Original Research Article

Experimental Investigation of Strength Characteristics of Concrete Using Tyre-Rubber as Aggregate

ABSTRACT

This research studied strength-characteristics of concrete using waste tyre-rubber as partial replacement for coarse aggregate in concrete construction and compares the results to those of conventional concrete. The specimens were produced with percentage replacements of the coarse aggregate by 5%, 10% and 15 % of rubber aggregate. A control mix with no replacement of the coarse aggregate was produced, to make a comparative analysis. The samples consisted of concrete cubes, cylinders and beams. Various tests (such as slump, compressive strength, splitting tensile strength and flexural strength tests), were conducted. Data-collection was mainly based on results of the tests conducted on the specimens in the laboratory. The results show that there is a reduction in compressive strength of the concrete, due to the inclusion of rubber aggregates. Compressive strength losses of 12.69%, 17.75% and 25.33% were noticed for 5%, 10%, 15% replacement of coarse aggregate, respectively; tensile strength losses of 13.01%, 20.12%, and 24.76% were observed, respectively, when 5%, 10%, 15% of the coarse aggregate was replaced, after 28 days of curing; -0.1%, -0.15% and 0.2% decrease in flexural strength was observed for 5%, 10% and 15% replacement, respectively, after curing for 28 days. Rubberised concrete was found to have some desirable characteristics (such as lower density, enhanced ductility, and a slight increase in flexural strength in the lower compressive strength concrete categories). The overall results show that it is possible to use recycled rubber tyres in concrete construction, as a partial replacement for coarse aggregates. Nevertheless, the percentage of replacement should be limited to 10% (which ensures the strength of the concrete is kept within the required range), and the application should be restricted to particular cases where the properties related to the replacement withthe rubber aggregates clearly indicate an improvement on conventional concrete, and so are desirable.

Keywords: Tyre-rubber, rubberised concrete, waste tyres, recycle, rubber aggregate.

1.0 INTRODUCTION

Recycling of waste rubber tyres in Civil Engineering practices is considered as both an ecological and economic solution to the environmental problem posed by such deposits, due to the advantages it can offer. It preserves natural resources and produces an eco-friendly material – in addition to reducing the highly dangerous environmental pollution dumping of tyres in landfill sites, constitutes. A large number of studies, experiments and practical test-projects have been undertaken in many countries to assess the modifications in the properties of concrete after addition of non-used rubber aggregates. These rubber aggregates have been used to replace fine or coarse aggregates in various proportions.

In Nigeria, waste rubber tyres are some of the predominant characteristic features of the physical environment. They are found dumped by the roadside in major cities like Ibadan and Lagos. There has been very little sensitization on the harmful effects of these non-biodegradable wastes in the Nigerian environment; with the increasing population, the presence of these wastes in the environment poses a greater risk to the citizenry. Non-biodegradable wastes can last for centuries [1]; they can cause environmental problems that affect more than just the land [2].

Some tyres are burnt (especially during civil protests and fights) – which causes air-pollution (through mixing of the obnoxious fumes producedand the air in circulation). Waste rubber tyres also have, embedded in them, heavy metals which, when exposed to air and moisture, corrode and leach toxins from the metals into the groundwater – especially when placed in wet soils. Most communities get their water supply from shallow wells and streams which are often contaminated by toxins produced by these wastes. Rubber compound is made from basic polymer, activators, accelerators, fillers, plasticizers, anti-degradants, curatives, etc. [3]. These constituents are released into the atmosphere when rubber is burnt – and are dangerous; for example, fillers (Carbon Black, Silica, Titanium Dioxide) are carcinogenic to humans, and also to animals. Generally, open burning of plastic or rubber wastes is dangerous not just to human health, but also to the environment; it releases chemicals into the atmosphere, such as dioxins and furans – apart from those already mentioned above [5]. Studies have linked dioxins and furans, specifically, to cancer and some respiratory diseases.

