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Enhancing Concrete Properties With Rubber Additives: Experimental Analysis And Performance Evaluation

Yaqoob Saif

University of Sfax, National School of Engineers of Sfax, Geomaterials, Civil Engineering Structures and Environment Research Unit, Sfax, Tunisia

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*Correspondence: Yaqoob Saif
Email: Yaqoob-yousif-oleiwi.saif@enis.tn

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Abstract: *This research investigates the effect of adding recycled rubber to concrete mixes as part of efforts to enhance environmental sustainability and improve the mechanical properties of concrete. The study focuses on evaluating the mechanical and physical performance of rubberized concrete by analyzing its properties such as compressive strength, tensile strength, and workability. Partial replacement of rubber by 0% to 15% of fine aggregate in concrete was studied, with standard tests conducted to determine the effect of rubber on overall performance. The importance of the research lies in providing a dual solution of reducing environmental waste from used tires, while improving some properties of concrete in non-structural applications. The results show that rubberized concrete achieves important advantages such as improved flexibility, abrasion resistance, and light weight, despite a slight decrease in compressive strength. The research also highlights the potential of using rubberized concrete in non-structural applications such as pavements, road barriers, and shock absorption systems. The research concludes by recommending further studies to improve the adhesion between rubber and concrete mix components, while exploring innovative applications to expand the use of rubberized concrete in sustainable construction projects.*

Keywords: *Rubber Concrete;,Fresh Concrete Mixes, Building Material*

Introduction

Concrete is an essential building material for infrastructure and is widely used all over the world due to its durability and adaptability. However, its production causes many environmental impacts because it emits carbon dioxide at a rate of about 8 to 9%. (Li & Li, 2018) (Mohammed, Hossain, & Wong, 2018). It also causes depletion of natural resources, so sustainable solutions must be found to achieve good performance and low environmental impact (C496/C496M, 2022).

To solve these crises, researchers suggested adding rubber tires, which are widely available in waste, as their number is estimated at more than one billion tires that are disposed of every year all over the world. Part of these tires are burned and the other part is sent to landfills, so they have a very large environmental impact on the air, water and soil (12390-3, 2021) (Gupta, Chaudhary, & Sharma, 2014).

One of the effective ways to get rid of rubber is to add rubber particles without aggregate to concrete. Rubber concrete has good and unique mechanical properties, including high flexibility, shock resistance and durability in certain situations (Aiello & Leuzzi, 2010). Taking into consideration that rubber does not only have benefits for concrete, as its addition also represents an economic and environmental benefit (Onuaguluchi & Panesar, 2014).

The use of rubber is important to encourage international initiatives that encourage innovation in construction. In order to achieve environmental and economic goals and benefits, researchers are trying to integrate and add recycled materials to concrete. For example, some researchers have studied that using recycled rubber instead of gravel or sand reduces environmental pollution, as rubber, when thrown in the waste, causes environmental pollution to the soil (Mendis, Al-Deen, & Ngo, 2017) (Silva, Oliveira, & Brito, 2020). However, it must be taken into consideration that the use of rubber reduces the compressive and tensile resistance, so it requires serious concrete mix design with the addition of additives to improve the mix (Tobeia, 2021).

The aim of this study is to know the effect of adding rubber to concrete and the effect of rubber on the mechanical and physical properties of concrete, where we shall provide suggestions for rubber concrete in non-structural applications by conducting experimental tests on several mixtures with different proportions of rubber and the results enhance the scientific discussion of sustainable construction methods by providing useful suggestions for striking a balance between mechanical performance and environmental benefits (Alizadeh, 2024).

Literature Review

Historical Development

The application of recycled materials in concrete has gained recognition in recent years, driven by increased environmental consciousness and continuous advancements in the science of structural materials. In the 1990s, researchers conducted initial works on rubberized concrete that helped in understanding the fundamental interactions between the rubber molecules and the mix components of concrete.

(Khatib & Bayomy, 1999) They examined the fundamental flaws of rubber concrete and their impact on mechanical properties. They were among the first to find these flaws. In addition to discovering this, they also showed that adding rubber to concrete has benefits which include flexibility, energy absorption, and low friction. The research opened up a wider field of further studies on this topic, especially studies on sustainability and environment footprint reduction.

Mechanical Properties

According to (Thomas & Gupta, 2021), adding rubber crumb instead of 10% of fine or coarse aggregate reduces the compressive strength by 15% because rubber is less stiff than conventional concrete blocks.

In addition, a study by (Ganjian, Khorami, & Maghsoudi, 2009)found that due to the flexibility and energy absorption capacity of rubber concrete, it increases its use in non-structural applications such as concrete pavements that require high flexibility, making it a desirable choice in applications that aim to achieve sustainable construction.

