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Research paper

RUBBERIZED CONCRETE AS A SUSTAINABLE AND GREEN BUILDING MATERIAL

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Abstract

The global environmental problems facing the world today largely stem from the excessive exploitation of natural resources. An increasing number of world studies aim to find ways to replace natural resources, introducing new building materials that utilize plants, polymers, and industrial or municipal waste. On the other hand, approximately 90% of waste tyres end up in landfills, meaning there is no designated plan for their further utilization. One of the various solutions for reducing tyres waste and protecting the environment involves using waste tyres in green building materials. This study investigates the properties of concrete mixtures in which a portion of the fine aggregate is replaced by waste rubber particles, with the aim of reducing existing waste and the need for natural aggregate. For the purposes of this paper, 4 different mixtures were tested that differ in the percentage of rubber: replacements of 0, 15%, 30% and 50% of the aggregate with waste tyre by volume. Consistency of the fresh concrete decreased as the percentage of waste rubber increases, as well as the bulk density of hardened concrete, resulting in lightweight building materials. The strength properties and water resistance of the tested samples also decreased with the increase of the rubber waste percentage. The results indicate that increasing the waste rubber in concrete mixtures has a significantly more adverse effect on compressive strength and water impermeability than on flexural strength. However, despite the reduction in strength caused by the use of rubber in the concrete, concrete with a high content of rubber particles (50%) would be suitable for non-load-bearing elements, whereas lower contents (15% and 30%) remain viable for structural applications. The positive properties of concrete with waste rubber are highlighted, their application is suggested.

Key words: *Rubberized Concrete, Waste Rubber, Green Building Materials, Sustainability*

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1. INTRODUCTION

The global environmental problems facing the world today largely stem from the excessive exploitation of natural resources by humans. An increasing number of studies aim to find ways to replace natural resources, introducing new construction materials that utilize plants, polymers, and industrial or municipal waste [1]. The goal is achieving lower bulk density and a more favourable thermal conductivity, while simultaneously maintaining strength properties comparable to those of traditional building materials.

Since vehicles have become an essential means of transport, there is a proportional increase in the number of tyres that have reached the end of their service life, i.e. that are no longer functional. This type of waste has been a prominent subject of research in recent years because is difficult to reuse or recycle. Approximately 90% of waste tyres end up in landfills, meaning there is no designated plan for their further utilization. One of the various solutions for reducing tyres waste and protecting the environment involves using waste tyres in sustainable building materials. In recent years, there has been significant scientific research focused on using waste tyres as a raw material in cement-based composites—specifically, concrete and mortar.

Ahmad et al. [2], Adwan & Alzubi [3], Bu et al. [4], Marinelli et al. [5], Motloq et al. [6], and others have investigated the potential of using specific quantities of waste rubber and its effect on concrete properties. Due to their exceptional strength, flexibility, and stress-control attributes, rubber granules are commonly used in cementitious composites as a replacement for fine (≤ 4.75 mm) and coarse (≤ 20 mm) aggregates. The literature confirms that the inclusion of rubber effectively improves concrete workability, [5]. Due to the poor bond between the cement matrix and the rubber, many researchers choose to treat rubber particles with 10% NaOH before incorporating them into the concrete [7]. Furthermore, when smaller rubber particle sizes are used, the concrete exhibits a lower wear depth. Compared to gravel particles, the compact and dense rubber-concrete matrix is more advantageous because the addition of rubber creates fewer voids than in conventional concrete, thereby reducing the depth of carbonation. Recycling rubber waste eliminates the need for tyre disposal, which is one of the major environmental challenges of the future [4].

Around 3.5 million tonnes of waste tyres are generated annually in Europe. Although Europe boasts the highest rate of waste tyres collection (approximately 95%), changes in environmental legislation and inadequate waste management capacity are creating a major problem [2]. Data regarding municipal waste for the period from 2020 to 2024 in Macedonia, obtained from the national State Statistical Office [8], is given in Table 1.

Table 1. Municipal waste in Macedonia 2020–2024, [8]

Municipal waste in Macedonia 2020 - 2024					
	2020	2021	2022	2023	2024
Total quantity of collected waste	630 086 t	632 087 t	605 638 t	621 686 t	627 471 t
Tyre waste	1005 t	1598 t	1478 t	1301 t	1136 t
Waste deposited at landfill	99,80 %	99,80 %	99,80 %	99,80 %	99,80 %

Although the volume of tyre waste appears insignificant compared to Europe, we frequently witness piles of untreated, stockpiled tyres as well as numerous illegal landfills across the country. There is no doubt that greater emphasis needs to be placed on this issue in the future.

