Journal of Engineering Research and Reports

Volume 24, Issue 6, Page 1-12, 2023; Article no.JERR.96499
ISSN: 2582-2926

Assessing Compressive Strength of Concrete with Waste Automobile Tire and Palm Kernel shells as Aggregates

Eric Boateng [a*], Charles K. Kankam [b], Anthony K. Danso [a], Joshua Ayarkwa [a] and Alex Acheampong [a]

[a] Department of Construction Technology and Management, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana.
[b] Department of Civil Engineering, KNUST, Kumasi, Ghana.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2023/v24i6819

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/96499

Original Research Article

Received: 17/12/2022
Accepted: 20/02/2023
Published: 24/02/2023

ABSTRACT

All throughout the world, millions of end-of-service life automobile tires and Palm Kernel Shells (PKS) are generated as waste that require proper disposal. The reuse of these wastes in concrete is regarded as a novel approach that has environmental, health and performance related benefits. On this basis, the current study was designed to investigate the coupled effect of using both PKS and tire chips as aggregates in concrete mixes on the compressive strength and other properties of concrete. A total of twenty-one (21) concrete mixes containing different volumes of PKS and tire chips as a partial to full replacement of the conventional crushed granite aggregates were prepared to evaluate their impact on the fresh (i.e. slump) and hardened (i.e. density and compressive strength) properties of the concrete at 7, 14, 21, 28, 56 and 90days of curing. The results showed that there is a systematic decrease in compressive strength, workability and density of concrete with increase in tire (T) and PKS (P) content. However, up to 50% total aggregate replacement

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**Corresponding author: Email: Ekboateng1@gmail.com;*

(TAR) level, adequate compressive strength can be achieved for structural purposes. At this optimum point, the mix with P75T25 recorded a compressive strength of 13.27 N/mm^2 which represents about 44% of the strength of the control mix. Generally, the inclusion of PKS aggregates improves compressive strength and decrease the rate of strength reduction.

Keywords: Rubberised concrete; palm kernel shell; compressive strength; waste materials.

1. INTRODUCTION

The Goal twelve (12) of the Sustainable Development Goals (SDGs) of the world, seeks to achieve the sustainable management and efficient use of natural resources and the environmentally sound management of waste materials to reduce their adverse impacts on the ecosystem and human health [1]. However, the achievement of these goals is threatened by the increasing accumulation of generated solid waste and the fast depletion of natural resources to meet the huge demand for concrete [2,3]. Regarding the latter, an estimated excess of about 10 billion metric tons of concrete is reported to be produced globally each year for the construction of various building and civil engineering structures [4]. This huge demand for concrete has resulted in the exploitation of natural resources such as sand and stones etc. to serve as ingredients for concrete and mortar. With each passing day, these mineral resources keep depleting prompting research into finding alternative construction materials that are sustainable, durable, user- and eco-friendly and more importantly economically affordable to be used for the production of concrete to preserve the needs of future generation.

In addition to the above, solid waste generation has become another global issue that needs to be addressed to fulfil the SDGs. Globally an estimated 12 billion tonnes of solid wastes were generated in 2002 from sources such as agricultural processes (e.g. palm kernel shell), used materials (e.g. waste automobile tires, glass, plastics, papers etc.) and industrial by-products (e.g. steel slags) [5,6]. The burning or disposal of these wastes at landfills contaminate land, air and water bodies thereby posing severe health and environmental risks [7]. With the figure expected to reach 19billion by 2025 [8] and 27 billion by 2050 [9], immediate measures are required to manage the teeming waste.

The reuse of waste materials as ingredients in concrete is hailed by many as a step in the right direction. The benefits are twofold: first it provides alternative sustainable material for concrete and then secondly, offers a strategic eco-friendly means of disposing the waste materials. Among these teeming wastes, end-of-service life automobile tire and PKS have been identified as possessing good characteristics that are required of aggregates for concrete [10-19]. This has led into various research studies geared towards investigating the physio-mechanical and durability properties of concrete produced from these wastes.

Tire is processed into crumb rubber or chips and used as fine or coarse aggregates to produce what is known as rubberised concrete. Eldin and Senouci [18], Khatib and Bayomy [19] among other earlier investigations on rubberised concrete (RC) established that, tire rubber is a good material for concrete due to its high impact resistance, ductility, toughness, sound and energy absorption capacities compared to normal concrete (NC). Jie et al. [20] also verified that the damping ratio of RC is more than normal concrete and this is beneficial in designing structures under dynamic loads.