Durability And Environmental Benefits

According to previous studies, rubber concrete in certain environmental conditions has shown high durability including corrosion resistance and freeze-thaw resistance, making it one of the sustainable construction options in difficult environmental conditions (Kumar & Das, 2023). In addition, it can support structural loads due to its light weight, which makes it suitable for use in designs that require low weight.

(Etxeberria, Vázquez, & Marí, 2007)The use of rubber material in concrete has a positive effect from the point of view of reducing the need for raw materials with adverse environmental effects, as they emit carbon emissions. Hence, for the case of recycled rubber use the extraction techniques is reduced that affect natural resources. Additionally, (Silva, Oliveira, & Brito, 2020) This study incorporated rubber into concrete for more environmentally friendly building practices by using recycled materials rather than disposing in the waste and thus having economic and environmental benefit.

Challenges And Research Gaps

(Lin & et al, 2022)Through its many advantages, rubber concrete suffers from weak adhesion due to the low capability of the rubber fraction in the mixture to adhere to the other materials, and this led to propose solutions to surface treatments. To overcome this issue researchers in this study proposed enhancing adhesion between mixture components through added chemicals so that it is strong enough to resist the pressures of a lacking adhesion.

Furthermore, (Siddique & Naik, 2004)Studies have shown that depending on exposure to different agents, exposure time and concentration, aggressive action of test agents can lead to accelerated deterioration of rubber concrete. The extent of their influence on the mechanical and physical properties of rubber concrete can be known through these studies.

Emerging Trends

Due to the additives and their positive effect when added to rubber concrete, new methods have been developed to improve the properties of rubber concrete. For example, adding additives such as polymer and nano silica has shown good and above-expected results in improving the durability and mechanical properties of rubber concrete mixtures (Singh, 2020). Nano silica enhances the bonding between the components of the concrete mixture and reduces porosity. Polymers improve the performance of concrete in different climatic conditions, increasing workability, flexibility and corrosion resistance. Through these developments, great potential appears to be available to overcome the current drawbacks of using rubberized concrete, which are low bonding and compressive strength.

In addition, these developments open the door to using rubberized concrete in a wider range of projects, especially those requiring lightweight, sustainable and harsh-resistant materials, which enhances its position in future construction methods (Ali, 2023).

Methodology

Materials

In order to obtain highly accurate results, we used high-quality materials throughout the experimental process. The table below explains the materials we used and their specifications:

Table 1. Materials and specifications

Material	Specification	Quantity Used
Cement	Ordinary Portland Cement (OPC)	400 kg/m³
Fine Aggregates	Natural sand (4.75 mm max size)	600 kg/m³
Coarse Aggregates	Crushed gravel (20 mm max size)	1200 kg/m³
Rubber Particles	Crumb rubber (1–5 mm size)	0%, 5%, 10%, 15% replacement
Water	Potable water	180 kg/m³
Admixtures	Superplasticizers	1.5% of cement weight

Mix Design

We prepared a concrete mix formulation in order to examine the effect of replacing rubber instead of aggregates at specific ratios of 5%, 10% and 15%. The mix formulation was prepared according to the guidelines of ACI 211.1. The table below shows the mix formulation and quantities:

Table 2. Mixture formulation

Mix ID	Rubber Content (%)	Cement (kg)	Fine Agg. (kg)	Rubber (kg)	Coarse Agg. (kg)	Water (kg)	Superplasticizers
Mix-0	0	400	600	0	1200	180	6
Mix-5	5	400	570	30	1200	180	6
Mix-10	10	400	540	60	1200	180	6
Mix-15	15	400	510	90	1200	180	6

Tests Conducted

- **Workability Test:** The slump test was carried out on fresh concrete mixes and the test was carried out according to EN 12350-2. The purpose of this test is to obtain results to evaluate the workability of each mix.
- **Compressive Strength Test:** Compressive strength test was conducted on concrete mixes and cubes of size 15x15x15 were used and the cubes were examined after 7, 14 and 28 days according to EN 12390-3 specification. The benefit of this test is to obtain compressive strength results for each mix.
- **Splitting Tensile Strength Test:** Tensile strength test was performed on concrete mixes using 30cm x 15cm cylinders and the cylinders were examined after 28 days according to ASTM C496 specifications. The aim of this test is to obtain results to know the tensile strength of each mix.

- **Density Test:** The hardened density test was performed on concrete mixes and cubes of size 15×15×15 cm were used and the cubes were examined after 28 days according to ASTM C642 specification. The aim of this test is to obtain results to know the density of concrete and the weight of concrete.

