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Effects of Tyre Derived Aggregate (TDA) as Partial Replacement of Coarse Aggregate in Concrete

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Abstract: The usage and reuse of waste tyre rubber in concrete production can cut down the use of raw materials which contributes to economic efficiency and sustainable development of the construction industry**.** This study is directed at assessing the effects of using the Tyre Derived Aggregate (TDA) as a substitute for coarse aggregate in concrete. A sum of eighty-six square cubes of 100 mm was cast and cured in fresh water for up to 28 days. Setting times, consistency and soundness tests were carried out on cement paste. However, slump, compressive strength and durability (i.e. water absorption) tests were carried out on the concrete. The results unveiled that the physical characteristics of cement considered fulfilled BS EN 196-3 (1995), and the slump of fresh concrete decreased as the percentage of TDA content stepped up. The water absorption raised, while the density of concrete made with TDA decreased as the percentage of TDA content stepped up. However, the strength of TDA-concrete increased as the curing age increased, and it decreased as the portion of TDA content raised. Nevertheless, the strength at 0%, 5% and 10% were 23, 21.67 and 18.33 N/mm^2 respectively. However, the strength of TDA-concrete made with 0 % TDA and 5 % TDA subjected to different temperatures decreased as the temperature increased, however, even at 50^{0}C the strength of concrete made with 5% TDA was found to be 20.5 N/mm^2 which is within the target compressive strength. It was concluded that the usage of TDA content in the production of concrete should not be greater than 5 % for better performance.
Keywords: Compressive Strength, Temperature, Tire Derived Aggregate (TDA) and workability

1. Introduction

A large number of tyres are discarded away in different parts of the world which severely affects the environment [1]. Waste tyres contribute severely to the environment on a large scale as they a bulky, non-biodegradable and prone to fire. Disposal of waste tyre rubber has become an essential environmental issue globally. It is considered one of the most critical environmental problems globally, due to its numerous disadvantages. However, despite its numerous disadvantages, concrete made with rubber tyres exhibits low mechanical properties and durability limiting its wide use in the construction industry [2]. Stockpiled tyres cause health, environmental and economic risks through air, water and soil pollution [2]. The continuous accumulation of discarded worn-out tires of vehicles leads to a significant challenge for proper disposal. It becomes a nuisance to the environment globally due to its non-degradable nature [24]; [26]. Globally, about 1.5 billion tyres are brought forth and all of these tires will become a waste of time [3]; [4]. When it comes to waste disposal management, the reduction of waste and its recycling is a very important characteristic both from an economical and environmental view. However, the utilization of crumb rubber from the scrap tyres as sustainable building materials in the construction industry helps to preserve natural resources. [25]. Alsaleh and Sattler [5] reported that crumb rubber from waste tires takes not less than 50 years to fully decompose. However, acceptable methods to dispose of the worn-out tires are needed to avoid burning or piling them in a landfill, burning them results in the production of arduous smoke and toxic run-off to waterways. Hence, researchers in the field of civil Engineering come up with alternatives for disposing of worn-out tires by incorporating them into constructions as aggregate (tyre-derived aggregate (TDA)). The alternatives include; the use of tire-derived aggregate (TDA) in asphalt pavements and cement concrete. However, a small percentage of TDA was found to be technically and economically feasible in the production of asphalt pavement [6]; [4] and [7]; [4]. It was reported by [4] that the most efficient way to dispose of the waste tyres and prevent the environment is to integrate them into cement-based products i.e mortar and concrete, to substitute natural aggregates.

Over the years, construction industries and researchers conducted research to determine the suitability of recycling or using waste tyres in form of tyre-derived aggregate (TDA) in civil engineering as a replacement for natural aggregate i.e fine and coarse aggregates. The attempts help in the proper disposal of waste tyres which in return prevent the environment from pollution [8]. The long life cycle of waste tyre rubber was one of the factors that motivated the interest of the researchers in the substitute of fine and coarse aggregates with rubber-based products in concrete or mortar [9] and [10].

