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Acoustic Enhancement of Sustainable Concrete Mixture Through Integration of Recycled Tyre Waste

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Abstract: This research examines the impact of rubber content on the acoustic and mechanical properties of concrete, using a mix ratio of 1:1.8:2.24 and replacing fine aggregate with 0%, 5%, 10%, and 15% rubber. From the result obtained for the compressive strength, the concrete with 0% wt reaches its highest strength which is 55.36 N/mm^2 at 28 days. For split strength test, the concrete with 15% wt reaches its highest strength 3.50 N/mm^2 at 14 days and for the flexural strength, it is observed that the concrete with 15% wt reaches its highest strength 5.01 N/mm^2 at 14 days. Resultsindicate that higher rubber content decreases compressive, tensile, and flexural strengths, particularly with longer curing times, due to the elasticity and low density of rubber. However, the sound absorption coefficient improves with increased rubber,peaking at 15% after 7 days of curing. While waste tyre rubber enhances acoustic properties, it negatively affects mechanical strength, making rubber concrete suitable for applications prioritizing sound performance over structural integrity, such as soundproof walls. Future research should focus on optimizing rubber concrete mix designs and improving mechanical properties.

Keywords: Rubber concrete, noise pollution, physical changes, sound absorption.

1. Introduction

The rapid urbanization and growth of the automobile industry have significantly increased waste tyre quantities, leading to serious environmental issues. This study investigates the use of waste tyre rubber particles as a replacement for fineaggregate in concrete, aiming to address waste disposal and reduce reliance on natural resources,to investgate the effects of replacing fine aggregate with tyre rubber on compressive strength,spilt tensile strength,flexural strength and sound absorption.

2. Background

As of the latest available information, noise pollution continues to be a significantconcern in many parts of the world, affecting urban, industrial, and natural environments.

In recent times, there is an increasing need for the design and developmentof mortar and concrete with an eco-friendly value. A simple and efficient method to prevent the rapid depletion of natural quarries (like sand, gravel, and crushed stone) and to maintain ecological balance is to use recycled materials, such as demolition waste or industrial by-products, instead of natural aggregates. The environmental aspects are not the only reason for the use of alternative aggregates. Indeed, a lotof waste products, including waste glass powder (Singh Shekhawat & Aggarwal, n.d.), plastics (Sharma & Bansal, 2016), ground granulated blast furnace slag(Özbay et al., 2016) wood ash (Cheah & Ramli, 2011) and crumb rubber from waste tyres (Zhang et al., 2022) properties suitable for being incorporated into cementitious matrices, bringing potential engineering functionalization in concrete materials, such as lightweight, higher durability, better shock absorption, and improved thermo-acoustic insulation properties.

Each year 2–3 billion tyres are scrapped in the US with similar quantities in Europe. It is estimated that approximately 40 million tyres are discarded per yearin the UK. Ireland produces over 35,000 tonnes of waste tyres which are banned from many landfill sites and may not be burned. With decreasing disposal options and increasing production, the volume of used tyres is becoming a major waste management issue.

The use of crumb rubber concrete (CRC) produced from broken down waste tyres to replace a portion of natural aggregates in concrete mixes has been the subject of much research, CRC is a durable composite material capable of absorbing andreflecting sound and if used on the exterior of a structure can shield the occupants fromambient street noise. High rise apartment occupiers for example are often overlooking busy streets with high noise levels, often uncomfortably high, passing into dwelling spaces.

3. Scope of Study

This study aims to determine the sound adsorption of crumb rubber concrete, in addition, the concrete mix with a ratio of 1:1.8:2.24 of cement, fine aggregate and coarse aggregate which then replaced the fine aggregate with the crumb rubber contentof 0%, 5%, 10% and 15% was studied. he use of the concrete mix ratio of 1:1.8:2.24 for cement, fine aggregate, and coarse aggregate is beneficial for several reasons, especially when incorporating crumb rubber. This ratio ensures a good balance amongthe materials, allowing the concrete to maintain strength while taking advantage of crumb rubber's sound-absorbing properties. The higher amount of fine aggregate (1.8) helps integrate the crumb rubber better, filling gaps and enhancing acoustic performance.

