Progressive Agriculture 30 (3): 328-334, 2019 ISSN: 1017 - 8139

Progressive Agriculture
Journal homepage:http://www.banglajol.info/index.php/PA

Application of waste tyre rubber chips as coarse aggregate in concrete

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Abstract

The practicality and the engineering properties of portland cement concrete (PCC) and three types of rubberized PCC mixes prepared by partially replacing the conventional coarse aggregate with rubber were examined. The rubberized PCC mixes contained 5%, 10% and 15% waste tyre rubber chips as replacement of conventional coarse aggregate. Different physical and mechanical properties of the control (0% rubber chips) and the rubberized concrete samples were determined. A 5% replacement of conventional aggregates resulted in a 5% reduction of compressive strength, a 10% replacement resulted in a 26% reduction and a 15% replacement resulted in a reduction of 47%. A 5% replacement of conventional aggregates resulted in a 6% reduction of tensile strength, a 10% replacement resulted in a 33% reduction and a 15% replacement resulted in a reduction of 53%. A 5% replacement of conventional aggregates resulted in a 13% reduction of flexural strength, a 10% replacement resulted in a 33% reduction and a 15% replacement resulted in a reduction of 42%. Although concrete made from tyres had lower strength than the normal concrete, rubberized concrete can find its use in landscaping, sports field ground, architectural finishing, lightweight concrete walls etc.

Key words: Rubberized concrete, aggregate replacement, compressive strength, split tensile strength, flexural strength

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Introduction

Polymeric wastes namely rubber (tyre) represents a major environmental problem with increasing relevance. Recycling is one of the most important processes of waste reduction; but recycling of waste tyre is particularly problematic because of their large generation rates and non-biodegradability. One possible way of reducing the volume of waste tyres in the environment is the incorporation of waste tyres in the most widely used construction material i.e. concrete as a partial replacement for coarse aggregate. Rubber aggregates are obtained from waste tyres using two different technologies: mechanical grinding at ambient temperature or cryogenic grinding at a temperature below the glass transition temperature. The first method generates chipped rubber to replace coarse aggregates. As for the second method, it usually produces crumb rubber to replace fine aggregates (Kotresh and Belachew, 2014). The potential for using rubberized concrete is huge, particularly in landscaping, sports fields, play grounds, architectural finishing and other engineering applications. Rubberized concrete mixes may be suitable for nonstructural purposes too; such as lightweight concrete walls, building facades and architectural units.

The use of waste tyres as partial replacement of fine and coarse aggregate in concrete has been researched for several years now. Previous research conducted show dramatic changes in the mechanical properties of concrete when tyre rubber is introduced to the mix due to the weak adhesion between the rubber particles and the cement paste. Many researchers found that compressive strength, flexural strength, unit weight etc decreased as the percentage of rubber aggregate increased. The compressive and tensile strength of rubberized concrete is also affected by the size, shape, and surface textures of the aggregate along with the volume being used (Bravo and Britto, 2012). However, some researchers have reported that concrete containing waste tyre rubber chips as aggregates has a higher energy absorbing capacity referred to as toughness.

Ghaly and Cahill (2005) studied the use of different percentage of rubber in concrete (5%, 10%, and 15%) by volume and noticed that as rubber content increased compressive strength decreased. Valadares *et al.* (2012) studied the performance of concretes with the same volume replacement of rubber wastes confirming the decrease of compressive strength. A waste rubber volume of 15% leads to a 50% compressive strength decrease. These authors reported that the rubber waste with low dimensions lead to lower strength loss and also that the rubber modification processes (mechanical grinding or cryogenic process) does not influence the compressive strength. Freitas *el al.* (2009) mentioned a 48.3% decrease in compressive strength for concretes with a waste rubber volume of 15%. Ganjian *et al*.(2009) also confirmed the decrease in compressive strength for increased rubber content. However, these authors obtained a slight increase in compressive strength when 5% of chipped rubber replaced the coarse aggregates probably due to a better grading of the mixture. This finding had already caught the attention of other authors. Snelson *et al*.(2009) used concretes with shredded tyre chips (15–20 mm) for aggregate replacement in several percentages (2.5%, 5% and 10%) reporting a loss in compressive strength. Aiello and Leuzzi (2010) used tyre shreds to replace fine and coarse aggregates concluding that the size of the rubber particles have a major influence on the compressive strength.

