, specifically at a water-to-cement ratio of 0.50.

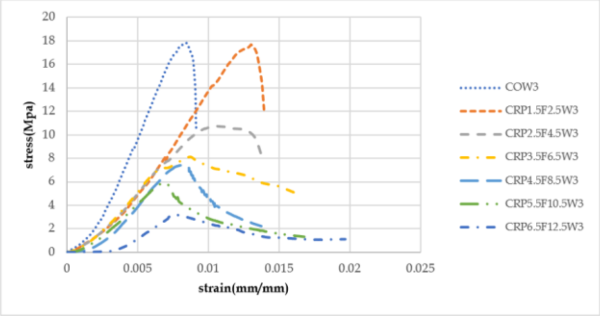

Figure 2. Stress-Strain Curve with Control and Rubber Concrete Samples (Water-to-Cement Ratio of 0.45)

This figure illustrates the stress-strain relationship for various concrete samples, encompassing the control specimen and those integrated with rubber crumb and rubber fibers. The examination is conducted at a water-to-cement ratio of 0.45, shedding light on the material's mechanical response under these conditions.

4. Conclusions

Increasing the quantity of rubber crumb and rubber fibers in concrete mixes results in a reduction in compressive strength due to the decreased adhesion and lower interparticle friction within the rubber particles and the inherent voids present between them. Rubber crumb and rubber fibers exhibit significant water absorption properties, leading to a decrease in slump when both materials are simultaneously incorporated into rubber concrete. Moreover, as the replacement percentage of rubber crumb and rubber fibers increases, the elastic modulus exhibits a consistent decreasing trend.

The high specific surface area and smaller pore sizes surrounding the interface between rubber and cementitious matrix particles allow rubber crumb to trap less air compared to rubber fibers. These interfacial pores in the rubber particles contribute to frost resistance and enhance concrete's resistance to freeze-thaw cycles.

Although rubberized concrete exhibits lower compressive strength, it showcases significantly higher elasticity compared to conventional concrete. Rubberized concrete can be considered an environmentally friendly "green" concrete, with the best performance observed when incorporating 5% rubberized concrete, optimized for both compressive strength and slump. These rubberized concrete mixtures also exhibit reduced weight compared to the control concrete.

Furthermore, the addition of rubber crumb and rubber fibers leads to a decrease in CO2 emissions, with an increasing trend as the replacement percentage rises. The maximum reduction in emissions was observed at a

5.8% rubber crumb and 16.5% rubber fibers replacement.

By examining various water-to-cement ratios and different percentages of rubberized concrete with the aid of SimaPro software, the optimal lifecycle conditions were determined, taking into account the data regarding CO2 emissions in rubberized concrete.

a) In water-to-cement ratios of 0.55, 0.50, and 0.45, the optimal condition with a 25% rubber replacement resulted in CO2 fossil reductions of 42%, 44%, and 46%, respectively, compared to concrete without rubber.

b) In three water-to-cement ratios of 0.45, 0.50, and 0.55, and the optimal condition for biogenic emissions, a 25% rubber replacement led to a 2% reduction in CO2 emissions compared to concrete without rubber.

Overall, the optimal condition for all compressive strength and biogenic fuel reductions across three water-to-cement ratios (0.45, 0.50, and 0.55) is the replacement of 4% rubber in concrete. In the case of a 0.55 water-to-cement ratio and the optimal condition, adding rubberized concrete results in a 42% reduction in CO2 fossil emissions compared to concrete without rubber.

5. References

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