Subsequent investigations looked at the mechanical [20-23], durability [24-27] and permeability [28] properties of rubberised concrete. From these studies and recent review publications [10,12], related to the properties of RC and its structural applications it was established that RC has lower strength properties. For instance, Khan and Singh [23] observed 15% and 43% decrease in compressive and tensile strengths respectively with a partial replacement of sand (0-15%) by tire crumb rubber. Notwithstanding the above, other studies have demonstrated that with proper treatment of the tire aggregates [29,30] and the use of supplementary cementitious materials such as fly ash, silica fumes [31], it is possible to produce RC of adequate strength for structural applications.

Regarding PKS, previous studies have investigated the physical characteristics of PKS as aggregates in concrete [13-17], evaluated the strength properties [16,17,32] and structural behaviour [14,33] of PKS concrete. From these studies, it was established that PKS concrete (PKSC) has similar characteristics and structural behaviour as normal weight concrete. However, just like other waste materials, strength decreases with an increase in PKS content. Teo et al., [15] achieved a compressive strength of 22MPa while Alengaram et al. [16] obtained a compressive strength of 37MPa with the incorporation of silica fumes and fly ash. These studies among others have demonstrated that it is possible to produce PKSC of adequate strength to meet the minimum required 17MPa cylindrical compressive strength (equivalence of 20MPa cube compressive strength) set by ACI 318 [34] for structural lightweight concrete.

Teo et al. [33] investigated the flexural behaviour of reinforced concrete beams made from oil palm shell (OPS) aggregates and found that OPS concrete beams exhibited the same flexural behaviour as other lightweight concretes and their deformation characteristics were within the allowable limits specified by current Codes of Practice. Acheampong et al. [14] also made similar observations in a study. In addition to the above, PKSC has also been found to have lower density, thereby making it a good material for lightweight concrete construction.

As per the above literature review, it is evident that researchers have directed great attention to investigating the utilization of tire and PKS in concrete as a solution to their disposal and to produce green concrete. That notwithstanding, there is limited empirical studies that assessed the coupled effect of having these two unique waste materials (i.e. PKS and tire) in the same concrete composite. Nordin et al., [35] investigated the performance of concrete mix in the presence of tyre particle and palm oil fuel ash. However, in this study, the PKS ash was used as binder (cement) and pozzolana in the concrete mix. The behaviour and overall performance of concrete is significantly determined by its constituent materials most especially the aggregates. In view of this, concrete that incorporates both PKS and tire as aggregates is a unique product with different performance characteristics. The aim of the current study was to explore the potential of using both PKS and tire as aggregates in the same concrete mix and evaluate their impact on the strength properties of concrete. Given the large volumes of solid waste being produced each year, this study sought to advocate for the use of multiple waste materials to produce concrete of good strength at lower cost for construction.

2. EXPERIMENTAL PROGRAM

2.1 Materials

The materials used for the study included crushed granite stones (maximum size 14mm), pit sand (nominal size 4.75 mm), palm kernel shell, worn-out automobile tire and ordinary Portland cement (Class CEM I 42.5 R). The PKS aggregates had a maximum particle size of 14mm and shell thickness of 6mm. The tire had bulk weight of 120kg -190kg and was cut into an evenly distributed size aggregates with a maximum size of 14mm. All the materials were obtained locally in Ghana. The aggregates were air dried in the laboratory (at temperature: 23 ± 2^{o}C and relative humidity: 50 ± 5%). The particle size distributions of the coarse and fine aggregates were determined through sieve analysis. Fig. 1 shows pictures of the aggregates used for the experimental program.

2.2 Preparation of Aggregates

The worn-out automobile tires were shredded manually using cutlass and knife into the required sizes. The shredded tire particles were then washed with potable water to clean off all impurities and subsequently soaked in 10% Sodium Hydroxide (NaOH) solution for 30mins to enhance its bond with the cement paste as recommended by previous studies such as Si et al. [36]. The solution was prepared by diluting 500g of NaOH pellets in 5000ml of deionized water.

Similarly, the PKS aggregates were washed and subsequently soaked in water for about 20minutes before being used. This was necessary to reduce the absorption of the free water required for cement hydration by the PKS aggregates [14].

