



Used Tyre as a Resource in Concrete Production in Zambia

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Abstract: The construction industry needs to find cost-effective materials to enhance the properties of concrete. Cement and aggregate are the major constituents in concrete production. This has inevitably led to a continuous and increasing exploitation of natural materials to produce the constituents for concrete production. The result has been the depletion of virgin raw materials and increased effects of environmental degradation. In this research, a study was carried out on the use of recycled rubber tyres as a partial replacement for coarse aggregates in concrete production. Recycled waste tyre rubber is a promising material in the construction industry due to its reduced weight, elasticity, energy absorption, sound and heat insulating properties. Literature suggests that there is a significant loss in the strength of rubberized concrete with increasing tyre content. Further, workability and bond properties have been reported to reduce as well. Therefore, it is necessary to control this loss of strength and other parameters in concrete in the replacement process of natural aggregates. This research aimed at studying the compressive, tensile and bond properties of used tyre rubber reinforced concrete. Test results from laboratory experiments enabled determination of mechanical, physical and durability properties, as well as establishment of the extent of substitution of normal aggregates with waste rubber as aggregate in concrete. Three classes of concrete, C15, C20 and C25 were produced by substitution of selected percentages of aggregates by treated chopped waste tyre rubber. The percentage replacement of coarse aggregates was 5, 15 and 25 per cent. The size of the chopped rubber aggregates varied from 20 mm to 19 mm. Slump, permeability and bulk density tests were conducted on fresh concrete mixes for both the normal and treated rubber modified concrete. Similarly, compressive strength, tensile splitting strength, bond test and durability against acid attack tests were conducted on hardened concrete. The research established that rubber modified concrete compares favourably with standard concrete, with up to 15 per cent replacement of coarse aggregate. At 15 per cent replacement, only 0.1 per cent loss of strength was established. There was noticeable reduction in properties with 25 per cent replacement. However, Rubber modified concrete performed better by gradual cracking at elevated temperatures. There is potential for rubber modified concrete products in Zambia which in turn mitigates adverse impacts resulting from over exploitation of natural aggregates and disposal of used rubber tyres.

Keywords: Waste Tyre, Aggregate, Concrete, Crumb Rubber, Percentage Replacement, Rubberized Concrete

1. Introduction

Concrete is the most widely used construction material in today's world. It is estimated by World Business Council for Sustainable Development (WBCSD) in 2017 that roughly 25 billion tonnes of concrete are manufactured globally each year [1]. This means over 1.7 billion truck loads each year, or about 6.4 million truck loads a day, or over 3.8 tonnes per

person in the world each year. It is very difficult to point out another material of construction as versatile as concrete. It is a material of choice where strength, durability, permanence, impermeability, fire resistance and abrasion resistance are required. The basic materials required for producing concrete include cement, fine aggregate (sand), coarse aggregate (broken stone or boulders) and water. Sand and coarse aggregates required for making concrete are obtained from

earth's crust, mainly from rock quarries or dredged from river beds.

Large scale exploitation of natural aggregates creates an environmental impact on society. Currently, humanity may be living in an unsustainable manner with respect to its usage of natural resources which may have a direct effect on climate change. This large-scale extraction of aggregates will ultimately lead to irreparable damages to the earth's natural resources. As such, we need to search for new construction materials.

Although the supply of natural resources is measurable, the demand for construction activities and demand for raw materials has increased greatly during the years. The growing demand for natural resources may cause the causalities such as technological improvements that have made more products available to society, raising affluence levels in the developing world and the overall increase in the overall global population Saviour [2]. The increasing awareness about the environment in Lusaka, Zambia, and worldwide has tremendously contributed to the concerns related to the disposal of the generated wastes. Reuse of bulky wastes is considered the best environmental alternative for solving the problem of waste disposal as cited by Al-Bakari et al. [3].

1.1. Methods of Recycling Waste Tyres

There are various techniques and technologies that can be used for processing post-consumer tyres, Yang et al [4]. These include:

- a) De-vulcanization: This is the process of reversal of the vulcanization process by application of heat and chemical treatment.
- b) Crumbing: This is the processing of the tyre into powdered particles using mechanical or cryogenic processes.
- c) Shredding and Chipping: this involves shredding of tyres into first bigger sizes and finally into particles of 20 - 30mm.