Atahan and Sevim,[11] ascertained the strength and impact resistance of concrete barriers having teared up waste tyre chips and the results indicated that with an increase in tyre chips, a step-down in the strength of concrete and modulus of elasticity was observed under static tests, while an increase in impact resistance was observed under dynamic tests. They concluded that all samples containing 20-40% aggregate replacement had not shown any substantial reduction in strength under the effect of static and dynamic loadings. Ganjian et al.,[12] conducted a study by incorporating TDA into concrete as coarse aggregate and waste tyre powder as cement replacement. They reported that with 5% replacement for both aggregate and cement there were no significant changes in the concrete mechanical properties as compared with the normal concrete. Kantasiri et al., [13] reported a loss in the weight of concrete at different temperatures which resulted in a reduction of the concrete densities and noted a step-down in the strength of the samples with high amounts of rubber (TDA) i.e. 15%. And the TDA proportion to coarse aggregate used ranges between 3 to 15%.

Issa and Salem, [14] examined the usage of TDA as a substitute for fine aggregate and they reported that with not greater than 25% replacement. They concluded that up to 25% of TDA replacement can be used. Aiello and Leuzzi, [15] conducted a volumetric substitute of natural fine aggregate with TDA in concrete. They claimed that a drop-off in strength and density of concrete at a higher percentage replacement which attributed to a change in specific gravity. Batayneh *et al*., [16] reported the loss in compressive strength of concrete produced with 100% waste rubber as a substitute for fine aggregate.

Al-Shathr *et al.*, [17] carried out a study using four different kinds of waste tires/rubbers as fine aggregates in lightweight mortar. Atahan and Yücel [18] observed a continuous disintegration in the strength of concrete with the loss of 93% of its strength when 100% rubber content was used to substitute the fine aggregate (sand). Akisetty *et al*., [19] evaluated the performance of asphalt mixtures made with TDA (rubber), and their relation with the properties of the binder, through different tests conducted on the binders. The result clearly showed that Tyre Derived Aggregate (TDA) can be utilized to enhance the characteristics of asphalt.

Finally, this study aimed at assessing the effects of TDA as a substitute for coarse aggregate on the mechanical characteristics of concrete.

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2. Materials and Methods

2.1 Materials

Materials used are fine aggregate, coarse aggregates, Tyre Derived Aggregate (crumb rubber), Cement and water.

The coarse aggregate used was obtained from a local quarry in Zaria, Kaduna State. The fine aggregate used was clean river sand obtained within Zaria, Kaduna state. The Tyre Derived Aggregate (crumb rubber) was sourced from Dan-Magaji balkanize in Zaria. An ordinary Portland cement (OPC) and potable water were used throughout the study.

2.2 Methods

2.2.1 Coarse aggregates and Tire derived aggregate (TDA)

Tests conducted on coarse aggregates and Tyre derived aggregate (TDA) were Aggregate impact value (AIV) according to BS 812 PART 111, Aggregate crushing value (ACV) according to BS 812 PART 112, Aggregate specific gravity according to (ASTM, C127), and Sieve analysis according to BS 812-103.2. The tyre-derived aggregates used in this work were cut to nominal sizes of 12.5-19 mm.

2.2.2 Fine aggregate

Specific gravity, sieve analysis and water absorption tests were carried out according to ASTM 128, BS 812-103.2, and BS 812 Part 3 respectively on fine aggregate.

2.2.3 Test on Cement

Consistency test, initial and final setting times tests were carried out according to BS EN 196 PART 3, while soundness of cement and specific gravity tests were according to BS EN 196 PART 3 and ASTM C188 respectively

2.3 Mix Proportion

A concrete mix ratio of 1:2:4 was designed using an Absolute Volumetric method and the proportions of the materials used are presented in Table 1.

Table 1: Concrete constituent proportions

% (TDA)	Cement (kg)	Water (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Tire Derived Aggregate (TDA) (kg)
0	5.90	2.95	11.81	26.04	0
5	5.90	2.95	11.81	24.74	1.30
10	5.90	2.95	11.81	23.44	2.60
15	5.90	2.95	11.81	22.13	3.91
20	5.90	2.95	11.81	20.83	5.21
100	5.90	2.95	11.81	0	26.04

2.4 Slump Test

The slump/workability test was carried out according to BS 1881:102 (1983) in order to determine the workability of a fresh concrete.