Other negative impacts include the physical nuisance value of the wastes to the environment, and the fact that the non-biodegradable waste dumps also serve as hideouts for rodents and reptiles which are dangerous[4]. Most of the wastes are also washed away by overland flow during heavy downpour – to block drainage channels, subsequently leading to flooding of the environment. Also, much of these non-biodegradable solid wastes contain toxic chemicals, which have serious implications on environmental sustainability and human health. In addition, discarded tyres are among the items that can hold water and, as such, create breeding grounds for mosquitoes (including the Culex mosquito that transmits West Nile Virus). They are often targeted as the prime candidates for mosquito breeding, because it is difficult to remove water from them, and they retain heat, which further exacerbates the conditions that attract mosquitoes [6]. Hence, proper disposal of waste rubber tyres is a major problem in Nigeria, and requires urgent attention.

Rubber is one of the most outstanding materials widely used in many engineering applications (such as automotive, civil and electrical). About 80 million tyres were part of 33 million vehicles manufactured in India in 2011 [7]. It is estimated that more than 270 million scrap-tyres weighing more than 3 million tons are produced in the United States each year;

this quantity is in addition to the more than 300 million scrap-tyres that are stockpiled already [7]. Landfill has been one of the methods for their disposal. However, as rubber tyres are not biodegradable, they remain in the land for a long time, causing an environmental hazard. In India, the use of tyres to generate thermal power in cement kilns, accounts for up to 20,000 tonnes per year. In industries, large amounts of waste tyres are utilized as fuel, pigment soot, in bitumen pastes, roof and floor covers and for paving finishes [7]. Aside from tyre-derived fuel, the most promising use of recycled tyres is in engineering applications, such as artificial reefs, erosion control and aggregates for asphalt and concrete.

Natural rubber is the main raw material used in manufacturing tyres, although synthetic rubber is also used [8]. Rubber is known to have excellent energy-absorbing characteristics. Researchers have found that rubber can effectively improve the ductility, reduce the weight, lower modulus of elasticity and prevent brittle failures of materials of which it is a component part. According to Neela et al [7], concrete is the second most widely-used material in the world. One of the potential ways of utilizing tyre waste is to adopt it in the construction sector for aggregate replacement[9].

As such, using rubber in concrete can help consume large amounts of otherwise waste rubber tyres, by replacing conventional (naturally-occurring) aggregates of concrete with rubber. Thus, reusing waste rubber tyres as replacement in concrete could be a potential solution to the environmental nuisance such tyres have hitherto posed.

2.0 MATERIALS AND METHOD

2.1 Materials

2.1.1 Cement

The cement type used in this research was Dangote Portland Cement, manufactured in

Nigeria. The main reason for using Ordinary Portland Cement (Type I) in this study is that this is, by far, the most common cement in use and is highly suitable for use in general concrete construction when there is no exposure to sulphates in the soil or groundwater [10]. The choice of Ordinary Portland Cement (OPC) from Portland Pozzolana Cement (PPC) also avoids any uncertainties in the results of the test.

2.1.2 Coarse Aggregate

Coarse aggregate used in this research was purchased from a construction site around the University College Hospital, UCH, Ibadan. Laboratory tests were carried out to identify the physical properties of the coarse aggregate (and similarly on the fine aggregate), and the results are displayed in Table 1. The coarse aggregate size used was 19mm, with the following physical properties determined:

(a) Moisture Content = 1.37%
(b) Unit weight of coarse aggregate =1511kg/m^3
(c) Bulk specific gravity = 2.79
(d) Bulk specific gravity (Saturated Surface Density basis) = 2.84
(e) Apparent specific gravity = 2.93
(f) Absorption capacity = 1.72%

2.1.3 Fine Aggregate

The fine aggregate sample used in this experiment was purchased from local sand suppliers at Ibadan along *Ojoo-Moniya Road, L-Adisa Area,* Oyo State, Nigeria. The following properties of fine aggregate were determined:

(a) Bulk Specific gravity = 2.41;

(b) Bulk Specific gravity (Saturated Surface Dry basis) = 2.51;

(c) Apparent Specific gravity = 2.61;

(d) Absorption capacity = 4.38%;

2.1.4 Rubber Aggregate

The source of the rubber aggregate was waste tyres which were collected from various dump-sites at *Moniya Area,* Ibadan, Oyo State. For uniformity of the concrete production and convenience, all the tyres were medium truck tyres, i.e. the study has concentrated on the performance of a single grade of waste tyre-rubber, prepared by manual cutting.

