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Comparative Analysis of Conventional Concrete Mixture and Concrete Incorporating Recycled Rubber and Iron Oxide

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Abstract **-** The exploration of the use of recyclable materials for concrete production and the improvement of its properties is a frequently employed resource to make the production of this material a sustainable and less environmentally harmful process. Therefore, the creation of a concrete based on recycled rubber and iron oxide represents a significant advancement for the industry, with rubber being a burgeoning material due to its continuous use in the industrial sector for its properties resistant to abrasion, UV rays, water, and chemicals. The application of recycled rubber in a concrete mixture result in a concrete that surpasses conventional concrete in compression and flexural strength, as well as energy absorption capacity. This signifies a step forward in utilizing rubber-derived waste, confirmed through laboratory tests where a comparison of sample properties was carried out to achieve a specimen with superior physical and chemical characteristics compared to those available in the market.

Keywords**:** rubber concrete; mechanical properties; rubber particles; iron ixode

1. Introduction

Concrete, an essential component in the construction industry, is widely acknowledged for its versatility and widespread application in various structures. This material, primarily composed of cement, water, and aggregates, possesses exceptional strength that has solidified its position as the cornerstone in infrastructure development. To mitigate the environmental impact stemming from traditional concrete production practices, alternatives have emerged aiming to enhance its sustainability. One such innovation lies in the incorporation of recycled materials, such as rubber from discarded tires and iron oxide, as partial substitutes for conventional aggregates. This addition not only contributes to environmental impact reduction but also optimizes the mechanical properties of the concrete.

The ongoing project aims to evaluate the feasibility and advantages of utilizing recycled rubber and iron oxide in concrete production. Focusing on mechanical behaviour, tests for compressive and tensile strength will be conducted on two variants of concrete with the addition, while maintaining a specified compressive strength of f'c=280 kg/cm2. The concrete samples for these tests are produced in the laboratories of a laboratory plant.

It is important to note that this study is limited to the specific context in Ecuador, without interregional comparisons, and centres on the use of two recycled materials (rubber and iron oxide), excluding the evaluation of other potential recycled materials in concrete production. Additionally, historically, recycled rubber from tires has demonstrated a positive contribution to the strength and durability of concrete, simultaneously addressing waste and environmental pollution challenges. Furthermore, the addition of iron oxide to the concrete mix not only improves workability in the fresh state but also reduces porosity, permeability, and the effects of carbonation in hardened concrete. These advancements represent a crucial step towards sustainable construction and environmental protection, integrating innovations that transcend conventional practices.

1.1. Literature Review

Rubber is known for being a versatile material with various applications. In [1], it is indicated that while rubber is a material that causes pollution, crushed rubber in recycled products helps reduce its negative impact on the environment. In a study conducted by [2], the viability of replacing fine aggregate with recycled rubber in different proportions in concrete is demonstrated without significantly affecting its compressive and flexural strength. [3] considered the possibility of replacing rubber for half of the total fine aggregate to promote the circular economy. In their tests, 5%, 10%, and 20% of the fine aggregate were replaced to evaluate the properties of the obtained samples, concluding that 5% recycled rubber does not alter the mechanical, physical, and chemical properties of the material. [4] stated that the mixtures regulated with rubber showed better water resistance than the established pattern sample. [5] After their tests on test tubes, the citation managed to demonstrate the compatibility of rubber with concrete along with its benefits.

Alongside rubber, iron oxide is also a material that can improve the strength of concrete. According to [6], it increases the density of concrete and reduces its porosity and permeability, making it less prone to crack over time. In [7], it was mentioned that iron oxide helps protect concrete from the carbonation process due to its carbon dioxide reduction action, making it an ideal material to include in its formula.

2. Materials

Concrete is essentially a mix of rocks and a binding paste. The paste, made of cement, water, and air bubbles, is crucial, while the rocks, categorized as fine or coarse, usually gravel and sand, are also vital. The paste takes up about 25% to 40% of the whole concrete volume, with cement around 7% to 15%, water 14% to 21%, and air bubbles 4% to 8%. Rocks, on the other hand, form about 60% to 75% of the total volume, creating a structure resembling rock due to chemical reactions.

