Behaviour of Coconut Shell Aggregate (CSA) Concrete at Elevated Temperature

A. Ibrahim[1] M. J. Garba[2] A. S. J. Smith[3] B. Muhammad[4] S. M. Ishaq[5]
[1]National Space Research and Development Agency, Abuja, Nigeria
[2]Centre for Satellite Technology Development, Abuja, Nigeria
[3]College of Civil Engeering & Architecture, China Three Gorges University, Yichang, China
[4]Faculty of Environmental Sciences, BAZE University Abuja, Nigeria
[5]Department of Civil Engineering, Bayero University Kano, Nigeria

Abstract— This paper attempts to study the mechanical behaviour of coconut shell aggregate (CSA) concrete subjected to elevated temperatures when coconut shell (CS) is used to replace coarse aggregate at 0, 10, 20 and 40% in concrete. The coconut shell used was obtained by breaking the shells into smaller sizes of less than 20mm after the fibres were removed. In order to produce control concrete samples with a minimum compressive strength of 15N/mm^2 at 28 days curing age, mix ratio of 1:2:4 and water-cement ratio of 0.55 were adopted alongside Absolute Volume Method (AVM) to prepare the concrete mix proportions for this research. The specific gravity of the concrete materials were determined as well as the workability of the fresh coconut shell aggregate concrete at various replacement using slump tests. Compressive strength of 48 samples prepared at various CSA replacements using 100mm x 100mm x 100mm cube mould and cured for 28 days was determined after 30 minutes exposure to temperatures of 100, 300 and 500^{o}C. Splitting tensile strength of 18 samples prepared at various CSA replacements using 200mm x 300mm cylinder mould and cured for 28 days was also determined after 30 minutes exposure to 500^{o}C temperature. The results of this study showed that at 10% replacement and 500^{o}C temperature, CSA concrete exhibits good behaviour in compressive strength and splitting tensile strength as it retained 67.3% and 53.7% of its strength respectively; as well as having a higher strength reduction coefficient ($K_c(\theta)$) of 0.673 in compressive strength compared to the 0.60 allowed for siliceous aggregates in BS EN 1992-1-2 [26]. However, slump results showed that CSA concrete has a very low workability. So, CSA can be used up to 10% to replace coarse aggregate in concrete to serve in non-load primary application areas.

Keywords: Coconut Shell, Compressive Strength, Concrete, Elevated Temperature, Splitting Tensile Strength

I. INTRODUCTION

Concrete is the most commonly used construction material in the world today. Throughout human history, the use of concrete as a building material has contributed significantly to the built environment. Concrete has been used in the construction of durable bridges, roads, water-supply structures, housing and commercial buildings to give people as social foundation, a thriving economy and serviceable facilities for many years[1]. This important construction material according to [2] consists, in its most common form, of Portland cement, fine aggregates, coarse aggregates and water; with each of these components contributing to the strength their concrete possesses.

Aggregate materials usually form a significant proportion of conventional concrete. These materials act as fillers or volume increasing components in concrete with some good qualities such as: sufficient toughness to withstand impact and vibratory loads, strong enough to bear compressive and normal tensile loads, free from impurities that can affect concrete quality, and its capability of producing an easily workable plastic concrete mixture [3]. Various types of aggregates (crushed stones, gravels, blast furnace slag, broken bricks) have been used successfully in producing good concrete. The use of these types of aggregates also helps to reduce environmental pollution and sanitise the application environment [3].

Coconut shell is an agricultural/industrial waste by-products from the coconut palm industry and causes nuisance to the environment when not properly disposed [4]. The quantity of solid waste is expanding rapidly. It is estimated that the rate of expansion is doubled every ten years. This is due to the rapid growth of population and industrial sector [5]. This waste material (coconut shell) is very light when compared to crushed granites or gravels as this unique property makes it a suitable material for possible use in concrete production to improve essential concrete properties and to reduce the environmental challenges resulting from its disposal.