2.3 Study Variables

The current study was designed to investigate the effect of partial to full replacement of granite coarse aggregate with both PKS and tire rubber aggregates on strength development of concrete. Consequently, three different coarse aggregates were considered: crushed granite stones, waste tire chips and palm kernel shell aggregates. The total aggregate replacement (TAR) level (i.e. the volume of granite coarse aggregate replaced in the mix), varied from: 0%, 25%, 50%, 75% and

100%. For each TAR level, five combinations of the PKS and tire were considered: P0T100; P25T75; P50T50; P75T25 and P100T0. Consequently, concrete with identification “R50-P25T75” implies 50% of the volume of granite aggregates in the control mix, is being replaced with PKS and tire aggregates such that 25% and 75% of the replaced volume is made of PKS and tire particles respectively. Thus, based on the above, a total of 21 concrete mixes were designed. The fine aggregate volume and water-cement ratio were however kept constant in all the mixes. Table 1 shows details of the mix proportions.

2.4 Mix Design, Sample Preparation and Curing

A normal Portland cement concrete, with a 28-day targeted compressive strength of 20MPa was designed as the control mix in accordance with the Department of Environment (DOE) [37] method. Based on the mix proportions shown in Table 1, the quantity of concrete required for each test was batched using the mass of the constituent materials and the mixing done using a mechanized concrete mixer. Each mixing cycle took approximately 4 minutes while slumps were measured for each mixing cycle to ensure consistency.

The fresh concrete was cast into the respective moulds and compacted in two layers using a vibrating table and finished smooth using a hand trowel. Immediately after the casting, specimens were covered with polythene sheets for 24 ± 2 hours at a laboratory room temperature of 23 ± 2 ^{o}C. This was done to protect the fresh concrete from moisture loss while setting and hardening for handling. After curing for 24 ± 2 hours in the moulds, the concrete specimens were stripped and placed inside a water tank filled with water (at a temperature of 23 ± 2 ^{o}C) for a specified number of curing days.

(a) (b) (c) (d)

Fig. 1. (a) Fine aggregate (b) Granite coarse aggregates (c) Tire aggregates (d) Palm Kernel shells

Table 1. Details of concrete mix proportions

Concrete Type	TAR	Mix ID	Cement (kg/m^3)	w/c	Mix proportions C:FA:CA:P:T
NWC (Control)	0%	R0-P0T0	462	0.45	1: 1.5: 2.5: 0: 0
PKS Modified Rubberized Concrete	25%	R25-P0T100	462	0.45	1: 1.5: 1.875: 0: 0.4
		R25-P25T75	462	0.45	1: 1.5: 1.875: 0.106: 0.301
		R25-P50T50	462	0.45	1: 1.5: 1.875: 0.202: 0.20
		R25-P75T25	462	0.45	1: 1.5: 1.875: 0.318: 0.1
		R25-P100T0	462	0.45	1: 1.5: 1.875: 0.424: 0
	50%	R50-P0T100	462	0.45	1: 1.5: 1.249: 0: 0.802
		R50-P25T75	462	0.45	1: 1.5: 1.249: 0.212: 0.601
		R50-P50T50	462	0.45	1: 1.5: 1.249: 0.424: 0.401
		R50-P75T25	462	0.45	1: 1.5: 1.249: 0.636: 0.2
		R50-P100T0	462	0.45	1: 1.5: 1.249: 0.848: 0
	75%	R75-P0T100	462	0.45	1: 1.5: 0.625: 0: 1.203
		R75-P25T75	462	0.45	1: 1.5: 0.625: 0.318: 0.902
		R75-P50T50	462	0.45	1: 1.5: 0.625: 0.636: 0.601
		R75-P75T25	462	0.45	1: 1.5: 0.625: 0.954: 0.301
		R75-P100T0	462	0.45	1: 1.5: 0.625: 1.272: 0
	100%	R100-P0T100	462	0.45	1: 1.5: 0: 0: 1.603
		R100-P25T75	462	0.45	1: 1.5: 0.421: 1.203
		R100-P50T50	462	0.45	1: 1.5: 0: 0.848: 0.802
		R100-P75T25	462	0.45	1: 1.5: 0: 1.272: 0.401
		R100-P100T0	462	0.45	1: 1.5: 0: 1.696: 0