Crumb rubber is effective at reducing noise because its porous structure helps dissipate sound waves, making the concrete ideal for applications like sound barriers and soundproofing in buildings. Additionally, this mix ratio supports the concrete's durability and stability, ensuring that it remains strong while also providing good sound absorption. Overall, this ratio enhances both the acoustic and structural qualitiesof rubberized concrete. As well as physical changes after replacing rubber to fine aggregate which including compressive strength, split tensile strength, and flexural.

4. Experiment

4.1. Conversion factor

In this test, the mixing conversion factor is using 1.54, as 1.54 is commonly usedat the same time, the 1.54 factor is an empirical value often used in practical construction, including in many mix designs that follow ACI 211.1 guidelines.

Aggregates, both fine (sand) and coarse, are made up of individual particles with small void spaces in between them. These void spaces are an inherent characteristic of the aggregates and cannot be eliminated completely, even when the aggregates are in acompacted state (Haque et al., 2012).

The volume of these voids needs to be accounted for when determining the actual quantities of materials required for the concrete mix.

4.2. Compressive Strength

Table 1. Concrete mix proportion with the tyre rubber in compressive strength

Tyre rubber (%)	Mix ratio	Cement (kg/m3)	Water (kg/m3)	Fine aggregate (kg/m3)	Coarse aggregate (kg/m3)	Tyre rubber (kg/m3)
0	1:1.8:2.24	4	1.8	7.7	8.7	0
5				7.3		0.4
10				6.9		0.8
15				6.5		1.2

Table 2. The compressive strength test result

Curing days	Compressive strength by composition, *N/mm²*			
	0%	5%	10%	15%
7 days	47.06	38.35	22.09	14.71
14 days	55.11	39.20	23.39	15.11
28 days	55.36	42.34	26.22	16.18

The data from this test indicates that increasing the rubber replacement of sand aggregate results in a decrease in compressive strength. This is primarily because rubber particles, when added to concrete, make the material more flexible and less dense thantraditional concrete, which relies on stiff aggregates like sand and gravel to achieve its compressive strength. Rubber is significantly less rigid than these aggregates and deforms more easily under load, which reduces the overall strength of the concrete. Additionally, the incorporation of rubber tends to increase the amount of air entrapped in the concrete mix, leading to greater porosity, further weakening the material's ability to withstand compressive forces.

The extent of the compressive strength reduction is closely tied to the percentage of rubber used to replace traditional aggregates. The data shows that as the rubber content increases, the compressive strength decreases more significantly. For example,(Ganjian et al., 2009)found that replacing 10% of fine aggregate with crumb rubber ledto a 20-30% reduction in compressive strength. Despite this reduction in strength, rubberized concrete gains advantages in flexibility and ductility, which can be beneficial in applications requiring impact resistance and energy absorption, such as pavements, sidewalks, and structures subjected to dynamic loads. Rubberized concretealso exhibits improved resistance to cracking, especially under conditions where traditional concrete might become brittle. The data also shows that compressive strength increases with longer curing times.As cement undergoes hydration—a chemical reaction with water—over time, theconcrete gains strength. Prolonged curing allows the hydration process to continue, resulting in higher compressive strength. Concrete does not achieve its full strength immediately but continues to strengthen, particularly when kept moist. This prolonged curing is essential for making the surface of the concrete harder and more resistant to abrasion and wear, which is especially important for areas subjected to heavy traffic ormechanical wear, such as pavements and industrial slabs.

4.3. Split Tensile Strength

Table 3. The split tensile strength test result

Curing days	Split Tensile Strength by composition, *N/mm²*			
	0%	5%	10%	15%
14 days	3.28	2.91	2.70	1.18
28 days	3.50	3.40	2.44	1.83

The data from this test demonstrates that adding rubber to concrete tends to reducesplit tensile strength, which is a critical measure of the concrete's ability to resist tensionand prevent cracking, thereby affecting its overall durability. The highest can be found in 0% 28 days 3.50*N/mm²*.Several factors contribute to this decrease in tensile strength. First, rubber particles have lower bond strength with the cement matrix compared to traditional aggregates like sand and gravel, which weakens the concrete' s ability to resist tensile forces. Additionally, rubber is more deformable than standard aggregates,meaning that under tensile stress, rubber particles are more likely to deform, reducing the concrete's overall tensile resistance. The inclusion of rubber can also introduce more air into the concrete mix, increasing its porosity and providing more voids where crackscan begin and propagate, further reducing tensile strength. Furthermore, rubber is less dense than traditional aggregates, resulting in a less compact concrete matrix, which also contributes to the decrease in tensile strength.

