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Flexural Strength of Concrete Beam Produced with Scrap Rubber Tyres as Partial Replacement for Coarse Aggregates

[1*] Amusan G. M.; [2]Orogbade B. O.; [3]Olaniyan O. S. and [4] David A. O.

[1, 2, 3, 4]Department of Civil Engineering, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria.
[3]Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State Nigeria.

[*] Corresponding Author E-mail: amusan.grace@oouagoiwoye.edu.ng Tel: 08036379211

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Abstract

The quantities of waste generation in Nigeria have increased significantly; posing greater risk to public health owing to indecent manner of disposal. Some solid wastes had been recycled; however, studies on scrap rubber tyre have not been fully exhausted. This research therefore investigated the flexural behaviour of concrete produced using scrap rubber tyre as partial replacement of coarse aggregate. Scrap Rubber Tyres (SRT) were chopped into smaller sizes; with 19 mm maximum size and used to partially replace coarse aggregate within 0 to 12% at 3% interval. The constituents were batched by weight. 45 concrete beams of grade 20 were cast and cured for 7, 28 and 90 days. Flexural strength behaviour of the specimens was tested; and the 0% SRT concrete serves as control. Data were analysed using Analysis of Variance at 5% Significance level. The slump and compacting factor of the fresh concrete ranged from 29-100 mm and 89-99%, respectively. The flexural strength of the rubberized concrete at 28 days were 21.3, 14.0, 13.2, 12.2, and 13.3 N/mm^2. Rubberized concrete at 3% partial replacement can be useful for light weight structural members. The scrap rubber tyres possess significant potentials which could advance its utilization under improve technology.

Keywords: Concrete, flexural strength and scrap rubber tyre,

Introduction

Concrete is a predominant material used in construction and competes directly with all other major construction materials like timber, steel, asphalt and stone, because of its versatility in application and its ability to be cast into any desired shape. In addition, concrete being a composite material, its production depends extensively on the availability of cement, sand and coarse aggregates such as granite, the costs of which have risen astronomically over the past few years due to high demand for concrete. This has drastically reduced the natural stone deposits (aggregates); causing serious damage on the environment and causing ecological imbalance (Osei and Jackson, 2012). The suitability of the choice of concrete for infrastructural development therefore, should align with the three components of sustainability; environment, economy and society (Zimaran, 2008).

Several researchers had explored various Science, Technology, Engineering and Mathematics (STEM) approaches to complement conventional concrete materials with the philosophy of enhancing resources within so as to meet the overall sustainability goal. To this end, different wastes that had constituted threats to human health had been harnessed in this regard (Ndoke, 2006; Olutoge, 2010). Among these numerous wastes is scrap rubber tyre. More than 242 million scrap tyres; approximately one tyre per person per year had been estimated to as waste tyre generation in United State. An average of four million tonnes of waste tyres are generated each year in the United Kingdom and Singapore was reported to discard six million tonnes of waste tyre in year 2008 (Siddique and Naik, 2004; Wallis, 2005). In Nigeria

10 million scrap tyres were estimated in 1996, with an annual generation rate of 10% each year. This implies that, about one million scrap tyres are being added to the waste stream annually (Elsien, 2006).

Bulk of these scrap tyres had been recycled and reused in developed world, Gintautas *et al.* (2007) used crumb rubber as fine aggregate replacement. Topçu and Demir (2007) studied durability of mortal and concrete with aggregate of discarded car tyres under environmental condition like freeze-thaw, seawater and high temperature. The researchers submitted that concrete produced with 10% rubber aggregate were appropriate in regions where the environmental condition was not harsh. Similarly, Son *et al.* (2011) investigated the efficiency of waste rubber tyres to improve the energy absorption capacity of reinforced concrete columns. The author concluded that concrete with waste rubber tyres offered good energy dissipation and suitable for seismic application.