C:FA:CA:P:T = Cement: Fine Aggregate:Granite Coarse Aggregate: Palm kernel shells aggregate: Tire aggregate; R = Total Aggregate Replacement level

2.5 Test Procedures

2.5.1 Test on fresh properties of concrete

Slump test was carried out to assess the workability of the various concrete mixes in accordance with ASTM C143 [38] specifications. The fresh concrete was filled into a standard frustum of a cone in 3 layers with each layer being compacted 20 times with a rod. The top of the flask was levelled. Immediately after removing the mould, the drop in height of the fresh concrete was measured using a metallic ruler. To facilitate the ease of removal of the mould**,** formwork releasing agent/oil was applied to the inside surface of the mould.

2.5.2 Compressive strength

The mean compressive strength was determined by testing 150 x 150 x 150 mm concrete cubes in compression in accordance with BS EN 12390-3 [39]. The specimens were tested in water saturated condition after initial curing in water for 7, 14, 21, 28, 56 and 90days days. Five (5) cubes per concrete mixture were selected and crushed using a 1000-kN capacity hydraulic Universal Testing Machine (UTM) at a loading rate of 0.3 MPa/sec. at the Civil Engineering Laboratory of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana (Fig. 2). The compressive strength of the concrete was evaluated using the following formula.

$$f_{cu} = (F/A) \quad (1)$$

where f_{cu} = cube compressive strength of test specimen(N/mm^2), F = failure load applied (N), A = contact surface area of test specimen (mm^2).

2.5.3 Density of hardened concrete

The density of the hardened concrete specimen was determined for each concrete mix. The specimens were allowed to air-dry for about 4 hours after they had been removed from the curing tanks. The weight of each specimen was measured using an electronic scale as shown in Fig. 3. The densities were calculated by dividing the weight of each specimen by its volume.

Fig. 2. Compressive strength test

Fig. 3. Measuring the weight of the test specimen

3. RESULTS AND DISCUSSION

3.1 Workability of the Fresh Concrete

Through the slump test, the workability of the PKS rubberised concrete composite was found to decrease with increase in PKS and tire contents (see Table 2). The control mix had a slump of 60mm but with the inclusion of PKS and tire aggregates, the value reduced to an average of 35mm for TAR ≤ 50% and decreased further as the TAR increased beyond 50%. This reduced workability may be attributed to the increased friction between the rough corrugated particle surface of the tire or PKS and the other ingredients of the fresh concrete. The above finding is consistent with the experimental results of Batayneh et al. [40], Onuaguluchi and Panesar [41], and Zhang et al. [42] who also observed a decrease in slump with increase in rubber content. It was also evident from the experimental results that admixtures should be used to improve workability for PKS rubberised concrete mixes with lower water-cement ratios as the absence of admixture reduced the general values of the slump. As posited by Collepardi et al. [43] and Neville and Brooks [44] superplasticizers are necessary to improve concrete's workability and performance. This is particularly important for concrete that uses lightweight aggregates such as PKS with high water absorption [45,46].

In addition to the above, it was observed that concrete with PKS and tire blend has better workability compared to mixes with only PKS or tire aggregates. Thus for PKS rubberised concrete composites, the use of admixtures and pre-soaking of the PKS aggregates in water is necessary to improve workability.

3.2 Density of the Hardened Concrete

With the emergence of high rise buildings in which the density (unit weight) of concrete is crucial, the preference for lightweight concrete is undoubtedly a necessity. From Fig. 4, the density of the PKS rubberized concrete was found to decrease substantially with the increase in tire and PKS content. The mixes with TAR ≤ 50% had densities more than 2000kg/m^3 conforming to normal weight concrete (NWC) whereas those with TAR > 50% were lightweight concrete (LWC) with densities less than 2000kg/m^3 [47,48]. Specifically, the control specimen had density of 2415kg/m^3 which decreased with an increase in PKS and tire content.

A reduction of 33% and 24% was recorded when the entire volume of the granite aggregate in the control mix was fully replaced with tire and PKS aggregates respectively. The general reduction in density can be attributed to the lower specific gravity of the PKS and tire aggregates as well as the air entrapping capability of rubber aggregates [10,15,16]. Thus, as more of the normal weight granite aggregate is replaced by lightweight PKS or tire aggregates, the density of the resultant concrete also reduces. This results conform with the findings of Alengaram et al. [16], Shafigh et al. [17] and Guyinisi et al., [31] who observed a reduced density for concretes that incorporate PKS or tire as aggregates. This decrease in density makes PKS rubberized concrete useful material for light weight structural members.