Given the relevance of the topic and the aforementioned reasons, the aim of this study is to evaluate the potential use of waste vehicle tyres while simultaneously reducing the consumption of natural aggregates in concrete. Several concrete mixture formulations were prepared, incorporating waste rubber aggregate at levels of 0%, 15%, 30%, and 50%. The properties of the concrete mixtures (fresh concrete consistency) and the properties of the hardened concrete (bulk density, compressive strength, flexural strength, and water impermeability) were evaluated.

2. MATERIALS AND METHODS

2.1. Materials

Several types of mix designs were prepared for the concrete mixtures, incorporating waste rubber aggregate at levels of 0%, 15%, 30%, and 50% of the fine aggregate. Table 2 shows the quantity of material required to produce 1 m³ of concrete.

Table 2. Mix design for C30/37 with CEM II/A-LL 42.5 R (1 m³)

Aggregate fraction [kg]				cement [kg]	water [kg]	admixture [kg]	rubber [kg]
0/4mm	4/8mm	8/16mm	16/32mm				
740	220	480	340	380	190	2.5	/

The concrete mixture was prepared in accordance with MKS EN 12350-1 [9]. A total of nine concrete cubes (15/15/15 cm) and two concrete prisms (10/10/50 cm and 15/15/60 cm) were produced for each mixture. Consequently, a volume of 0.0709 m³ of concrete was required for each mixture to produce the necessary number of specimens. To replace 15%, 30%, and 50% of the fine aggregate in the tested specimens, quantities of 2.11 kg, 4.23 kg, and 7.04 kg were used, respectively.

Portland cement CEM II/A-LL 42.5 R was used to prepare the mix designs presented in this paper. Its composition consists of 80–94% clinker, 6–20% limestone, and 0–5% other constituents. It has a strength class of 42.5 MPa and exhibits high early strength. Two different types of aggregate were used: river aggregate (0/4 mm) from the Aradiko Kop Skopje processing plant. In accordance with the MKS EN 1097-3 [10] standard, with bulk density of 1590 kg/m³, and crushed limestone aggregate (4/8, 8/16, and 16/32 mm) from the In Mak Kumanovo quarry. Water from the Skopje municipal water supply system was used to prepare the concrete mixtures.

Ading's SUPERFLUID 21M1M was used in the preparation of the concrete mixtures. It enables a high degree of water reduction in the concrete and the production of concrete with high consistency classes. The admixture was 0.65% of the cement mass.

A waste tyre is defined as a tyre that has reached the end of its useful life and is discarded—or intended or required to be discarded—by the end user. For this research,

the raw material was supplied by the company "Uni-Royal Kompani" from Prilep, Fig.1. In accordance with the MKS EN 1097-3 [10], the bulk density of the waste tyre material was determined to be 395 kg/m³.



Figure 1. Finely chopped waste rubber



Figure 2. Determination of consistency (Source: Authors)

2.2. Methods

The consistency of fresh concrete is determined in accordance with MKS EN 12350-2 [11], as presented in Fig.2. The tested samples were taken in accordance with MKS EN 12350-1 [9].

The density of hardened concrete is determined in accordance with MKS EN 12390-7 [12]. The standard offers two methods for calculating the specimen volume: by water displacement and by calculation based on measured dimensions, taking into account prescribed tolerances. In this test, the volume of the concrete specimens was determined by calculation; specifically, the specimen dimensions were measured, and the volume V was recorded in m³. The specimens are weighed on a scale with an accuracy of 0.1 g, and their mass is recorded in kg.

The compressive strength of the specimens was determined in accordance with the EN 12390-3 standard [13]. The specimen was tested in a machine that meets the requirements specified in EN 12390-4 [14]. The maximum load sustained by the test specimen is recorded, and the stress is then calculated. Figure 3 shows the measurement equipment. The test specimens shall be cubes, prisms or cores that meet the requirements set out in the standards [15]. After removing the specimens from the curing tank, they must be tested within 10 hours. The loading rate is in the range of 0.6 ± 0.2 MPa/s. After applying an initial load not exceeding 30% of the failure load, the load is applied to the specimen without impact, increasing continuously at the selected constant rate (±10%) until the specimen can no longer sustain the load.

The flexural strength test was conducted in accordance with MKS EN 12390-5 [16]. The testing equipment must comply with MKS EN 12390-4 [14]. The load-application equipment consist of two lower rotating supports and two upper ones designed to distribute the load into two equal parts, Fig. 4. Both the upper and lower supports must be made of steel and have a diameter of 20 to 40 mm. Their length must be at least 10 mm greater than the width of the specimen to be tested. Before being placed in the testing press, the specimen must be dry; specifically, if it has been cured in a water bath, it must be allowed to stand or have excess water wiped off. The load is applied normally to the side of the mould where it was filled, at a constant rate ranging from 0.04 MPa/s to 0.06 MPa/s.