Consequently, Wakili *et al*. (2018) conducted appraisal on concrete modified with waste tyre rubber chips. The study showed a significant increase in mechanical strengths of rubber chips concrete compared with unmodified rubber chips concrete. Gemeda and Alemu (2020) also produced concrete with percentage replacements of the coarse aggregate by 10, 20, 30, 40 and 50% of rubber aggregate. Reduction in compressive strength of the concrete, as well as, slight increase in flexural strength without admixture were noticed. Finally, study on tyre crumb rubber as a replacement for fine aggregate in silica fumes concrete (Kaurav *et al.*, 2021), showed a decrease in the compressive strength, split tensile strength and flexural strength when the percentage of rubber content increase.

In under developed and developing countries, larger percentage of this tyre waste are either discarded indiscriminately or abandoned at landfill site and in some cases, stocks piled (Wallis, 2005; Emiroglu and Michelle, 2006). The increasing piles of scrap rubber tyre in turn render landfill treatment impracticable due to scarcity of land and non-biodegradable of rubber waste. Thus presents the threat of uncontrolled fires, producing a complex mixture of chemicals harming the environment and contaminating air, soil and vegetation (Elsien, 2006).

All the above suggested that there is a strong need to use recycled waste material, particularly waste tyres in an environmentally friendly way. In this study, concrete production is considered, with the aim of examining the flexural strength of concrete beam produced with scrap rubber tyres as partial replacement for coarse aggregates to proffer solutions to various environmental threats caused by waste tyres disposal and that of diminution of natural resources emanated from production of conventional concrete using natural aggregates.

Materials and Methods

Materials

Ordinary Portland cement, fine aggregate, coarse aggregate, scrap rubber tyre and water were the materials used in the study. Details of the materials properties and the tests performed are as described below:

Cement

Ordinary Portland cement was used. It was conformed to the requirement of BS12 (1996).

Fine aggregate

The fine aggregate used for this research was sharp sand, sourced from a river in Abeokuta. Sample of fine aggregate was analyzed using sieve analysis apparatus, the representation of the aggregate size is presented in Figure 1. The fine aggregate used passed through 4.75 mm and retained on 2.36 mm sieve. It was free from silt, impurities and organic matter. It conformed to the requirement of BS882 (1992).

Coarse aggregate
The coarse aggregate used was granite. The maximum coarse aggregate size was 19 mm. It was obtained at quarry in Abeokuta, Ogun State, Nigeria. The coarse aggregate sample was analyzed using sieve analysis apparatus and conformed with the requirements of BS882 (1992).

Scrap rubber tyre
Scrap Rubber Tyres (SRT) were collected within Abeokuta. For the purpose of uniformity, the tyres collected were restricted to medium truck tyre. The tyres were chopped into smaller sizes equivalent to 19 mm maximum aggregate size and cleansed properly to take away any dirt that might be detrimental to concrete. The SRT was later sun dried and kept in waterproof sacks. A representative sample of the SRT and particle size distribution is presented in Plate 1 and Figure 1, respectively.

Plate 1: Chopped rubber tyre sample

Water
Water is a universal solvent; the water used for concrete mixing was clean and free from oil.

Methods

Mix proportion and casting of concrete specimens
Granite was partially replaced with SRT at the dosage of 0 - 12% by weight of coarse aggregate. Concrete mix ratio 1:2:4 with water cement ratio of 0.5 was used by weight. The mixing was carried out with the use of a mixing machine. Five mixes were prepared using 3, 6, 9 and 12% of SRT to partially replace coarse aggregate while the mix with 0%SRT served as control. This was done to determine the proportion that would give the most favourable result. Table 1 shows the weight of the material constituents used. Concrete beam specimens of 400 × 100 × 100 mm and were cast and covered with polyurethane sheets. They were demoulded after 24 hours and cured in water at room temperature until the due hydration age for each of the tests.

Experimental procedures - Flexural strength test
Beam mould, 400 × 100 × 100 mm were used to for the concrete specimen for flexural experiment. The concrete was cast using the material combinations as presented in Table 1, and cured for 7, 28 and 90 days. At the due curing age, the beam specimens were placed under Universal Testing Machine (UTM). The machine was loaded, until the concrete specimen failed. The failure load for each of the tests were

noticed for each of the concrete specimen. The flexural strengths of the concrete specimens were evaluated in accordance to BS 1881 (1983).