Even though concrete is the most commonly used construction material, it exhibits some major setbacks in its properties which makes it not to always fulfil some crucial requirements in service [1]. Prominent amongst its setbacks is its proneness to elevated temperature. Concrete when exposed to high temperature (especially fire), deteriorates in its properties. Of particular importance are: loss in compressive strength, cracking and spalling of concrete [6], destruction of the bond between cements and aggregates and the gradual deterioration of the hardened cement paste. [7] opined that a concrete structure subjected to high temperatures will fail in many of different ways such as colour, compressive strength, elasticity, concrete density and surface appearance. [8] also explained that Strength loss is to a large extent influenced by the aggregate type and the strength of the concrete at room temperature. The ability of concrete to resist weathering actions, chemical attacks, abrasion, fire or any other process of deterioration makes it have good durability property. Concrete is termed durable when it keeps to its form and shape within the allowable limits while exposed to different environmental conditions [6]. The effect of increase in temperature on the strength of concrete is not much pronounced up to a temperature of about 250^{o}C but above 300^{o}C at which definite loss of strength takes place [9].

This research therefore aims to utilize coconut shell as coarse aggregate to replace crushed granite in concrete production and to evaluate its mechanical behaviour when subjected to elevated temperatures beyond 25ºC.

II. MATERIALS AND METHODS

A. *Materials*

Ordinary Portland cement (OPC) manufactured by Dangote with a specific gravity of 3.15 was used for this research. The chemical composition of the cement conformed to the specification of [10] for common cements. The coarse aggregates used were crushed granite of nominal size of 20mm obtained from Rano quarry site in Kano state, Nigeria; and coconut shell aggregate (CSA). The coconut shell was obtained from a local vendor in Kano, Nigeria and the fibre was removed, the shell was air dried and broken into smaller sizes of not greater than 20 mm before it was used. The coarse aggregate was found to conform to [11]. The fine aggregate used was clean river sand from Chalawa River in Kumbotso Local government area of Kano state, Nigeria; and it conformed to [11]. Portable clean water supplied to Civil Engineering laboratory by Bayero University Kano was used; and it conformed to [12].

B. *Methods*

1) *Specific Gravity*

This test was conducted on cement, sand, crushed granite and coconut shell in accordance with [13]. The specific gravity of cement, sand, crushed granite and coconut shell is shown in Table 2.

2) *Concrete Mix Proportions and Specimen Preparations*

Concrete mix ratio of 1:2:4 and water-cement ratio of 0.55 was used to obtain concrete mix proportions using Absolute Volume Method (AVM) to study the behaviour of coconut shell aggregate (CSA) concrete subjected to elevated temperature. The concrete mix proportions were carefully batched by weight in line with [14]. The concrete specimens used for compressive strength test were cast using 100mm x 100mm x 100mm cube mould; while the specimens used for splitting tensile test were cast using 200mm x 300mm steel cylinder mould. The concrete mix proportion is shown in Table 1.

CS content (%)	Cement (kg)	Coconut shell (kg)	Granite (kg)	Sand (kg)	Water (kg)
	Concrete mix proportions for compressive strength test				
0	6.911	0.000	20.249	12.440	3.801
10	6.911	2.025	18.224	12.440	3.801
20	6.911	4.050	16.199	12.440	3.801
40	6.911	8.100	12.149	12.440	3.801
CS content (%)	Concrete mix proportions for splitting tensile strength test				
0	6.511	0.000	19.076	11.719	3.581
10	6.511	1.908	17.168	11.719	3.581
20	6.511	3.815	15.261	11.719	3.581
40	6.511	7.630	11.446	11.719	3.581

Table 1: Concrete quantities at various replacement of coconut shell aggregate (CSA)

3) *Slump of Coconut Shell Aggregate Concrete*

The slump of freshly mixed coconut shell aggregate concrete was determined in accordance with [15] and the result is shown in Fig. 1.