Table 2. Slump of the concrete mixes

SN.	Mix ID	Concrete slump (mm)	SN.	Mix ID	Concrete slump (mm)
1	0R-P0T0	60	12	75R-P0T100	15
2	25R-P0T100	37	13	75R-P25T75	19
3	25R-P25T75	39	14	75R-P50T50	29
4	25R-P50T50	43	15	75R-P75T25	42
5	25R-P75T25	43	16	75R-P100T0	35
6	25R-P100T0	38	17	100R-P0T100	10
7	50R-P0T100	25	18	100R-P25T75	20
8	50R-P25T75	29	19	100R-P50T50	32
9	50R-P50T50	35	20	100R-P75T25	18
10	50R-P75T25	37	21	100R-P100T0	30
11	50R-P100T0	28			

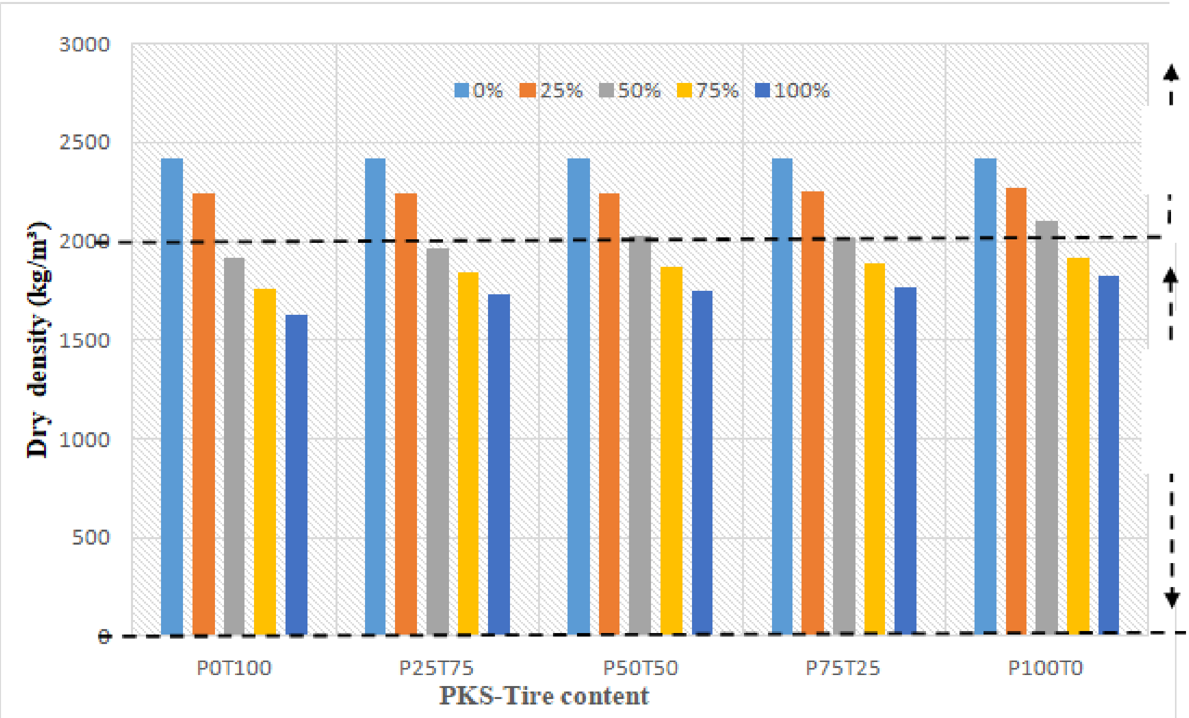

Fig. 4. Air dried densities of the PKS rubberised concrete composite

3.3 Compressive Strength

Figs. 5 and 6 show variations of compressive strength with changes in the Total Aggregate Replacement (TAR) and age of curing respectively. From Fig. 5, there is a systematic decrease in compressive strength with increase in the total aggregate replacement level. At 0% TAR level, the 28-day compressive strength of the control specimen was 21.27 N/mm^2 and it decreased gradually as the volume of PKS and tire in the concrete mix increased. Generally, the rate of