Guneyisi *et al*. (2010), analyzed the tensile strength of concretes containing silica fume, crumb rubber and tyre chips. The results again confirmed that the decrease of tensile strength reduction is less influenced by the rubber content than for the compressive strength. This tendency was also observed by Pierce and Williams (2004). This result appears to be due to the fact that rubber particles prevent crack opening. Valadares (2009) obtained a higher tensile strength for concretes with rubber waste particles with a higher dimension which agrees with the previous finding. However, Ganjian *et al.* (2009) reported that the tensile strength of concrete with chipped rubber used as aggregates was considerably lower than for concrete containing powdered rubber. This behavior maybe related to the very low adhesion between the chipped rubber and the cement paste. One reason for this could be that chipped rubber was prepared in the laboratory with the help of a scissor a procedure quite different from the rubber waste particles shredded by a grinding process which favors a harsh surface. According to Aiello and Leuzzi (2010), when tyre shreds are used to replace fine aggregates a high tensile (flexural) strength is obtained. A replacement of the volume of fine aggregates (50% or 75%) leads to a strength reduction of only 5.8% and 7.30%. But if the same percentages were used to replace coarse aggregates a 28.2% strength reduction will take place.

The properties of fresh and hardened concrete (mechanical properties, namely compressive, tensile and flexural strengths) were studied using a rubberized concrete prepared by replacing conventional coarse aggregates with waste tyre rubber chips at 5, 10 and 15 percent.

Materials and Methods

***Materials and Properties*:** The basic materials required for this study are:

1. Cement (OPC), 2. Fine aggregate (river sand; FM 1.49), 3. Water, 4. Coarse aggregate (Picked Khoa; 4.75-9.5mm), 5. Waste tyre rubber chips of size 15-25mm.

***Testing of aggregates*:** The following tests were conducted for tyre rubber chips and khoa:

1. Sieve analysis, 2. Specific gravity and water absorption.

Preparation of concrete mix: In this study, the cement: sand: coarse aggregate proportion used was 1:1.5:3 and the water cement ratio was 0.55. Table 1 shows details of the control and rubberized concrete mixes.

Table 1. Mix proportion of concrete.

Percentage (%)	Cement	Fine aggregate	Coarse aggregate	Rubber Aggregate
	%	%	%	%
0	100	100	100	0
5	100	100	95	5
10	100	100	90	10
15	100	100	85	15

***Slump test*:** Slump test was performed with the fresh concrete mix before the placing them into the moulds.

Compressive strength: The concrete mixtures were placed in the 2.78 X 2.78 inch cube moulds. After 24 hours, the cubes were demoulded and after another 24 hours they were submerged in water for curing. The test method was followed according to ASTM Designation: ASTM C109 / C109M.

***Tensile strength*:** The cylinders used for the split-tensile strength test were 6 inch in length and 3 inch in diameter. The test procedure was followed according to ASTM designation C 496.

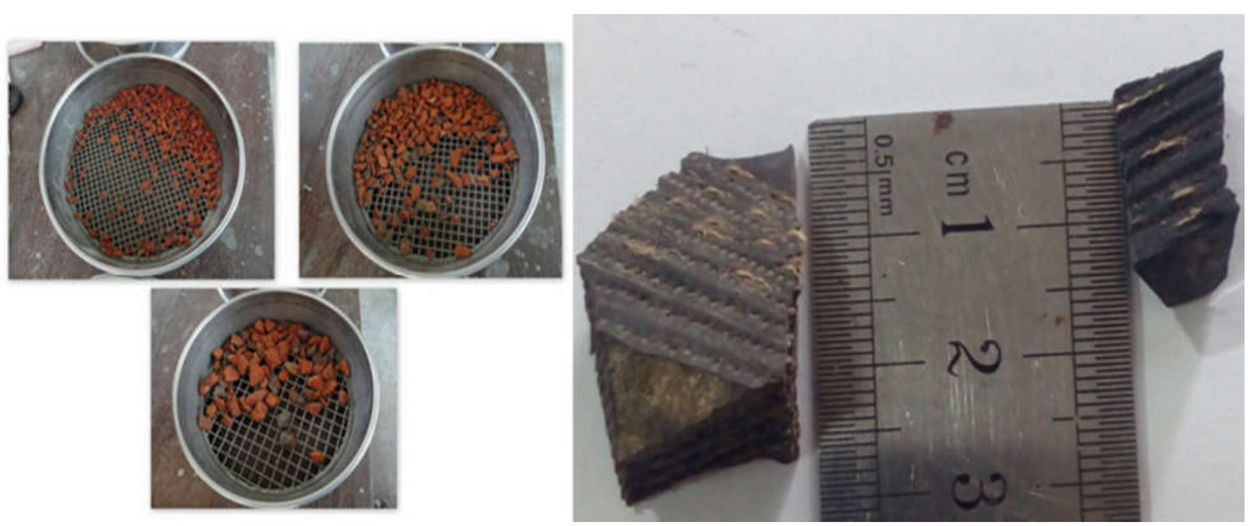

Figure 1. Coarse aggregates used in this study.

Flexural strength: The required sizes of specimens for flexural strength were 3 in X 3 in X 12 in. The test procedure was followed according to ASTM designation C 78.