Figure 3. Compressive strength testing equipment *Figure 4. Flexural strength test (Source: Authors)*

The depth of penetration of water under pressure is determined in accordance with MKS EN 12390-8 [17]. The specimen may be a cube, prism, or cylinder, with minimum dimensions of 150 mm for the surface to be tested and no other dimension less than 100 mm, Fig.5. Testing began when the specimen was 28 days old. The surface subjected to pressure must be roughened using a steel wire brush. The specimen was placed in the testing apparatus and subjected to a pressure of 500 ± 50 kPa for a duration of 72 ± 2 hours. After the pressure had been applied for the specified duration, the specimen was removed from the testing apparatus. Excess water is removed from the side subjected to the pressure. The specimen was split into two parts, perpendicular to the face subjected to the pressure. After splitting, the specimen was allowed to dry so that the depth of water penetration is clearly visible. The water penetration was measured from the surface subjected to the pressure to the tip of the penetration and was expressed in millimetres (mm).





Figure 5. Impermeability testing equipment *Figure 6. Water penetration depth (Source: Authors)*

Compressive strength testing was performed on six concrete cubes for each mix design (two each at 7, 14, and 28 days). Water impermeability testing was conducted on three concrete cubes, and flexural strength testing was performed on two concrete prisms.

3. RESULTS

Testing of the fresh concrete consistency was performed in accordance with the MKS EN 12350-2 standard [11]. The results are presented in Figure 7. The density of hardened concrete, obtained according to [12] is presented in the Figure 8.

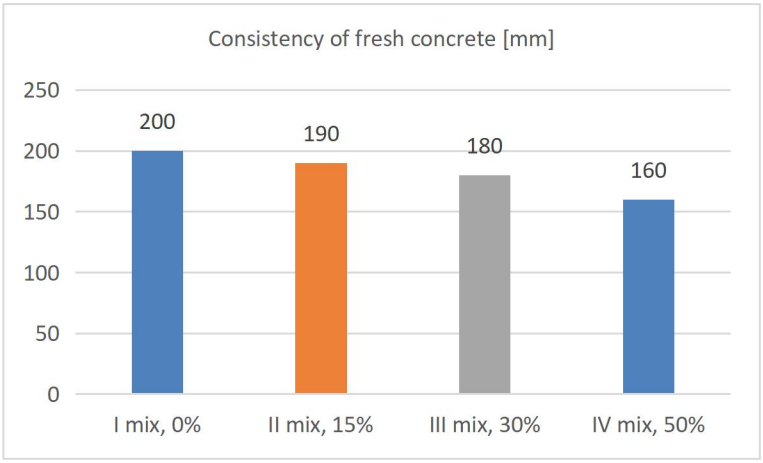


Figure 7. Consistency depending on the percentage replacement of fine aggregate with waste rubber

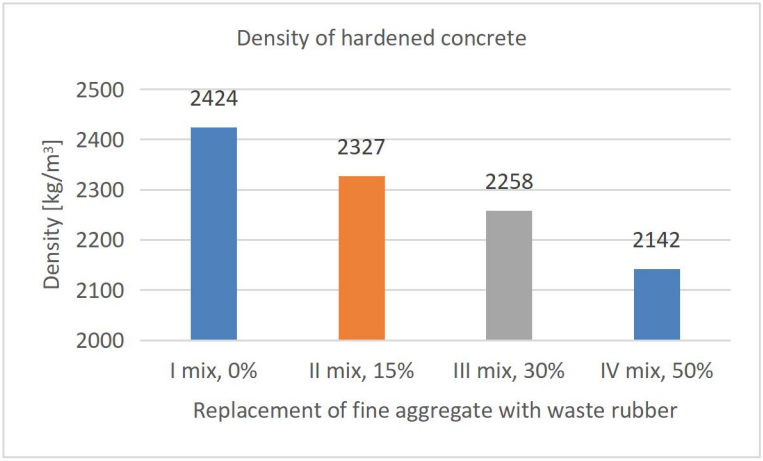


Figure 8. Relationship between density and percentage replacement of fine aggregate with rubber

Compressive strength was tested in accordance with MKS EN 12390-3 [13]. A testing machine compliant with MKS EN 12390-4 [14] was used for this purpose. Flexural strength was determined in accordance with the MKS EN 12390-5 standard [16]. The results for compressive strength at 7, 14, and 28 days and for the flexural strength for all the tested specimens are presented in Table 3.