Results And Discussion

Workability

We conducted a workability test and the results showed that increasing the rubber content in concrete mixes leads to a reduction in shrinkage, which makes workability low due to the irregular shape of the rubber particles' surface and the lack of adhesion of the mixture components to the rubber, which negatively affects the flow. These results indicated the need to improve the mix design, including the use of additives to compensate for the negative effect on workability while maintaining the benefits associated with adding rubber.

Table 3. Slump Test

Rubber Content (%)	Slump (mm)
0	85
5	70
10	55
15	40

In order to increase the workability it is necessary to add additives such as superplasticizers and others. Adding these materials improves workability even with the addition of rubber and does not cause any change in the mechanical properties. We conclude from this that adding rubber without adding other auxiliary materials has a negative effect on concrete mixtures and leads to a decrease in workability.

Based on the results we have shown, we advise you to strike a balance between adding rubber and additives so as not to affect workability. For example, sidewalks need good workability to ensure surface leveling. Therefore, mixes must be carefully designed to meet the requirements of each application while maintaining the distinctive properties of rubber concrete

Compressive Strength

The results of the compressive strength of rubber concrete showed that it decreases as the rubber increases, due to the lower hardness of the rubber particles compared to the natural aggregate. The rubber weakens the mixture, which reduces its ability to withstand compression. In addition, the addition of rubber reduces the cohesion between the components of the mixture. In order to treat this condition, it is necessary to add adhesive materials to increase the cohesion between the rubber and the components of the mixture, such as nano silica or pozzolan and other additives.

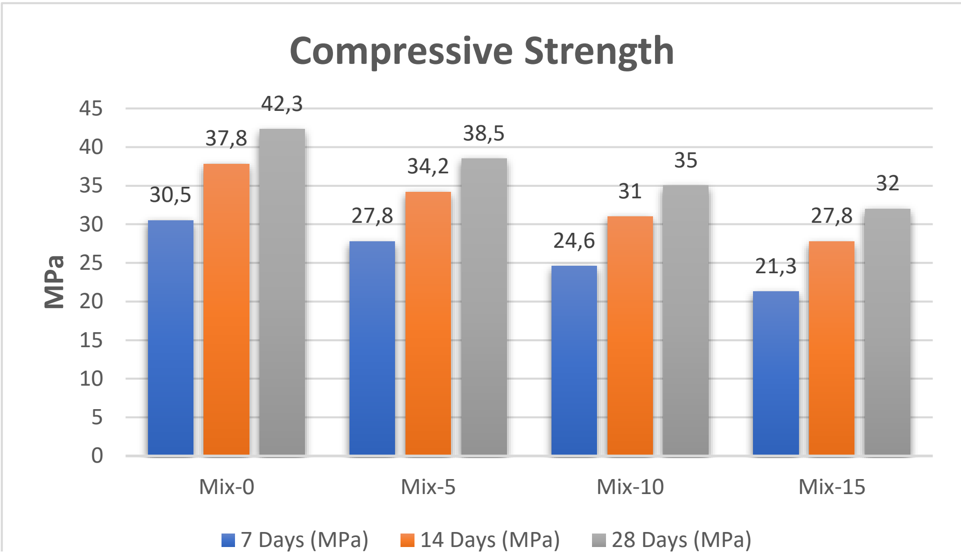

Figure 1. Compressive Strength

From the results that appeared to us that the compressive strength decreases with the increase of rubber, we conclude that the addition of rubber mixtures is not suitable for use in applications that require high load-bearing capacity. However, despite this, rubber concrete mixtures can be used in many non-structural applications that do not require high loads such as sidewalks, playground floors, decorative walls and noise barriers, where in these applications the concrete is required to have high durability and it is not important for it to be resistant to high pressure, as the addition of rubber to these applications is of economic and environmental benefit, taking into account the balance between the components of the mixture.

Tensile Strength

The results of the tensile strength test showed results consistent with the compressive strength test, as the tensile strength decreased with increasing rubber due to the weak bond between the rubber and the components of the mixture, as well as the difference between the rubber requirements and the hardness of the cement, which causes cracks when exposed to tensile pressure. However, these mixtures can be used for applications that do not require tensile strength, such as road barriers, insulation panels, and other non-structural applications, taking into consideration that improving materials must be added to the mixture to improve the tensile properties.