Shrinkage: The required sizes of specimens are 3 in X 3 in X 12 in. The test procedure was followed according to test method IS: 1199-1959(2004).

Figure 2. Test of rubberized concretes for compressive, spilt tensile and flexural strengths.

Results and Discussion

Portland Composite Cement with 4.75 mm to 9.5 mm picked khoa as coarse aggregate, river sand as fine aggregates were used for concrete mix. For this research, shredded tyre rubber of size 15-25mm replaced course aggregate by 5%, 10% and 15% by volume. For the concrete mix, water cement ratio was 0.55. A total of 24 cubes were made and cured for 7 and 28 days for compressive strength tests. Another 24 cylinders were made and cured for 7 and 28 days for split tensile strength test, an additional 24 beams were made and cured for 7 and 28 days for flexural strength test and shrinkage test.

Physical properties of fine and coarse aggregates: Specific gravity, water adsorption, effective size and FM of the fine and coarse aggregates used in this study are listed in Table 2.

Table 2. Physical properties of fine and coarse aggregates.

Properties	Fine aggregate	Coarse aggregate	Rubber Chips
Specific gravity	2.61	2.65	1.21
Water absorption (%)	…………	10	0
Size (mm)	< 4.75	4.75-9.5	15-25

Properties of rubberized concrete

Water absorption: The concrete cubes were also tested for water absorption at 28 days. Table 3 shows the water absorption results. As seen from the figure, the water absorption increased with the increase in % rubber chips in the concrete. This is due to the fact that as more and more rubber chips were added to the concrete mix, more voids were created and hence they became more permeable to water.

Table 3. Water absorption of control and rubberized concrete.

Specimen	% Rubber	Water absorption (%)
A_0	0	8
A_1	5	9
A_2	10	11
A_3	15	14

***Specific gravity*:** From the test, specific gravity of rubber tyre aggregates and mineral coarse aggregates are 1.27 and 2.65, respectively. From Table 4 it is evident that specific gravity of rubberized concrete cylinders decreases with the increase in rubber tyre aggregates.

Table 4. Specific gravity of conventional concrete and various rubberized concrete mixes.

Specimen	% rubber	Specific gravity
A_0	0	1.66
A_1	5	1.60
A_2	10	1.53
A_3	15	1.49

***Workability*:** The replacement of coarse aggregate by waste tyre rubber chips affects workability of concrete. The workability of rubberized concrete shows a decrease in slump with increase of waste tyre rubber chips as coarse aggregate. The normal concrete mix (0% rubber chips) has a higher workability compared to the 5%,10% & 15% replaced concrete mixes as shown in Table 5 and workability is seen to decrease as percentage of rubber chips increased in concrete. Depending on the type of work this particular concrete is to be used, any percentage of rubber chips can be chosen.

***Compressive strength*:** The cubes were cured in the laboratory by submerging them in water at room temperature and are tested after 7 and 28 days with the help of Compression Testing Machine. The results of crushing strength of conventional and rubberized concrete cubes of same concrete grade are shown in Figure 3. The test results show that addition of rubber aggregates resulting to significant reduction in compressive strength compared to conventional concrete at 7 and 28 days.

Table 5. Result of workability test.

Specimen	% rubber	Slump (mm)
A_0	0%	75
A_1	5%	40
A_2	10%	25
A_3	15%	20

The rubber chips act as voids in the matrix and also the bond between the waste tyre rubber aggregate and concrete mix weakens due to their presence. With the increase in % rubber, the void content of the concrete increases too, resulting in a decrease in strength. Portland cement concrete's strength is dependent greatly on the coarse aggregate's density, size and hardness. Since the aggregates are partially replaced by the rubber, the reduction in strength is only natural. A 5% replacement of conventional aggregates resulted in a 5% reduction of compressive strength, a 10% replacement resulted in a 26% reduction and a 15% replacement resulted in a reduction of 47%. The 5% replacement is acceptable in construction where high strength is desired.

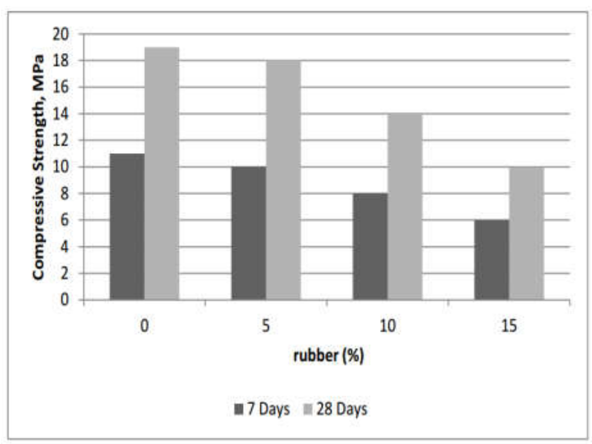

Figure 3. Comparison of compressive strength of concrete with different percentages of waste tyre rubber chips.