decrease in strength is lower for mixtures containing PKS aggregates than those with tire aggregates. In other words, the addition of PKS aggregates to tire in a concrete mix improves strength. At 25% TAR level, the mix with P0T100 recorded a compressive strength of 11.47 N/mm^2 but increased to 14.78, 18.48, and 20.41 N/mm^2 respectively when 25%, 50% and 75% of the volume of the tire was replaced with PKS aggregates (see mix ID P25T75, P50T50 and P75T25). Similarly, at 50% TAR level, the mix with P0T100 recorded a strength of 5.51N/mm^2, whereas that with P100T0 was 15.437 N/mm^2. Thus a significant improvement in strength is achieved with the inclusion of PKS aggregates. Notwithstanding the above, failure of

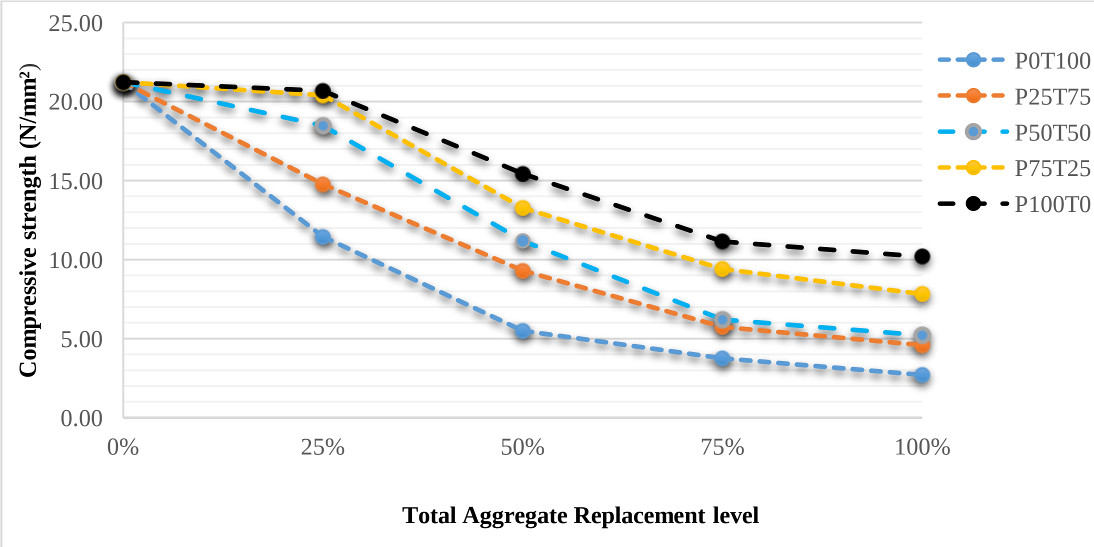

Fig. 5. Effect of total aggregate replacement level on compressive strength

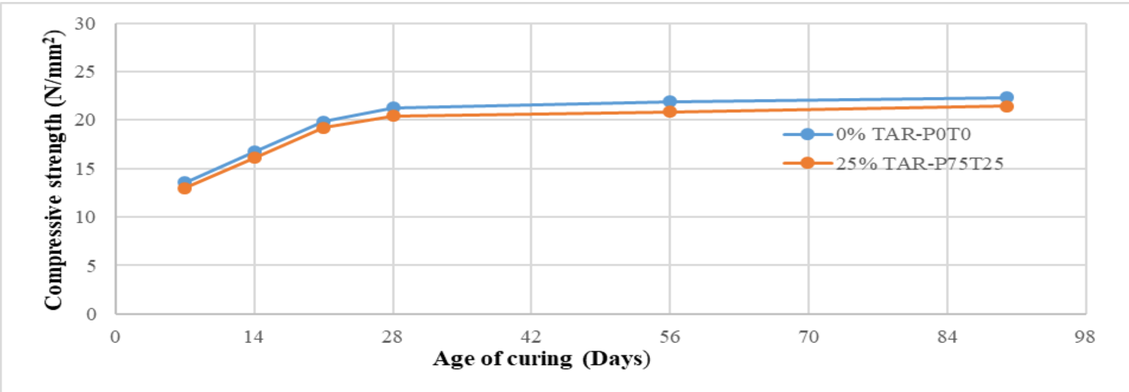

Fig. 6. Compressive strength with age of curing

the concrete becomes more explosive with increase in PKS content hence a blend with tire in the form P25T75 to P75T25 is idea.