1.2. Statement of the Problem

Zambia has recently expanded in the construction industry and the need to diversify in the use of alternative materials is imperative. Also the country has been on a rampart campaign to deal with disposal of solid waste. Based on this we need to discover the effect of recycled tyre on the structural performance of concrete and also establish whether the use of rubber reinforced concrete is technically and economically viable in Zambia.

1.3. Research Significance

The significance of this research work can be considered on both economical as well as the environmental aspects. In terms of the economic aspects, this study intended to reduce the cost of concrete production by reducing the quantity of natural aggregates required in a particular mix.

In terms of the environmental aspect, this study aimed at reducing the amount of waste tyre rubber available in order

to conserve the environment.

1.4. Research Objectives

The main objective of this research was to study the compressive and splitting tensile strengths of rubberized concrete with respect to other properties of normal concrete such as toughness and ductility and its behaviour at elevated temperatures using different mixes.

The specific objectives were to:

1. Establish material properties of rubber concrete, through laboratory testing and recommend where rubberized concrete could be used in the Zambian construction industry.
2. Conduct laboratory testing aimed at providing information that could be used in drafting a practical rubber concrete mix specification for structural and non-structural or low-loading usage in Zambia.
3. Observe and compare crack patterns, residual strain and behavior at elevated temperatures and harsh environments of normal and rubberized concrete.

2. Literature Review

2.1. Review on Mechanical Properties of Rubberized Concrete

Goulias and Ali studied the effect of rubber strips on concrete properties [5]. They investigated the effect of rubber strips on compressive and tensile strength of concrete.

The results showed that concrete specimens with rubber strips from scrap tyres exhibit higher compressive strength and stiffness than the specimens with fine and shredded rubber aggregates.

Kaloush et al. tested various properties of concrete and compared them to concrete with rubber aggregates [6]. They observed that as the rubber content increased, the tensile strength decreased, but the strain at failure increased. Higher tensile strain at failure is indicative of more ductile mixes. It was established that rubberized concrete is more resistant to thermal changes.

Kumaran et al. in their study concluded that the reduction of compressive strength and tensile strength can be reduced by adding some superplasticizers and industrial wastes as partial replacement of cement will definitely increase the strength of waste tyre rubber modified concrete [7]. They concluded that further study will be needed to increase performance against fire.

Zheng et al. worked on rubberized concrete and replaced the coarse aggregate in normal concrete with ground and crushed scrap tyre in various volume ratios [8]. Ground rubber powder and the crushed tyre chip particles ranging in size from about 15 mm to 4 mm were used. The effect of rubber type and rubber content on strength, modulus of elasticity was tested and studied. The stress-strain hysteresis loops were obtained by loading, unloading and reloading of specimens. Brittleness index values were calculated by hysteresis loops. Studies showed that compressive strength

and modulus of elasticity of crushed rubberized concrete were lower than the ground rubberized concrete.

Eldin and Seouci in their paper observed that accumulations of worn-out automobile tyres create fire and health hazards [9]. As a possible solution to the problem of scrap-tyre disposal, he conducted an experimental study to examine the potential of using tyre chips and crumb rubber as aggregate in Portland-cement concrete. They examined the strength and toughness properties of concrete in which different amounts of rubber-tyre particles between 10 and 50 per cent of several sizes were used as aggregate. They observed that the concrete mixtures exhibited lower compressive and splitting-tensile strength than did normal concrete.

Selvakumar and Venkatakrishnaiah in their research paper concluded that the compressive strength of chipped rubber concrete with 5 per cent replacement was 38.66 MPa higher than the strength of normal concrete 36.73 MPa at 28 days [10]. The compressive strength of rubberized concrete with 10 per cent replacement, gave acceptable strength of 33.47 MPa. In splitting tensile strength, the strength of rubberized concrete was lower than the strength of normal concrete. In the flexural strength test conducted on rubberized concrete, it showed a decrease in strength when compared to the strength of normal concrete. From the test results, it was found that the rubber possesses less bonding ability which had affected the strength of the concrete.