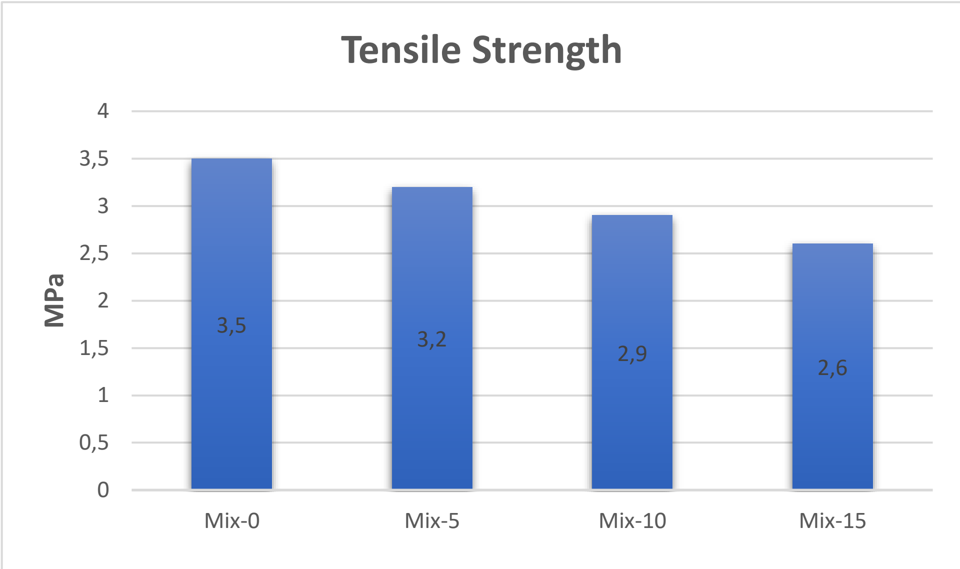

Figure 2. Tensile Strength Test

The poor bonding between the mixture components and the rubber is what causes the low tensile strength. However, tensile strength is less important in non-structural applications, making rubberized concrete a suitable choice for these applications that do not require high tensile and flexural strength.

However, some previous studies have indicated that surface treatments of rubber particles, such as chemical coating or physical property improvements, can increase the bonding between rubber and cement, making the tensile properties good. These improvements can expand the application of rubber concrete to new areas requiring higher tensile strength, while maintaining its environmental and economic benefits.

Density

When the hardened density test was performed, the density of rubber concrete decreased with increasing rubber content, indicating its potential for use in lightweight applications.

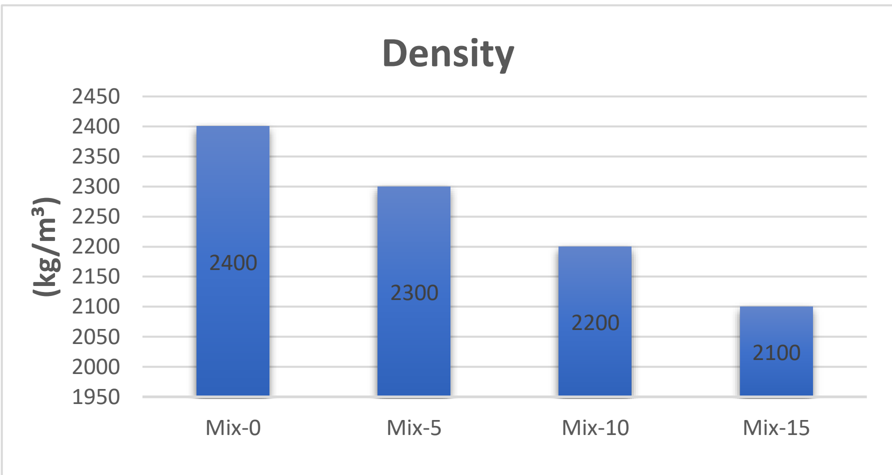

Figure 3 : Density Test

The reduction in density enhances the appeal of rubberized concrete for applications where weight reduction is critical, such as modular construction and precast elements. Additionally, the lower density contributes to easier handling and transportation, further reducing the environmental and economic costs associated with construction processes.

Conclusion

Rubberized concrete demonstrates significant potential in addressing both environmental and practical challenges in the construction industry. The incorporation of recycled rubber particles offers a sustainable solution to mitigate the disposal issues of waste tires, aligning with global efforts toward circular economy practices. Although the reduction in compressive and tensile strength limits its use in structural applications, the benefits such as reduced density, improved impact resistance, and enhanced sustainability make it an attractive option for non-structural purposes such as pavements, noise barriers, and lightweight construction elements.

Future research should focus on optimizing rubber content to balance strength and sustainability while exploring surface treatments and advanced admixtures to improve the bonding characteristics of rubber particles. Long-term performance studies under varying environmental conditions are also necessary to validate the durability of rubberized concrete in practical applications. Additionally, integrating nanotechnology and hybrid materials could unlock new possibilities for enhancing its mechanical properties and expanding its applicability to broader construction scenarios. By addressing these research gaps, rubberized concrete could play a pivotal role in advancing sustainable construction practices and reducing the environmental footprint of the construction industry.

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