***Tensile strength*:** The results of split tensile strength test for different concrete cylinders are shown in Figure 4. It was concluded that as the percentage of waste tyre rubber chips in concrete increased, the tensile strength decreased. A 5% replacement of conventional aggregates resulted in a 6% reduction of tensile strength, a 10% replacement resulted in a 33% reduction and a 15% replacement resulted in a reduction of 53%. The waste rubber tyre chips used in this study did not have the steel wires in them, so addition of these chips did not increase the tensile strength of the concrete specimens. Rather the increase in rubber chips led to a decrease in tensile strength. This could be due to lack of bonding between the rubber chips and the mortar and also due to the increase in voids.

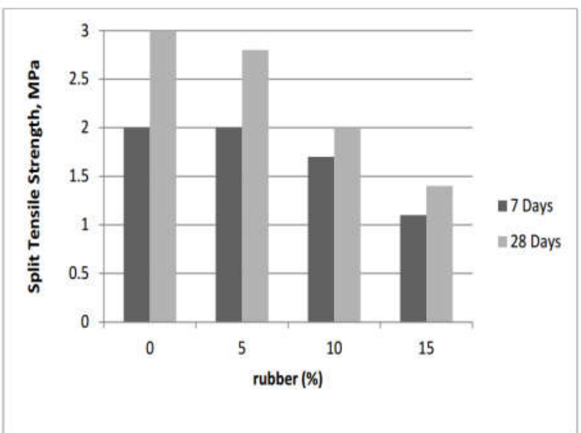

Figure 4. Comparison of split tensile strength of concrete with different percentages of waste tyre rubber chip.

Flexural strength: The Flexural strength of fresh concrete specimen and other specimens containing 5%, 10% and 15% tyre rubber aggregate are shown in Figure 5. It was concluded that as the percentage of waste tyre rubber chips in concrete increased, the flexural strength decreased. A 5% replacement of conventional aggregates resulted in a 13% reduction of flexural strength, a 10% replacement resulted in a 33% reduction and a 15% replacement resulted in a reduction of 42%.

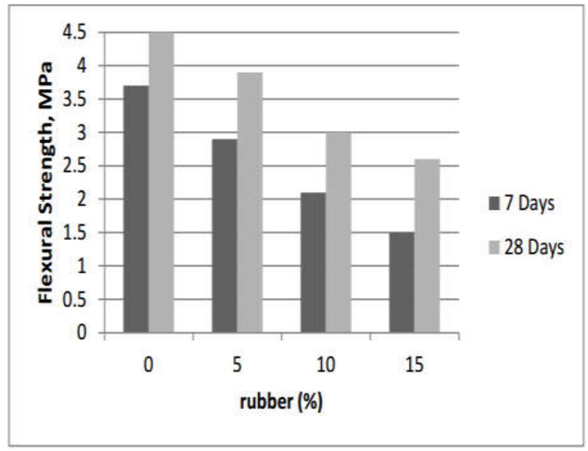

Figure 5. Comparison of flexural strength of concrete beams with different percentages of waste tyre rubber chips.

***Shrinkage*:** The shrinkage of fresh concrete specimen and other specimens containing 5%, 10% & 15% coarse rubber tyre aggregate was determined for 7 days and 28 days. Table 6 shows the different shrinkage values of the concrete specimens. The change was higher at 15% replacement.

Table 6. Shrinkage of concrete specimens of normal concrete and rubberized concrete.

% Rubber	**% Shrinkage**	
	7 days	**28 Days**
0	0.24	0.42
5	0.26	0.46
10	0.29	0.48
15	0.31	0.57

Conclusions

The general objectives of this research was to evaluate the fresh and hardened properties of a concrete produced by replacing part of the natural coarse aggregates with an aggregate produced from locally available waste tyre. Workability of fresh concrete decreased with increasing percentage of rubber chips. Specific gravity is also seen to decrease with increase in rubber chips. The compressive, tensile and flexural strengths decreased with increase in rubber chip aggregate replacements; but the 5% replacement results are acceptable. Rubberized concrete can be used in non-load bearing members i.e. lightweight concrete walls, other light architectural units, thus rubberized concrete mixes could give a viable alternative to where the requirements of normal loads, low unit weight, Medium strength, high toughness etc. The overall results of this study show that it is possible to use recycled rubber tyre aggregates in concrete construction as partial replacement of mineral coarse aggregates with 5% replacement giving best performance results with compressive, tensile and flexural strengths reduction of 5%, 6% and 13% respectively compared to non- rubberized concrete.

Rubberized concrete will give better performance than conventional concrete where vibration damping is required, such as in building as an earthquakes shock-wave absorber, in foundation pads for machinery, and in railway stations. Rubber aggregates in concreter should also make the material a better thermal insulator, which could be very useful.

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