2.2. Review on Physical Properties of Rubberized Concrete

Antil observed that chipped rubber concrete can be used where lightweight mixes are required [11]. Slump only reduced by 1.08 per cent up to 10 per cent use of rubber. Furthermore, he noted that increased content of rubber increased its toughness.

Nehdi and Khan represented the overview of engineering properties and potential applications of cementitious composites containing recycled tyre rubber [12]. They reported about the effect of using rubber in concrete on density (unit weight) and on-air content. Crumb rubber of different sizes was used in the concrete. Due to the low specific gravity of rubber, the unit weight of rubcrete mixtures decreased as the percentage of rubber increased.

Ganjian *et al.* investigated the performance of concrete mixtures incorporating 5.0 per cent, 7.5 per cent and 10.0 per cent of discarded tyre rubber as aggregate and cement replacements [13]. Different percentages by weight of chipped rubber were replaced for coarse aggregates. The results showed that with up to 5 per cent replacement, no major changes on concrete characteristics would occur, however, with further increase in replacement ratios considerable changes were observed.

Aiello and Leuzzi investigated the properties of various concrete mixtures at fresh and hardened state, obtained by partial substitution of coarse and fine aggregate with different volume percentages of waste tyres rubber particles, having the same dimensions of the replaced aggregate [14]. The results showed a lower unit weight compared to plain concrete and good workability. The results of compressive

and flexural tests indicated a larger reduction of mechanical properties of rubber concrete when replacing coarse aggregate rather than the fine aggregate.

Cairns *et al.* tried to envelop tyre aggregate in cement in advance to change the transition between it and the cement matrix [15]. The authors concluded that there was a significant improvement of compressive strength by 10 per cent addition of rubber aggregates. This trend was maintained regardless of the w/c ratio or the different sizes of coarse tyre aggregate used.

The researchers, Guneyisi *et al.* also presented the mechanical properties of rubberized concrete [16]. The test results showed a reduction in compressive strength and modulus of elasticity with the increase in rubber content from 0 per cent to 50 per cent.

Albano *et al.* reported results on the influence of scrap rubber addition to portland concrete composite [17]. The results for destructive and non-destructive testing showed that, when weight proportion increased and particle size of scrap rubber decreased, flow and density of the concrete composite in the fresh state decreased, as well as compressive strength and splitting tensile strength in the dry state.

2.3. Summary

As mentioned previously, most of the literature review has shown a significant decrease in the mechanical properties of concrete after the addition of tyre rubber particles as aggregates. The use of only coarse rubber particles affects the properties of concrete more negatively than do only fine particles.

Moreover, the plastic energy capacity of the normal concrete increased by adding rubber. Due to their high plastic energy capacities, concrete showed high strains, particularly under the impact effects.

2.4. Future Trends of Rubberized Concrete

Several studies confirm that the uses of waste tyre rubber in concrete are sustainable in terms of economy, environment and mechanical performance of concrete. However, there are very limited investigations on applications of rubberized concrete in reinforced structural members so far.

As observed from this study, the application of rubberized concrete in full-scale reinforced concrete beams and columns could be successfully implemented under service as well as extreme loading conditions. It was reviewed that the rubberized concrete columns can be able to undergo more than two times lateral deformation without buckling failure compared to the conventional one. Meanwhile, the investigations on uses of advanced materials to confinement on the structural columns incorporating rubberized concrete also have a good potential.

3. Methodology

3.1. Chopped Rubber

The tyre rubber used in the experiments was applied in the

following two size gradings and it was obtained from the nearest tyre rubber centre in Lusaka, Zambia. Chopped rubber was used for the replacement of coarse aggregate in concrete. The rubber tyre aggregate was cut with a cutter and hacksaw to the size between 10-20 mm, as shown in Figure 1. The rubber aggregates used to replace coarse aggregate in the present investigation were made by manually cutting the tyre into the required sizes (Figure 1). This proved laborious and difficult to handle in the initial stages. However, all these challenges could easily be avoided if a large scale production is devised and proper cutting tools and machinery utilized for this particular usage.