4) *Compressive Strength of Coconut Shell Aggregate Concrete*

The compressive strength of coconut shell aggregate concrete was carried out after curing for 28 days in accordance with [16] using Avery Denison Compression Machine of 2000kN load capacity at constant compression rate of 15kN/s. The test was done after exposing the 100mm x 100mm x 100mm concrete cube specimens to temperatures of 25, 100, 300 and 500ºC for 30 minutes. The compressive strengths result is shown in Fig. 2.

5) *Splitting Tensile Strength of Coconut Shell Aggregate Concrete*

This test was conducted on coconut shell aggregate concrete after 28 days curing in accordance with [17]. It was carried out after 30 minutes exposure of the 200mm x 300mm steel cylinder concrete specimens to 500ºC temperature. The splitting tensile strength result is shown in Fig. 3.

III. RESULTS AND DISCUSSIONS

A. *Specific Gravity*

The specific gravity of cement, sand, crushed granite and coconut shell as shown in Table 2 reveals that the specific gravity of sand and crushed granite are within the limit of 2.4 and 3.0 specified for natural aggregates [18]. The specific gravity of coconut shell is outside the limit of specific gravity specified for natural aggregate and it is 15.22% less than the crushed granite's used.

Materials	Specific Gravities
Cement	3.15
Sand	2.56
Crushed granite	2.65
Coconut shell	2.30

Table 2: Specific gravity of concrete making materials

B. *Slump of Coconut Shell Aggregate Concrete*

The slump of coconut shell aggregate concrete as presented in Fig. 1 decreases as the percentage of coconut shell content increases, with 83.33% difference between 0% and 10% replacement of coarse aggregate with coconut shell. The sharp decrease in slump may be due to the rough and irregular shape of coconut shell aggregate with increased surface area, thereby requiring more water for the same workability [19]. The slump result up to 20% coconut shell content shows that coconut shell aggregate concrete is within the range of very low workability (5-10mm) as described in [20].

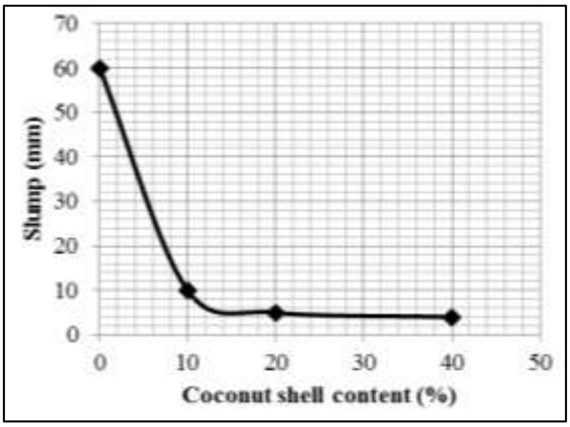

Fig. 1: Slump of coconut shell aggregate concrete

C. *Compressive Strength of Coconut Shell Concrete*

The compressive strength of coconut shell aggregate concrete as shown in Fig. 2 decreased with increase in both coconut shell content and temperature. This may be due to the easily combustible nature of coconut shell which favours steam-pressure build up followed by high tensile stress in agreement to Ugbaja as cited by [21]; [21] and [22] findings that the compressive strength of concrete decreases as temperature increases: due to the destruction of active strength generating ingredients like cement and aggregates; due to the rapid loss of moisture which prevents long term hydration; and due to the rapidly changing temperature field which causes rapid changes in stress-strain relationship respectively. It is clear from the results obtained that the fire exposure duration of 30 minutes has a significant effect on the residual strength of the control concrete as well as all percentage replacement of coarse aggregate with coconut shell at all temperature above room temperature (that is 25ºC). The percentage strength loss of the normal concrete at 500ºC is 20.7% whereas that at 10, 20 and 40% is 32.7, 42.2 and 76.1% respectively. The high percentage increase in strength loss with higher replacement content of coconut shell could be due to the stress generated at the interface between the coconut shell-granite aggregate and the hardened cement paste on heating [23]. Therefore, based on the compressive strength property of coconut shell aggregate concrete, coconut shell can be used up to 10% to partially replace coarse aggregate for production of light weight concrete to serve in non-load primary application areas since it retains up to 67.3% of its strength at 10% replacement.