2.1.4 Water

In this research, tap-water supplied by the Department of Agricultural Engineering, University of Ibadan, was used in all mixes.

2.2 Experimental Methods

2.2.1 Test Arrangement

In this study, a total of four mixes of concrete grades (C25) were produced with partial replacements of the coarse aggregate by 5%, 10% and 15% of the rubber aggregate, respectively. In addition, a control mix with no replacement of the coarse aggregate was produced to make a comparative analysis. The mixture proportions of the basic ingredients (i.e. cement, water, and fine aggregate), were the same for the control and rubberised concrete samples. However, a certain amount of the coarse aggregate was replaced by an equal volume of rubber aggregate to form rubberised concrete.

2.2.2 Sample Sizes

Beam-moulds used were of size 10 x 10 x 500 mm for the flexural strength test; cylinder-moulds of size 100 x 200 mm for the split-tensile strength test, and cube-moulds of size 100 x 100 mm for the compressive strength test.

Table 1. Sieve Analysis of Coarse Aggregate

Sieve Size (mm)	% Passing
37.5	100.00
19	100.00
12.5	51.64
9.5	22.16
4.75	0.35
Pan	0.36

Table 2. Sieve Analysis of Fine Aggregate

Sieve Size (mm)	% Passing
4.75	98.22
2.36	95.45
0.425	84.56
0.212	42.38
0.150	12.68
0.075	1.59
Pan	0.01

2.2.3 Casting and Testing of Materials

Compressive, flexural and split-tensile strength tests were carried out in accordance with the BS 12390. The compressive and split-tensile strength tests were carried out at the Materials Testing Laboratory of the Department of Civil Engineering, University of Ibadan. The flexural strength test was carried out at the Department of Agricultural Engineering of the University of Ibadan.

3.0 RESULTS AND DISCUSSION

The results obtained for the compressive, flexural and split-tensile strength tests are as follow:

3.1 Compressive Strength Test Results

The compressive strengths of concrete specimens were determined after 7, 14 and 28 days of standard curing, respectively.

Losses in compressive strength of 11.38%, 17.02% and 23.23% were observed when 5%, 10% and 15%, respectively, of the coarse aggregate was replaced by an equivalent volume of rubber aggregate, after curing for a period of 7 days. The observed losses of strength when the concrete cubes were cured for a period of 14 days were 12.36%, 16.98% and 25.03% for 5%, 10% and 15% replacement of coarse aggregate with rubber, respectively. For rubberised concrete cured for 28 days, losses of 12.69, 17.75 and 25.33% were noticed for 5%, 10%, 15% replacement of coarse aggregate with rubber, respectively. Table 3 gives details of the compressive strengths of the control concrete and the rubberised concrete.

Fig. 1. Compressive strength test of concrete cube

Table 3. The average compressive test results (C25 grade)

% Rubber	Average Compressive Strength (N/mm^2)		
	After 7 days cure	After 14 days cure	After 28 days cure
0.00	18.98	23.21	28.38
5.00	16.83	20.34	24.78
10.00	15.75	19.26	23.34
15.00	14.59	17.40	21.19

3.2 Split-Tensile Strength Test

Losses of up to 11.54%, 21.68% and 25.17% were observed, respectively, when 5%, 10%, and 15% of the coarse aggregate was replaced by rubber after 7 days of curing.

The observed losses of strength when 5%, 10% and 15 % of coarse aggregate was replaced by rubber aggregate and cured for a period of 14 days were 11.59%, 21.35% and 25.47 %, respectively.