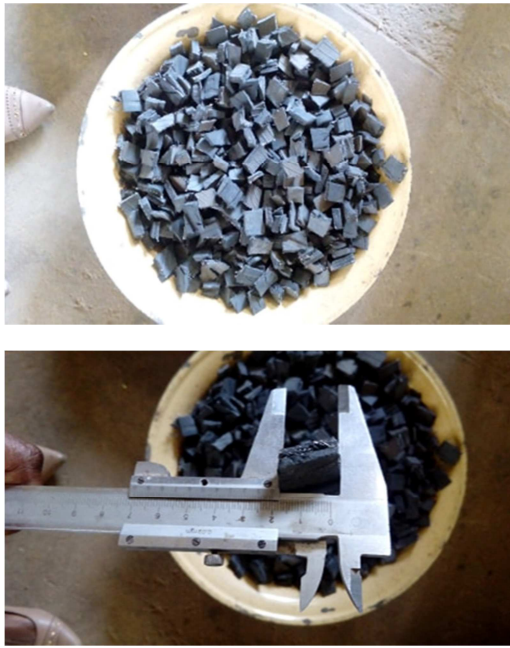


Figure 1. Coarse rubber aggregates obtained from used tyres.

3.2. Number of Specimens

Six mixes were prepared in this study and 36 cube (150mm x 150mm x 150mm) samples prepared compression test. In addition, 18 samples of cylinders (150mm diameter x 300mm height) for tensile splitting test were prepared. There were six cubes and three cylinders for each percentage replacement of coarse aggregate with tyre scrap, by volume. The percentage replacements were 5 per cent, 15 per cent and 25 per cent. The Compaction factor test was conducted for each fresh mix, and compressive strength testing was at 7 and 28 days, respectively, and tensile splitting strength tests were conducted on respective specimens.

3.3. Workability and Casting of Concrete Cubes

Figures 2 shows the Slump test whilst Figure 3 shows the casting of the control concrete and rubberized concrete specimens in moulds.

The standards used included; BS EN 12620:2013 on Grading Sand and Aggregates; BS 812 on Impact Value; BS EN 12390-3:2019 on Testing Concrete for determination of Compressive Strength of Concrete and Bulk Density.



Figure 2. Slump of normal and Rubberized Concrete.



Figure 3. Casting of control and rubberized concrete specimens.

4. Results and Discussion

4.1. Workability

The design mix had a targeted slump of 80mm to 100mm. The replacement of coarse aggregate by scrap tyre rubber affected the workability of the concrete. Figure 4 shows reduced workability with increased tyre rubber content for C20, however, the workability for both normal concrete and rubberized concrete fell within the designed limits.

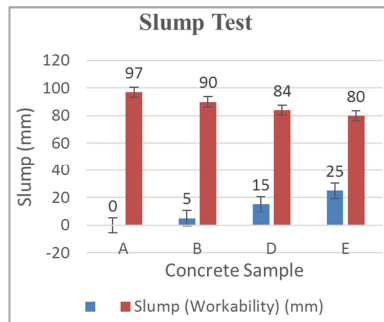


Figure 4. Slump Test Results.

4.2. Compressive Strength

The compressive strength reduction with increasing percentage rubber replacement indicated nearly linear reduction, at both 7 and 28-day ages. The percentage reduction for each percentage replacement remained nearly consistent at 20-25% reduction, compared to the control, as

observed from Figure 5.

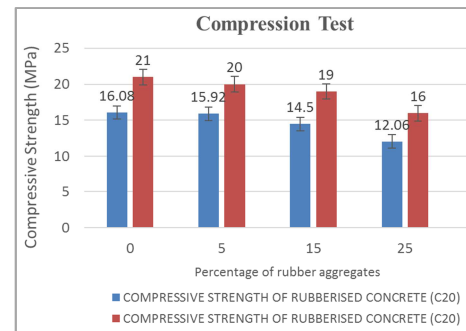


Figure 5. Compression test results of concrete at 7 and 28 days.