Table 1: Mixture proportions

Matrix designation (% of SRT)	Cement (kg))	Fine aggregate (kg)	Coarse aggregate (kg)	SRT (kg)	Water (kg)
0	4.14	8.29	16.57	0.00	2.07
3	4.14	8.29	16.07	0.49	2.07
6	4.14	8.29	15.58	0.99	2.07
9	4.14	8.29	15.33	1.49	2.07
12	4.14	8.29	14.58	1.99	2.07

Results and Discussion

Materials characterization

The fine, coarse aggregates were well graded. It had coefficient of curvature (C_c) of 1, 1.08 and 1.8, for fine aggregate, coarse aggregate and SRT, respectively. The fine aggregate passed through 4.75 mm and retained on 2.36 mm sieve, while the coarse aggregates and SRT passed through 20 mm and retained on 14 mm sieve. The particle size distribution curves for the materials are as presented in Figure 1.

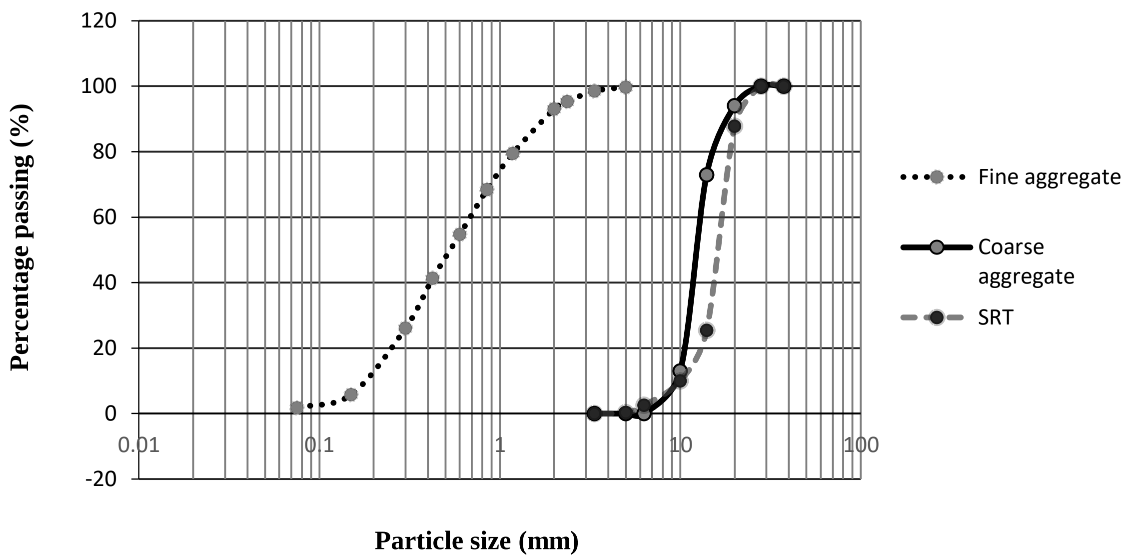

Figure 1: Particle size distribution of aggregates

Concrete fresh properties

The results presented in Table 2 shows that the workability rating of all the specimens were good. The slump and compacting factor values increased as percentage dosage of SRT increases.

Table 2: Concrete fresh properties

Designation	0% SRT	3% SRT	6% SRT	9% SRT	12% SRT
Slump (mm)	29	75	80	90	100
Compacting factor	0.89	0.97	0.98	0.99	0.99

The 12% SRT had the highest compacting factor and slump values of 0.99 and 100 mm, respectively. This agrees with previous studies (Siddique and Naik, 2004; More, *et al*., 2015).

Flexural Strength

The results presented in Figure 1 show the trend of improved flexural strength as curing age advances for all the specimens. This implies that the hydration occurred at steady and uniform rate within the mass concrete. The rubberized concrete had flexural strength values of 14.0, 13.2, 12.2 and 13.3 N/mm^2 for 3, 6, 9 and 12% SRT dosage, respectively at 28 days compared to control with flexural values of 21.3 N/mm^2. The 3% SRT concrete flexural strength values were comparable to the control. The 9% SRT concrete had the lowest flexural strength values at 7 and 28 days; however, the strength later improved at 90 days curing age. This agrees with More, *et al*. (2015) study on waste tyre crumb rubber.