2.5 Compressive Strength Test

The strength concrete was tested on concrete made with the addition of TDA content in accordance with [20], for grade 20 concrete. A sum of 86 square cubes (100mm x 100 mm x 100 mm) was cast and placed in water for 7, 14, and 28 days and an average of three samples were taken at each curing period. The control sample (0 % TDA) and samples with the optimum percentage (5% of TDA) were subjected to different temperatures ranging from 20^{0}C to 300^{0}C, and their compressive strength s were checked.

2.6 Water Absorption Test

The Water absorption test consists of measuring the weight of samples in a dry state and measuring them again after 24 hours of being immersed in water and calculating the absorption percentage. The test was carried out according to ASTM C67-14.

3.0 Results and Discussion

3.1 Tests on Aggregates

The outcomes of the tests performed on a fine aggregate and coarse aggregate were shown in Table 2 and satisfied their respective code, which implies that the materials are good enough for concrete works. While Figures 1 and 2 present the particle gradation of fine aggregate and coarse aggregate respectively.

Table 2: Characteristics of fine aggregate and coarse aggregate

Tests	Code	Values	Limit
Aggregate Crushing Value (%)	BS 812 Part 112	18.65	Max. 25
Aggregate Impact Value (%)	BS 812 Part 111	18.87	Max. 25
Specific Gravity of Coarse Aggregate	ASTM C127	2.70	2.55 – 2.75
Bulk Density of Coarse Aggregate (kg/m^3)	ASTM C127	1460	1200-1750
Specific Gravity of Fine Aggregates	ASTM C128	2.65	2.65 – 2.70
Bulk Density of Fine Aggregates (kg/m^3)	ASTM C127	1602	1520-1680
Specific Gravity of TDA	ASTM C128	1.21	____
Bulk Density of TDA (kg/m^3)	ASTM C127	410.46	____
Water Absorption for Coarse Aggregate (%)	BS 812 Part 2	0.56	< 2
Water Absorption for Fine Aggregate (%)	BS 812 Part 3	8.62	< 15

It was observed from gradation curves that the coarse aggregate was well graded, while the fine aggregate was classified as zone-1 based on BS 882 (1992) grading limits for fine aggregates. Figure 1: Particle size distribution for Coarse aggregate.

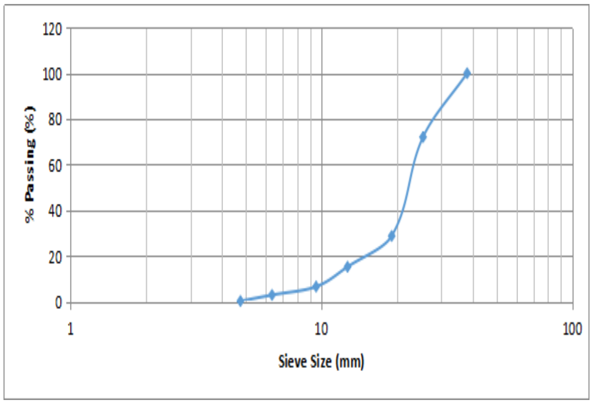

Figure 1: Particle size distribution for Coarse Aggregate

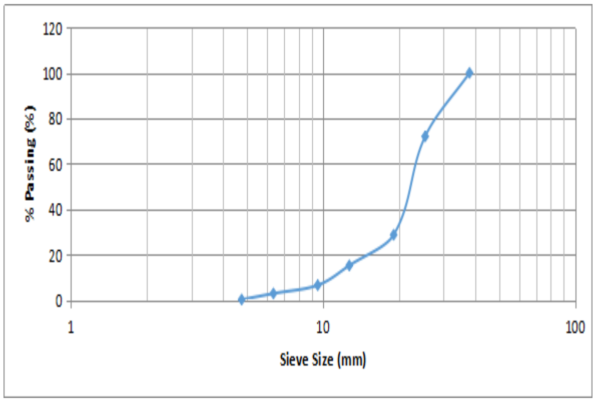

Figure 2: Particle size distribution for Fine Aggregate

3.2 Physical Properties of Cement

The test result conducted on the physical characteristics of cement in accordance with BS EN 196-3 (1995) was shown in Table 3. And based on the results obtained, the characteristics of the cement have satisfied the code requirements and recommendations.