4.3. Tensile Splitting Strength Test

After 28 days curing of concrete cylinder, the tensile splitting strength test was carried out on each concrete cylinder of each blend and results are shown in Figure 6.

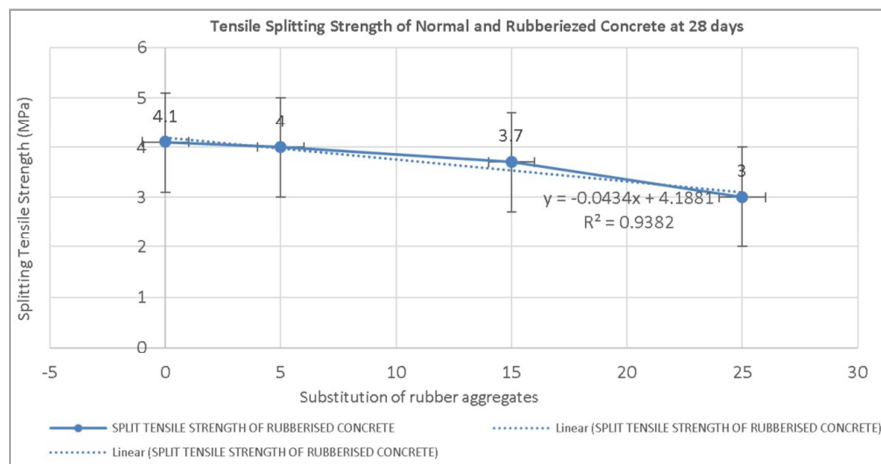


Figure 6. Tensile splitting strength results of concrete at 28 days.

4.4. Density of Wet Concrete

Figure 7 shows variation of density for various mixes. The results indicated linear density reduction with increasing rubber substitution.

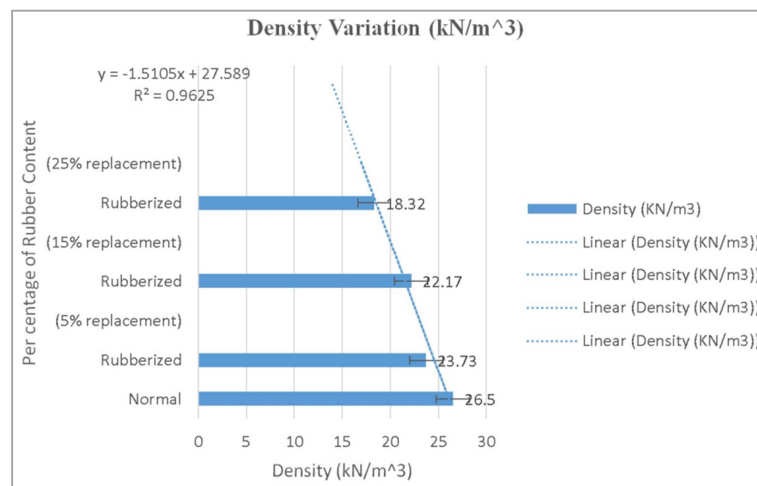


Figure 7. Wet Concrete Density variation with percentage of rubber content.

4.5. Residual Strength Test

Rubber is combustible under fire and has low decomposition temperature. Therefore, rubberized concrete is not safe compared to normal concrete under a direct fire condition. However, rubberized concrete exhibited lower spalling damage under fire. After exposing the rubberized concrete specimens with 5 per cent, 15 per cent and 25 per cent chopped rubber to 100°C for 48 hours. Figures 8, 9 and 10 show patterns of failures whilst, the residual compressive strength reduction is illustrated in Table 1. When the specimens were subjected to compression loading, it was observed that normal concrete did not crack, however, failure was rapid and brittle. On the other hand, the rubberized concrete had some cracks after being heated but the failure was gradual and uniform.



Figure 8. Rubber reinforced concrete and normal concrete exhibiting some cracks after being subjected to heat at 100°C for 48 hours.



Figure 9. Compression test of heated rubber reinforced concrete.