Further analysis of the results revealed that, compressive strength of the concrete is directly related to the age of curing (see Fig. 6). For all the mixes, the compressive strength increased rapidly with age until the 28th day after which strength development was gradual until 90 days. Generally, compressive strengths achieved at 28 days were 21.27 N/mm^2 and 20.40 N/mm^2 for the control specimen and the PKS rubberised concrete respectively. The 7-day compressive strengths were 16.7N/mm^2 and 16.1N/mm^2, for the control specimen and the PKS rubberised concrete respectively. Thus, for all the mixes, the 7-day strengths were approximately 79% of the strength gain on the 28th day. Given the low water - cement ratios of the concrete mixes and Ordinary Portland cement class (45.5 R), the strength development during the first 7 days could be attributed to the higher hydration rate and thus strength of the cement paste. On the 90th day, only a marginal 5% and 3% increase in the 28–day strengths were recorded for the normal weight granite filled concrete and the PKS rubberised concrete respectively. Explaining the above, Neville [49], noted that hydration of cement paste usually run its full course by the 28th day and any further strength gain beyond this point is expected to be minimal. Hence the marginal increase in strength beyond the 28 days observed in the current study is consistent with the findings of Neville [49]. The compressive strength of PKS-rubberised concrete can be calculated based on the 28-day strength.

The above trend of reduction in compressive strength with an increase in tire content is consistent with the findings of Eldin and Senouci [18], Romanazzi et al., [50]; Odeyemi et al., [51] and Ghedan et al., [52]. Generally, the reduction in strength as reported by the above studies is linked to factors such as the comparatively weaker bond between aggregates (i.e. tire and PKS) and cement paste which results in non-uniform stress distribution during loading; hydrophobicity and lower specific gravity of rubber aggregates leading to upward movement of rubber particles during vibration, resulting in non-homogeneous concrete and air entrapment in concrete because of hydrophobic nature of rubber aggregates. Besides these, factors such as shape, size and surface texture of the tire and PKS aggregates could contribute to the strength reduction. The results of the current study compare closely with the experimental results of Odeyemi et al., [51] who reported a compressive strength of 14.80N/mm^2 for a mix with w/c of 0.5 and 50% PKS content as against the 15.44N/mm^2 recorded in the current study for similar mix proportion.

4. CONCLUSION

In this study, the effects of used automobile tire chips and palm kernel shell as coarse aggregates on the compressive strength, workability and density of concrete were investigated. For the first time, the overall performance of concrete mixes incorporating these two waste materials up to 100% replacement of the conventional crushed granite coarse aggregate was measured in terms of the compressive strength and fresh properties of the concrete. Based on the results obtained and the analysis thereof, the following conclusions can be made:

1. Incorporating PKS and tire particles in concrete reduces its workability. This reduction is about 33%, 48%, 53% and 63% for mixes with 25%, 50%, 75% and 100% total aggregate replacement respectively. The mixes containing both PKS and tire particles have better workability compared to mixes with either only PKS or tire only. The use of admixtures is therefore recommended especially for lower w/c ratio to improve workability.
2. The density of rubberized concrete decreases substantially with the increase in tyre rubber content due to lower specific gravity and air entrapping capability of rubber aggregates. This characteristic is useful for lightweight structural members. Concrete mixes with TAR ≤ 50% have densities greater than 2000kg/m³ conforming to NWC while those with TAR > 50% are LWAC with densities less than 2000kg/m³. A reduction of about 33% and 24% is expected when granite aggregates are fully replaced with tire and PKS aggregates respectively.
3. There is a systematic reduction in the compressive strength of concrete with an increase in PKS and tire content from 0% to 100%. However, the rate of strength reduction decreases with increase in PKS content. Thus, PKS aggregates can be used to enhance the strength of rubberised concrete.
4. From practical point of view, total aggregate replacement level should not exceed 50% of the total coarse aggregate volume (TCAV) due to the severe reductions in strength beyond this point. At this optimum level, the tire content should not exceed 25% of the TCAV whereas the PKS can be increased up to 75% of the TCAV.

As further research, more extensive work needs to be done in the following areas: (1) Durability properties of this concrete composite under adverse weather conditions such as elevated temperature and chemical attack. (2) The use of these waste materials as both fine and coarse aggregates in concrete

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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