The relationship between the flexural strength and percentage replacement of fine aggregate with waste rubber is presented in Fig. 10.

The depth of water penetration under pressure is determined in accordance with MKS EN 12390-8 [17], as presented in Figure 6. The results measured at 28 day are presented in Table 4 and Figure 11.

Table 3. Compressive strength at 7, 14 and 28 days and flexural strength of different mixtures

Property	Specimen	I mix, 0% waste rubber	II mix, 15% waste rubber	III mix, 30% waste rubber	IV mix, 50% waste rubber
Compressive strength 7 days [MPa]	1	49.9	28.9	23.9	17.3
	2	49.4	29.4	24.7	16.8
	Average	49.65	29.15	24.3	17.05
	± SD	0.354	0.354	0.566	0.354
Compressive strength 14 days [MPa]	1	51.5	32.6	26.4	18.8
	2	55.2	33.1	27.2	18.2
	Average	53.35	32.85	26.8	18.5
	± SD	2.616	0.354	0.566	0.424
Compressive strength 28 days [MPa]	1	56.1	34.7	28.4	20.7
	2	59	35	28.9	20.3
	Average	57.55	34.85	28.65	20.5
	± SD	2.051	0.212	0.354	0.283
Flexural strength 28 days [MPa]	1	5.030	4.540	3.980	2.120
	2	5.640	4.210	3.620	2.370
	Average	5.335	4.375	3.8	2.245
	± SD	0.431	0.233	0.255	0.177

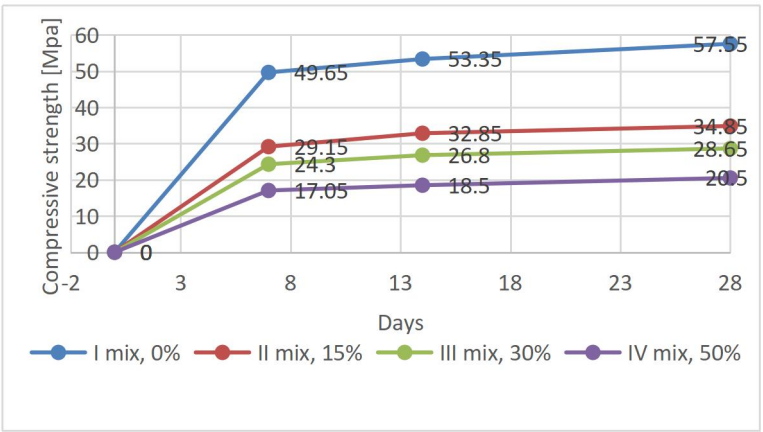


Figure 9. Increase in compressive strength at 7, 14 and 28 days for different mixtures

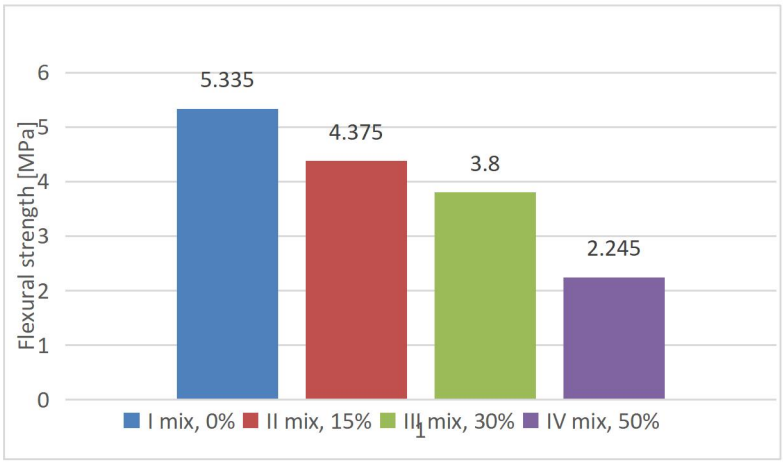


Figure 10. Flexural strength versus percentage replacement of fine aggregate with waste rubber

Table 4. Water penetration at 28 days for samples of different mixtures

Property	Specimen	I mix, 0% waste rubber	II mix, 15% waste rubber	III mix, 30% waste rubber	IV mix, 50% waste rubber
water penetration [mm]	1	19	32	40	47
	2	20	39	46	52
	3	21	37	44	54
	Average	20	36	43.33	51
	± SD	1.000	3.606	3.055	3.606