Likewise, for rubberised concrete containing 5%, 10% and 15 % by volume of rubber aggregate cured for 28 days, losses of 13.01%, 20.12%, and 24.76% were observed, respectively. Table 4 gives details of the split-tensile strengths of the control concrete and the rubberised concrete.

Fig. 2. Split-tensile testing of concrete cylinder

Table 4. Split-tensile strength test result

% Rubber	Split Tensile Strength (N/mm^2)		
	After 7 days cure	After 14 days cure	After 28 days cure
0.00	2.86	3.06	3.69
5.00	2.53	2.71	3.21
10.00	2.24	2.41	2.95
15.00	2.14	2.28	2.78

3.3 Flexural Strength Test

The results show that the flexural strength increased, compared to the control mix, for rubber aggregate content of 5% and 10%. For rubber aggregate content of 15%, a flexural strength reduction was observed as compared to the control mix. This indicates that improvements in flexural strength are limited to a relatively small rubber aggregate content. The details are given in Table 5.

Table 5. Flexural Strength Test Results.

% rubber	Flexural Strength (N/mm^2)
0.00	3.22
5.00	3.31
10.00	3.35
15.00	3.01

4.0 CONCLUSION

The following conclusions can be drawn from the results of this experiment:

1. A reduction in unit-weight of up to 4.82% was observed when 15% by volume of the coarse aggregate was replaced by rubber. A similar trend of reduction in unit-weight of the rubberised concrete was observed in all the other samples containing rubber aggregates. The low specific gravity of the rubber-chips (compared to the mineral coarse aggregates) produced a decrease in the unit-weight of the rubberised concrete.
2. Losses in compressive strength (ranging from 12.69% to 25.3%) were observed after 28 days of standard cure. The reason for the strength reduction could be attributed both to a reduction of quantity of the solid load-carrying material, and lack of adhesion at the boundaries of the rubber aggregate. Soft rubber particles behave as voids in the concrete matrix; therefore, rubber aggregate tends to behave like weak inclusions (or voids) in the concrete, resulting in a reduction in compressive strength. Although the compressive strength values have considerably decreased with the addition of waste-tyre pieces, their values are still in the reasonable range for 5% to 15% replacement-values, because the intended compressive strengths of 25N/mm^2 were achieved in these categories.
3. The results of the splitting tensile strength tests show that there is a decrease in strength, with increasing rubber-aggregate content (like the reduction observed in the compressive strength tests). One of the reasons that splitting tensile strength of the rubberised concrete is lower than the conventional concrete is that bond strength between cement-paste and rubber-tyre particles is poor. Besides, pore structures in rubberised concretes are much more than conventional concrete.
4. Reduced compressive strength of rubberised concrete (due to the inclusion of rubber aggregates), limits its use in some structural applications. Nevertheless, it has a few desirable characteristics such as lower density, higher impact- and toughness-resistance, enhanced ductility and a slightly increased flexural strength in the lower-strength concrete mixes. A significant advantage of increase in flexural strength was achieved by limiting the

replacement amount to only 10% of the coarse aggregate. For rubber-aggregate contents of 15%, a flexural strength reduction was observed, compared to the control mixes. The reduction indicates that improvements in flexural strength are limited to a relatively small rubber-aggregate content.

5. The visual observation of the patterns of failure mode revealed that the rubberised concrete does not exhibit typical compression-failure behaviour. The control concrete showed a clean split of the sample into two halves – whereas the rubber aggregate tended to produce a less well-defined failure. Moreover, the mode of failure was a gradual type (rather than the brittle failure in the control concrete). This may be an indication of greater ductility in rubberised concrete than the control concrete.
6. The use of rubber aggregates from waste tyres addresses many issues. These include: reduction of the environmental threat posed by waste tyres; introduction of an alternative source to aggregates for concrete-production; and enhancing the weak properties of concrete (by the introduction of different ingredients other than the conventionally-used natural aggregates, ultimately leading to the conservation of natural resources). In addition to meeting recycling and sustainability objectives, it is indicated for generating products with enhanced properties in specific applications.

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