Table 3: Physical Properties of Cement Test Result

Tests	Code	Value	Limit
Initial Setting Time (min)	BS EN 196 PART 3	66	>45
Final Setting Time (min)	BS EN 196 PART 3	207	<375
The soundness (mm)	BS EN 196 PART 3	2.4	<10
Consistency (mm)	BS EN 197-1:2009	5.5	5-7
Specific Gravity of cement	ASTM C188	3.0	3.15

3.3 Slump Test

The result of the slump test conducted on concrete with varying percentages of TDA content was demonstrated in Figure 3. It revealed that as the portion of TDA increased the slump was found to be decreased, it showed that the concrete became less workable as the percentage of TDA increased, indicating that more water is needed to make the mixes more workable. This is perhaps ascribed to a high surface area of TDA for fixed water content, and it may be because the TDA absorbed water more than the normal aggregate. The same behaviour was noticed by [21] and [22].

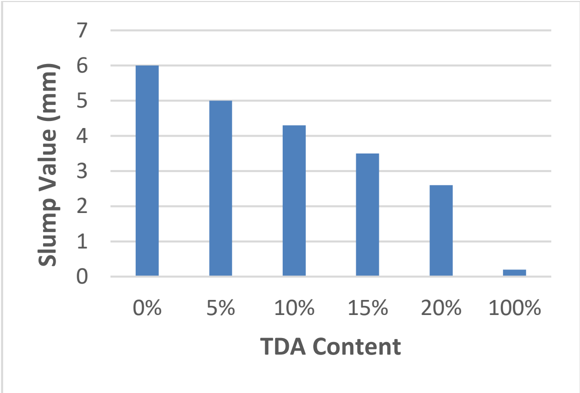

Figure 3: Slump against % of TDA Content

3.4 Compressive Strength

The results of the compressive strength test conducted on hardened concrete are demonstrated in Figure 4. It was noted that the strength of TDA-concrete increased with an increase in the curing period. The increase in strength is due to the hydration of cement. On the other hand, the compressive strength of concrete decreased as the percentage of TDA content increased, this is in agreement with [23]. The decrease in strength may be due to the macro-porosity of the concrete made with rubber (TDA) [25]. Moreover, the reduction in strength is due to the increase in voids as a result of the increase in the addition of rubber (TDA) [26]. The same pattern was reported by [21].

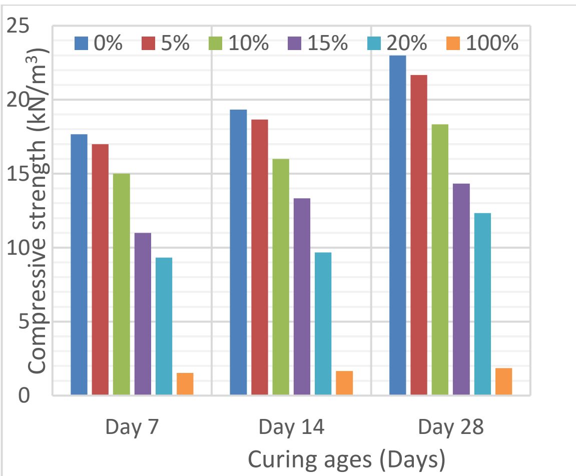

Figure 4: Compressive Strength against percentage of TDA Content

3.5 Compressive Strength of Concrete Subjected to Different Temperatures

The results of the compressive strength of concrete subjected to different temperatures, ranging from 20^0C to 300^0C are presented in Figure 5. The outcomes indicated that the strength of TDA-concrete decreased as the temperature and TDA content increased. The decrease in strength may be due to the deterioration of concrete as a result of the temperature effect. The reduction in strength is also due to the increase in voids as a result of an increase in the addition of rubber (TDA) [26].