4.4. Flexural Test

Table 4. Concrete mix proportion with the tyre rubber in flexural

	Mix ratio	Cement (kg/m3)	Water (kg/m3)	Fine aggregate(kg/m3)	Coarse aggregate (kg/m3)	Tyre rubber (kg/m3)
0	1:1.8:2.24	10.6	4.8	20.5	23.2	0
5				19.5		1.0
10				18.5		2.0
15				17.4		3.1

Table 5. The flexural test result

Curing days	Flexural Strength, N/mm^2 by composition			
	0%	5%	10%	15%
14 days	4.97	4.53	3.54	3.30
28 days	5.01	3.74	3.47	3.12

This study reveals that increasing the rubber content in concrete results in a decrease in flexural strength, which measures a material's ability to resist bending forces. The highest can be found in 0% 28 days 5.01N/mm^2.Several factors contribute to this reduction when rubber is incorporated into the concrete mix. Firstly, rubber, being a soft and flexible material, is significantly less stiff than traditional aggregates like sand or gravel. This lower stiffness reduces the concrete's overall ability to resistbending forces. Additionally, rubber's deformability under load further diminishes the concrete's capacity to withstand flexural stresses, as the material becomes more prone to deformation.

Another factor contributing to the reduction in flexural strength is the weaker bondbetween the rubber particles and the cement matrix. The bond between traditional aggregates and cement is typically stronger, allowing the concrete to carry more load under flexural stress. However, rubber particles form a weaker bond with the cement paste, leading to a reduction in the concrete's load-carrying capacity. Furthermore, the inclusion of rubber increases the air voids within the concrete, raising its porosity. Higher porosity makes the material less resistant to bending forces, as the voids provide areas where cracks can form and propagate. Additionally, rubber is less dense than traditional aggregates, resulting in a lower overall density of the concrete, which often correlates with decreased strength.

4.5. Sound Absorption Test

Table 6. Concrete mix proportion with the tyre rubber in sound absorption

Tyre Rubber(%)	Mix ratio	Cement (kg/m3)	Water (kg/m3)	Fine aggregate (kg/m3)	Coarse aggregate (kg/m3)	Tyre rubber (kg/m3)
0	1:1.8:2.2 4	0.2	0.1	0.3	0.4	0
5				0.28		0.02
10				0.27		0.03
15				0.25		0.05

This study reveals that increasing the rubber content in concrete improves soundabsorption, particularly in the mid to high-frequency range (500-2000 Hz). Rubber particles enhance the porosity of the concrete, creating voids that trap and dissipate sound energy, making the material more effective at absorbing sound in this frequency range. Additionally, the elasticity of rubber compared to traditional concrete aggregatescontributes to better sound absorption, as it allows the material to more efficiently dissipate the energy of sound waves.

However, the data also shows that as the curing time increases, the sound absorption coefficient (SAC) tends to decrease. This is because, as the concrete cures, the matrix hardens and the rubber particles become more integrated into the structure. As the material stabilizes and the concrete continues to hydrate and set, its porosity decreases slightly, leading to a reduction in sound absorption. While the SAC may stillremain relatively high, the decreased porosity and increased stiffness of the material contribute to a slight decline in sound absorption performance over time.

The findings of this study are consistent with previous research, such as the workby (Flores Medina et al., 2016), which also found that the sound absorption coefficientof rubberized concrete increases with higher rubber content, particularly in the mediumand high-frequency ranges. This improvement is likely due to the formation of pores inthe concrete by the rubber particles, which increase its porosity and enhance its sound absorption performance. Additionally, the lower elastic modulus of rubber compared totraditional aggregates results in reduced stiffness, making the concrete more capable of absorbing mid to high-frequency sound waves.