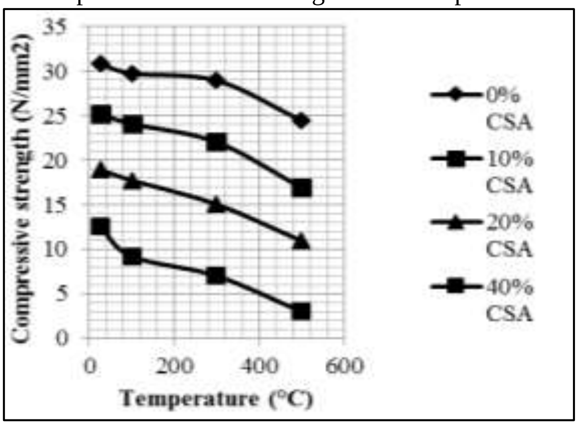

Fig. 2: Compressive strength of coconut shell aggregate concrete

D. *Splitting Tensile Strength of Coconut Shell Concrete*

The splitting tensile strength of coconut shell aggregate concrete decreased with increase in coconut shell content and temperature from 25ºC to 500ºC as shown in Fig. 3. The decrease in spitting tensile strength may be attributed to the weak microstructure of coconut shell aggregate concrete which allows initiation of microcracks [24] as the temperature is raised from 25ºC to 500ºC in line with [25] research which explained that cracking in concrete is generally due to tensile stresses and structural damage of the member in tension generated by progression in microcracking. It can be seen that coconut shell aggregate concrete deteriorates at a high rate when tested in tension as it lost 46.3% of its tensile strength at 10% replacement and 500ºC. This indicates that severe microcracking occurred in the coconut shell aggregate concrete due to fire.

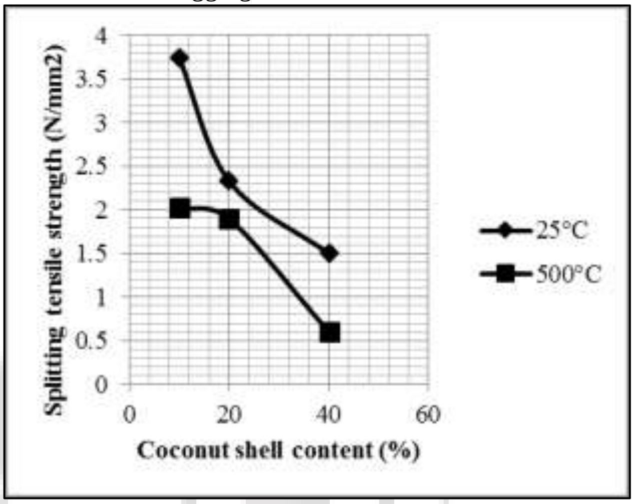

Fig. 3: Splitting tensile strength of coconut shell aggregate concrete

IV. CONCLUSION

The behaviour of coconut shell aggregate (CSA) concrete at elevated temperature based on its mechanical properties showed that CSA can be used in application involving elevated temperatures. The compressive strength loss at 300ºC was not very significant (12.4% and 20.5% for 10% and 20% CS content respectively) up to 20% coconut shell replacement when compared to 0% coconut shell replacement of 6.1%. Also, the splitting tensile strength loss at 500ºC was below 50% at 10% coconut shell replacement. From the results obtained, coconut shell can be used up to 10% to replace coarse aggregate for production of light weight concrete prone to fire accidents.

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