2.1. Properties of Materials

2.1.1. Recycled Rubber

The Rubber, a natural plant-derived polymer, is fundamental in various industries due to its elasticity, flexibility, and resistance to deformations. These properties make it ideal for tires, machinery, and moulded rubber products. Chemically, its basic compound is isoprene (CH2). However, its durability presents environmental challenges, as it is non-biodegradable and can take centuries to decompose. This poses a significant environmental issue, especially with the massive number of discarded tires ending up in landfills. By recycling rubber, such as using it crushed in recycled products, this negative impact can be mitigated, working towards more sustainable environmental solutions. Some of these features are outlined in the technical data sheet provided by the suppliers in Table 1.

Table 1: Physical Properties of Crumb Rubber.

Physical Properties	• Form: Solid (granules and powder) • Color: Black • Odor: Characteristic rubber odor • Density g/cm3: 0.7942 – 1.032 • Specific weight: 1.15 – 1.27 • Moisture: <0.75% • Flash Point (°C): 300 - 450

2.3. Iron Oxide

Iron oxides, chemical compounds of iron and oxygen, play a crucial role in everyday applications, including paints, coatings, and concrete coloring. Specifically in concrete, these oxides are utilized to achieve translucent tinting by dye penetration. The iron oxide content in concrete products is generally limited to a range of 1% to 10%, with an optimal percentage of 5-8% to maintain mechanical strength. These oxides are fundamental in providing coloring options in the realm of concrete. It's carefully dosed, considering the final specimen, as outlined in Table 2 provided by product suppliers.

Table 2: Physical Properties of Nubifer R-4530

Physical and Chemical Properties	Typical Value	Analysis Method
Specific Gravity	4.8	ASTM D-153
Fe_2O_3 Content	>94%	-
Heat Resistance	800ºC 5min	NCF-33
Acid Resistance	5	NCF-35
Alkali Resistance	5	NCF-35
Light Resistance	8	NCF-32
Weather Resistance	5	NCF-32

3. Experimental Investigation

During the laboratory practice, our focus was on exploring concrete properties by incorporating recycled rubber and iron oxide into the mix. To progress in the mix design, a detailed characterization of both coarse and fine aggregates was conducted. This included measuring specific weight, fineness modulus, absorption percentage, and aggregate moisture content. These measurements are vital to adjust the material quantity in the concrete mix, ensuring the desired properties are achieved.

A total of ten mix designs were carried out in three stages. In the first stage, a nominal concrete mix was designed without recycled rubber or iron oxide. In the second stage, recycled rubber was incorporated in varying percentages as a partial substitute for fine aggregate. This stage required design adjustments as the samples didn't meet the desired concrete characteristics. In the third stage, additional designs were created based on the best design from the previous stage but with the addition of iron oxide in different proportions. For each design, they were complemented with 12 cylindrical specimens, and appropriate procedures for concreting were followed, including material weighing recommendations and material homogenization using the mixer. The samples underwent tests for consistency, density, and resistance to compression and diametral compression. Additionally, an analysis of particle size distribution in the sample was conducted through a particle size analysis.

The inclusion of recycled rubber as a partial replacement for fine aggregate and the addition of iron oxide had a significant impact on concrete properties. Designs incorporating six percent recycled rubber as a partial replacement for fine aggregate and nine percent iron oxide showed more promising results in terms of compression strength and diametral compression. These results indicate that these additions can be viable strategies to enhance concrete properties without compromising its mechanical strength.

4. Results and Discussion

In this research, the impact of incorporating recycled rubber and iron oxide on concrete strength at different ages was evaluated in comparison to standard concrete. Compression and diametral compression tests were conducted at various stages with different proportions of recycled rubber and iron oxide. The results indicated that the incorporation of recycled rubber decreased the concrete density, whereas iron oxide increased it. Regarding compression strength, samples with 5% recycled rubber as a partial replacement for fine aggregate and 9% iron oxide demonstrated the highest compression strength at 28 days. This outcome is reflected in Figure 1 and Figure 2.