Table 7. The sound absorption test result

Air gap	Sound Absorption Coefficient (SAC)								
	250Hz	500Hz	750Hz	1000Hz	2000Hz	3000Hz	4000Hz	5000Hz	5600HZ
0% 7D									
10mm	0.209	0.163	0.109	0.095	0.117	0.236	0.137	0.179	0.279
20mm	0.243	0.134	0.108	0.078	0.119	0.243	0.123	0.169	0.209
30mm	0.222	0.125	0.102	0.077	0.120	0.241	0.122	0.170	0.285
0% 14D									
10mm	0.250	0.201	0.180	0.133	0.124	0.134	0.127	0.113	0.213
20mm	0.282	0.212	0.174	0.134	0.138	0.131	0.120	0.106	0.365
30mm	0.298	0.219	0.166	0.133	0.147	0.117	0.110	0.102	0.283
5% 7D									
10mm	0.270	0.253	0.150	0.114	0.143	0.306	0.182	0.247	0.763
20mm	0.360	0.200	0.133	0.105	0.146	0.297	0.180	0.249	0.700
30mm	0.354	0.184	0.128	0.103	0.148	0.294	0.179	0.254	0.789
5% 14D									
10mm	0.128	0.105	0.081	0.069	0.074	0.134	0.126	0.122	0.471
20mm	0.126	0.103	0.079	0.068	0.075	0.134	0.127	0.122	0.466
30mm	0.126	0.104	0.077	0.067	0.076	0.132	0.124	0.123	0.470
10% 7D									
10mm	0.166	0.122	0.090	0.075	0.087	0.136	0.134	0.144	0.831
20mm	0.166	0.116	0.089	0.073	0.093	0.137	0.137	0.147	0.818
30mm	0.158	0.111	0.084	0.068	0.093	0.133	0.134	0.145	0.797
10% 14D									
10mm	0.221	0.172	0.136	0.109	0.123	0.148	0.135	0.162	0.559
20mm	0.212	0.157	0.123	0.099	0.127	0.147	0.136	0.161	0.560
30mm	0.202	0.145	0.113	0.093	0.127	0.145	0.134	0.161	0.540
15% 7D									
10mm	0.198	0.161	0.130	0.101	0.143	0.209	0.163	0.180	0.891
20mm	0.191	0.150	0.122	0.098	0.145	0.208	0.162	0.181	0.870
30mm	0.194	0.147	0.119	0.097	0.146	0.207	0.161	0.184	0.815
15% 14D									
10mm	0.440	0.280	0.199	0.151	0.091	0.130	0.145	0.121	0.315
20mm	0.439	0.279	0.198	0.151	0.092	0.129	0.140	0.121	0.318
30mm	0.433	0.271	0.200	0.152	0.093	0.129	0.137	0.122	0.311

5. Conclusion

In this study, flexural, compressive, and split tensile strength, properties generallyincrease with curing but decrease with the addition of rubber due to changes in the concrete's structural integrity. Adding rubber particles will reduce the flexural strength, compressive strength, and split tensile strength of concrete. Rubber particlescan act as voids or weaken the bonding between concrete and aggregates, leading to lower strength compared to standard concrete. Based on the results, it demonstrates aconsistent trend across compressive, tensile, and flexural strengths: the addition of the waste tyres negatively impacts the strength of the concrete. For compressive strength,the concrete with 0% wt exhibits the highest compressive strength, while the 15% wt mixture has the lowest. The 0% wt mixture reaches its peak strength 55.36 N/mm2 at28 days, while the 15% wt mixture peaks at 14 days. Next, the tensile Strength, which similar to compressive strength, the concrete with 0% wt shows the highest tensile strength, with the 15% wt mixture exhibiting the lowest. The 0% wt mixture reaches its peak strength 3.50 N/mm2 at 28 days, while the 15% wt mixture peaks at 14 days.The trend continues with flexural strength, where the 0% wt mixture displays the highest strength, and the 15% wt mixture has the lowest. While the 0% wt mixture reaches its peak strength 5.01 N/mm2 at 28 days, the 15% wt mixture peaks earlier at 14 days. Interestingly, the 15% wt mixture shows a higher flexural strength at 14 dayscompared to the 0%wt mixture, suggesting a potential positive effect on early strength development.

The sound absorption coefficient improves with the addition of rubber and can vary with curing. Initially, SAC increases due to increased porosity, but it stabilizes or decreases slightly once the concrete is fully cured. Adding rubber enhances the SAC of concrete, particularly at mid to high frequencies. Rubber increases the material's porosity and elasticity, improving sound absorption. The findings indicate that while the optimal strength is achieved with 0% rubber content, the addition of rubber, especially at lower percentages, can significantly improve sound absorption without drastically compromising structural integrity. However, the 15% rubber mixturedemonstrates a unique early strength development, suggesting that rubber may facilitate initial curing benefits. Overall, this research highlights the dual benefits andtrade-offs of using crumb rubber in concrete, paving the way for its application in sound-sensitive environments while necessitating careful consideration of strength requirements in structural applications.

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