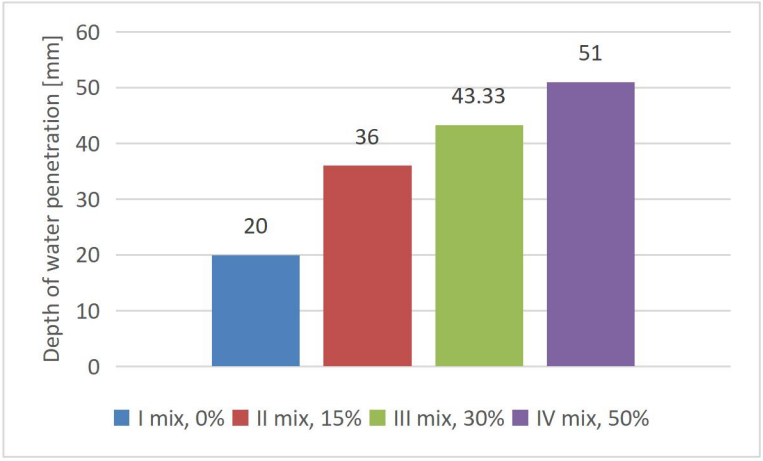


Figure 11. Depth of water penetration at 28 days, depending on the percentage replacement of fine aggregate with waste rubber

4. DISCUSSION

An analysis of the fresh concrete results leads to the conclusion that the consistency decreases for a constant water-cement ratio and varying amounts of waste rubber particles (samples with 0%, 15%, 30%, and 50% replacement). The control mix exhibits the highest consistency value (200), whereas consistency decreases as the rubber content in the concrete composition increases (Fig.7). Although the samples containing 50% waste rubber show a 20% reduction in consistency compared to the reference sample, all mixtures fall within consistency class S4. Therefore, the concrete possesses sufficient workability to be used as pumped concrete.

Due to the low density of the rubber, increasing its content results in concrete that is lighter than the reference mix. A 4% reduction in density is observed in concrete with a 15% rubber addition compared to the reference, while a 6.8% reduction is noted with a 30% addition; an 11.6% reduction in density is observed with a 50% rubber compared to the reference of 2424 kg/m^3 (Fig.8). Based on the presented mechanical properties of the corresponding cubes and prisms, it can be immediately concluded that increasing the percentage of waste rubber replacing fine aggregate reduces strength characteristics and increases water penetration, as presented in Table 3 and Figures 9 and 10. Compared to the control specimen with 0% rubber (57.55 MPa), the compressive strength of concrete decreased by 39.4% at 15% replacement, by 50.2% at 30% replacement, and by 64.4% at 50% replacement. Regarding the flexural strength of tested prisms, it decreased by 18% at 15% replacement, by 28.8% at 30% replacement, and by 57.9% at 50% replacement, compared to the control specimen with 0% rubber (5.335 MPa). Water penetration through concrete cubes increased by 80% at 15% replacement, by 116.5% at 30% replacement, and by 155% at 50% replacement, compared to the reference sample with 20 mm, Fig. 11 and Table 4.

The tests conducted indicate that increasing the percentage of waste rubber in concrete mixtures has a significantly more adverse effect on compressive strength and water impermeability than on flexural strength. The results show that, despite the reduction in strength caused by the use of rubber in the concrete, concrete with a high content of rubber particles would be suitable for non-structural applications.

5. CONCLUSION

This paper investigates the properties of concrete mixtures and hardened concrete in which a portion of the fine aggregate is replaced by waste rubber particles. Several different concrete mix designs were prepared with waste rubber aggregate contents of 0%, 15%, 30%, and 50%. The consistency of fresh concrete and bulk density, compressive strength, flexural strength and water impermeability of hardened concrete were tested. Given the lack of prior research in this field in Macedonia, any conclusion from this study highlighting the beneficial properties of concrete incorporating waste rubber represents a potential opportunity to reduce rubber waste, mitigate environmental impacts associated with rubber incineration and the excessive extraction of stone aggregates, lower concrete costs, and advance circular economy

goals within the construction industry. The research contributes in the field of green concrete with rubber. The possibility of shredding waste vehicle tyres and reusing them as a partial replacement for concrete aggregates offers a range of benefits for ecosystem preservation: it is a sustainable practice for managing vast quantities of waste tyres, given their low cost and availability, and it reduces the consumption of natural sand used in concrete. The research on rubberized concrete confirm its practical applicability in construction projects and serve as an incentive for engineers to pursue more sustainable solutions. The use of rubberized concrete could offer additional benefits, such as reduced CO_2 emissions, savings in resources and energy, and lighter structures, which need to be confirmed through a life-cycle assessment.

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