Figure 10. Failure pattern of heated rubber reinforced concrete and normal concrete after being subjected to compression forces.

Table 1. Residual Compressive Strength of C20 Grade with varying rubber contents.

Rubber content (%)	Residual compressive Strength (MPa)
	100°C for 48 hours
0	19.8
5	18.1
15	16.87
25	14.21

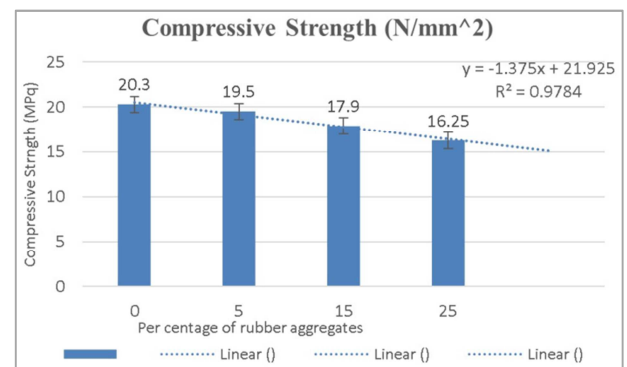


Figure 11. Variation of compression strength of concrete after treatment in sodium sulphate solution for varying rubber contents.

4.6. Resistance to Aggressive Environment (Sulphate Attack)

The compressive strength values after submerging the specimen in 10-liter water and 100 ml Sodium Sulphate for 7 days for the control concrete and that with replacement of 5 per cent, 15 per cent and 25 per cent rubber concrete, are as shown in Figure 11.

Sulfate attack on concrete can lead to expansion, cracking, strength loss, and disintegration of the concrete. While the porosity of rubberized concrete is higher than that of normal concrete, the chemical absorption of the former is generally higher than the latter. Some previous experiments have returned positive results and confirmed the high resistance of rubberized concrete to sodium sulphate and water

penetration.

From the literature review, rubberized concrete faces a lower long-term loss in strength compared with normal concrete under sulphate exposure conditions, and such loss in strength decelerates as the amount of rubber increases.

5. Conclusions and Recommendations

This chapter presents the conclusions from the findings of the research. It has been established from the literature that tyre production is continuously increasing in parallel with the economic and industrial development in the world. Disposal and burning of waste tyres have been proven as harmful for environmental safety and therefore, recycling of rubber is the most desirable alternative. The application of recycled waste tyre rubber in concrete construction is an effective and sustainable process. Waste tyre rubber can be utilized in concrete as a replacement of fine aggregates, coarse aggregates, binders, and fibres. However, in this research, a replacement of coarse aggregates was used to determine the suitability of using rubber aggregates in concrete production.

5.1. Conclusions

From the test results and analysis of this experimental work, the following conclusions were arrived at:

- 1) With up to 15 per cent replacement of coarse aggregate, Rubber modified concrete performance was comparable to normal concrete, by treating the surfaces of the tyre rubber, the compressive strength of the concrete was enhanced.
- 2) The Slump was not significantly affected by increased tyre rubber replacement, hence workability remained acceptable.
- 3) The slight reduction in unit weight of rubberized concrete specimens with increasing percentage of rubber substitution is beneficial in terms handling costs.
- 4) Strength loss was observed in both rubberized and normal concrete at elevated temperature but cracking was gradual in rubberized concrete.
- 5) Rubberized concrete performed well under fire and corrosive environments.

5.2. Recommendations

- 1) Research and academic institutions in Zambia should conduct additional studies on the use of rubber aggregates in concrete construction.
- 2) Designers should incorporate the use rubberized concrete by first conducting laboratory tests on the desired properties.
- 3) Long-term performance of rubberized concrete should be studied by research and academic institutions.
- 4) This research used single graded rubber aggregates of size 19 - 20 mm. The effect of various gradings of tyre rubber and percentage replacements should be investigated.

- 5) Additional research must be conducted, considering the type, age, quality of tyre rubber, and aggressive environments in the manufacture of rubberized concrete.
- 6) Alternative Pre-treatment methods of waste tyre rubber should be studied by academic, research institutions and concrete manufacturing companies.

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