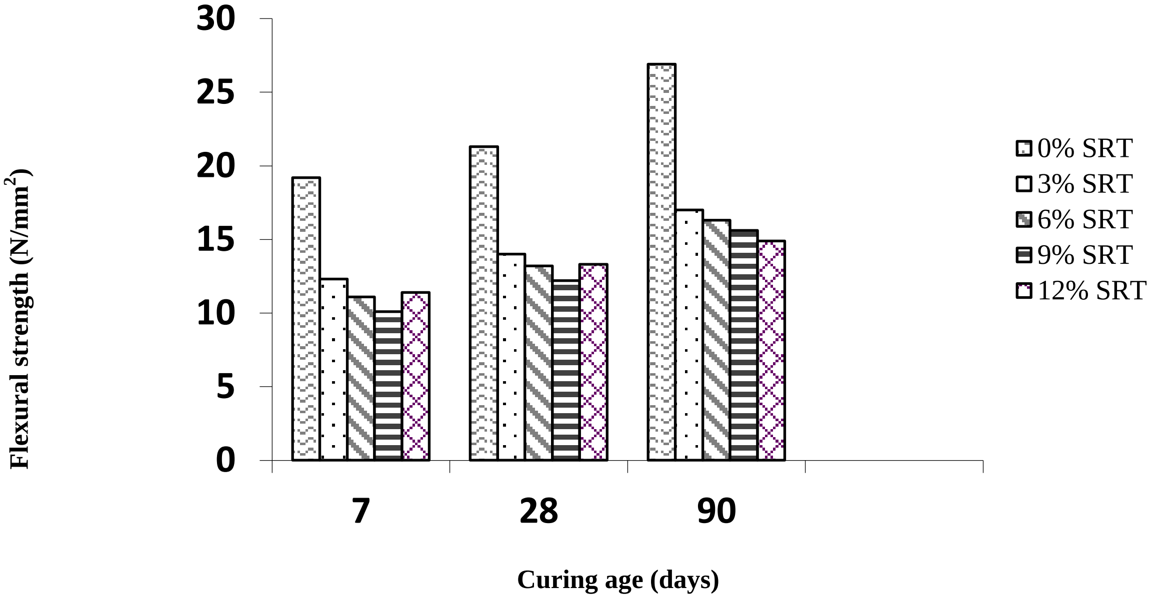

Figure 2: Comparison of flexural strength at different %SRT content

Table 3: ANOVA of flexural strength of control and rubberized concrete

Test	Sum of squares	Df	Mean square	F_{cri}	Sig.
Between groups	453.87	1	455.87	5.31	0.00
Within groups	3.70	8	0.49		(S)
Total	457.77	9			

Significant difference of flexural strength characteristics between the control and the rubberized concrete showed zero difference between the groups. This implies a higher level of accuracy and greater confidence in the experimental work.

Conclusions

The objective of reducing environmental burden caused by scrap rubber tyre pollution menace was achieved. The slump and compacting factor values of the concrete increased as percentage dosage of SRT increase with 12% SRT giving the highest compacting factor and slump values of 0.99 and 100 mm respectively. The rubberized concrete had highest flexural strength value of 13.3 N/mm^2 for 12% dosage as compared with the control with 21.3 N/mm^2 at 28 days. Therefore, the indiscriminate dumping of scrap rubber tyre as waste can be reduced when used as alternative coarse aggregate in production of light weight concrete.

Based on the results of the findings from the research the following suggestions are made.

i. Scrap rubber tyre that causes pollution can now be used at 12 % dosage in the replacement of coarse aggregates in the production of light weight concrete.
ii. The use of locally available materials in infrastructure development would be met with the use of scrap rubber tyre as construction materials.
iii. Subsequent studies should be conducted on 0-5% replacement of granite with scrap rubber tyre and in steps of 1%.

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