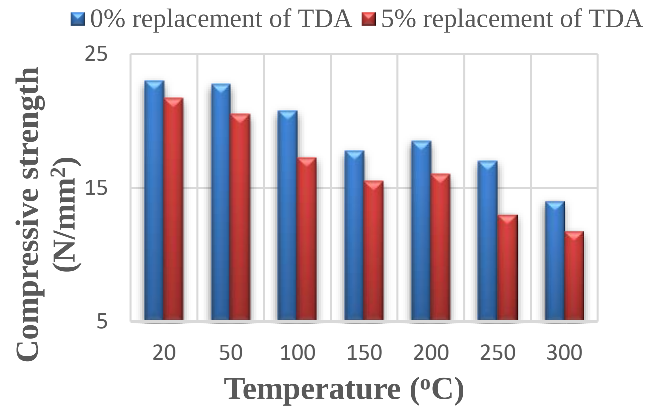

Figure 5: Compressive Strength against Temperature

3.6 Density of TDA-Concrete

Figure 6 showed the relationship between mean density and the percentage of TDA content. It was observed that as the portion of TDA content raised the density of the concrete decreased. The reduction in density is a result of flocculation of the rubber (TDA) content which creates large voids and leads to higher porosity and also due to lower density of rubber (TDA) compared with coarse aggregate [25]. The same behaviour was observed by [25] and [26].

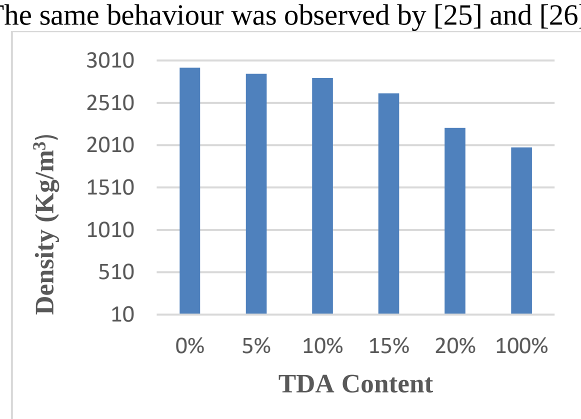

Figure 6: Density against percentage of TDA Content

3.7 Water Absorption

The results of water absorption of TDA-concrete were presented in Figure. 7. It was observed that as the portion of TDA content increased, the amount of water absorbed increased, this agreed with [12] and [22]. The increase in water absorption may be due to a higher percentage of void in the mix with an increase in rubber and the porous nature of TDA. Hence, the concrete becomes more permeable to water as explained by [21]. A similar trend was observed by [2].

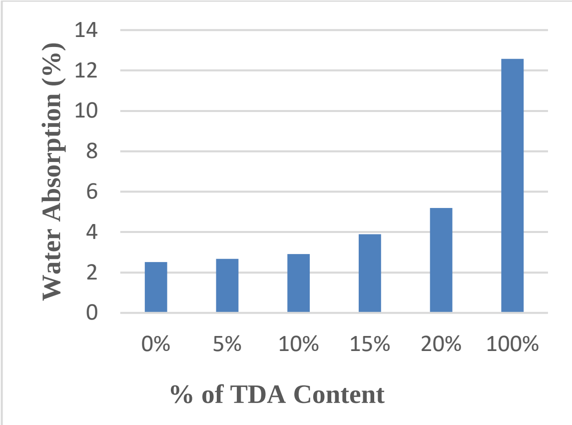

Figure 7: Water Absorption against percentage of TDA Content

4.0 Conclusions

This study examined the effect of tyre-drive aggregate (TDA) as coarse aggregate on concrete strength. The conclusions derived are as follows;

1. The workability (slump) of fresh concrete stepped down consistently with an increase in the quantity of Tyre Derived Aggregate (TDA).
2. The compressive strength of TDA-concrete decreased progressively with an increase in the percentage proportion of TDA content.
3. The addition of TDA content decreased the density of concrete.
4. The use of TDA content in the production of concrete should not be greater than 5 % for better performance.

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