Materials	Weight in kg for 1m3			Weight in kg for 22 liters		
	5%	10%	15%	5%	10%	15%
HE Cement	321	317	313	8.98	8.87	8.77
Sand	917	822	737	27.3	24.48	21.94
Stone	828	874	745	22.95	21.73	20.64
Water	181	178	176	3.67	4.77	3.87
Rubber	48	91	130	1.35	2.56	3.65
Iron oxide	0	0	0	0	0	0
Superplasticizer	3.53	3.49	3.45	0.049	0.049	0.048
Retardant	1.76	1.74	1.72	0.099	0.098	0.097

Fig 1: Design of concrete mix with addition of recycled rubber as partial replacement for the mass of fine aggregate.

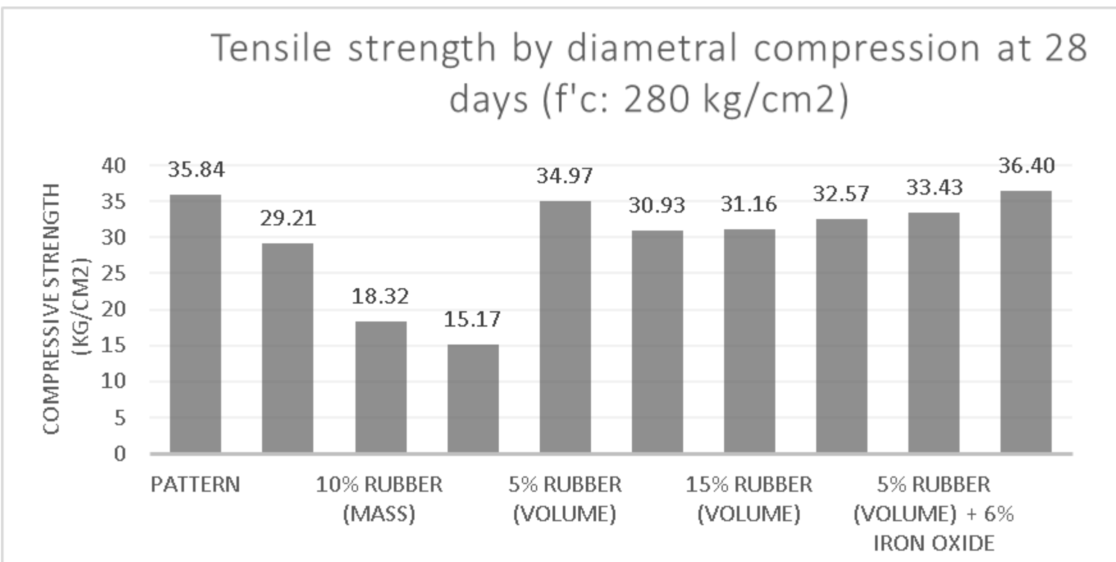

Fig 2: Percentage of tensile strength by diametral compression at 28 days of age.

5. Conclusion

Based on the information we conclude that:

• The inclusion of recycled rubber and iron oxide in concrete reduces landfill waste and cuts carbon footprint in construction.

• The workability properties of concrete are not significantly impacted by incorporating recycled rubber from end-of-life tires. However, the concrete density might be compromised.

• The optimal percentage for partial replacement of fine aggregate volume is 5% recycled rubber, achieving a 4% increase in concrete strength without affecting its density and durability.

• The presence of 9% iron oxide as an additive in the concrete mixture with 5% recycled rubber provides high early-age strengths.

• It is recommended to use aggregates from the same source and saturation level to ensure uniformity and quality of the concrete. Also, keeping the equipment moist during mixing is suggested to prevent a decrease in water content.

• It was observed that the sample with 5% recycled rubber as partial replacement for fine aggregate and 9% iron oxide showed the highest compression strength at 28 days.

• The combination of 5% recycled rubber and 9% iron oxide in concrete demonstrated promising results in terms of strength and environmental benefits.

• Long-term durability tests up to 90 days of age should be conducted to assess the effect of incorporating rubber and and iron oxide on concrete durability.

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