

Effect of Coconut Shell Aggregate on Shrinkage Cracking in Concrete using Modified Ring Test

I. Ismail¹, A. Ocholi², and J. O. Bashir³

¹Department of Civil Engineering, Umaru Ali Shinkafi Polytechnic Sokoto, Nigeria.

^{2,3}Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria.

*Corresponding author email: ismailisahillela85@gmail.com

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ABSTRACT

This study investigates the effect of coconut shell aggregate (CSA) as partial replacement for natural coarse aggregate on the restrained shrinkage cracking behavior of concrete. Concrete specimens with 0%, 10%, 20%, and 30% CSA were cast to simulate restrained drying shrinkage conditions in accordance with AASHTO PP34-99. Crack initiation, width and length were monitored for 70 days. Results show that increasing CSA content delayed crack initiation and reduced crack severity. Crack width and length reduced from 0.2mm and 87mm in control concrete to 0.15mm and 72mm respectively when 10% CSA was added. Notably, at 20% and 30% CSA, no shrinkage cracks were observed, indicating a significant improvement in cracking resistance. Split tensile strength decreased by 8.5%, 13.4% and 17.1% for 10%, 20%, and 30% CSA respectively. These findings demonstrate the potential of CSA as a sustainable alternative aggregate that enhances concrete durability under restrained shrinkage conditions.

Keywords: Coconut Shell Aggregate, Drying Shrinkage, Crack Behavior, Restrained Shrinkage, Sustainable Concrete, Lightweight Aggregate



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INTRODUCTION

A Portland cement concrete is a quasi-brittle material by nature with a low capacity for deformation under tensile stresses (Muhammed, 2017). But it provides structures with strength, rigidity and resilience from deformation, these characteristics result in concrete structures lacking the flexibility to move in response to environmental or volume changes (Bluey, 2019). The change in volume that concrete undergoes during the hydration process is known as shrinkage (Zeeshan, 2015). This shrinkage is a complex physical material response that concrete displays

and often affects concrete in an adverse manner, it depends on many factors, including the quantity of cement, properties of aggregates, the mixture composition, temperature and the age of concrete, relative humidity of the environment and the size of the structure (Idris et al., 2015; Zakiah et al., 2010). Shrinkage of concrete would not be a major concern to structural engineers if concrete members were free to shrink without restraint, Concrete members that often contract are restrained by its supports, bonded reinforcement or adjacent structure, each of these restraints involved the

imposition of a gradually increasing tensile force on the concrete, which may lead to time-dependent cracking, increases in deflection and widening of existing cracks. The larger shrinkage at the surface causes cracks to develop, that may with time penetrate deeper in to the concrete (zakiah et al., 2010; Sadiqu & sristi 2016) and causes the corrosion of reinforcement through carbonation, which neutralizes the alkaline nature of the hydrated cement paste (Ozgun, 2015).

As concrete production increases due to high growth of infrastructure, alternate waste materials in place of aggregates were introduced not only to protect environment but also to makes concrete a sustainable and environment friendly construction material. Many studies had shown that agricultural waste coconut shell can also be used as coarse aggregate for lightweight concrete production, because of its less density and impact value (Gunasekaran & kumar 2008). The use of coconut shell as aggregates has created a need for knowledge concerning fundamentals and performance characteristics of concrete made with this material. In all types of construction, it is essential to produce a concrete that is durable. The materials used must perform the required function under all conditions to which they are exposed. The acceptance of new materials then depends on their ability to perform as designed under the conditions they encounter.

Previous studies have focused mainly on the mechanical strength of CSA concrete, but limited attention has been given to its restrained shrinkage behavior. Therefore, this study aims to evaluate the shrinkage cracking characteristics of CSA concrete using a modified ring test method, comparing it with conventional concrete to determine the influence of CSA content on crack development and resistance.

MATERIALS AND METHODS

Materials

Materials for this research experiments were locally sourced from the immediate environment in sokoto state. BUA Sokoto brand of ordinary Portland cement (OPC) of grade 42.5N conforming to BS and ASTM standards commonly used in concrete, free from hard lumps and of uniform colour used as the binder was bought from local cement market in Sokoto state. The fine and coarse aggregate (natural stone) was obtained from a nearby local aggregate site. The maximum size of coarse aggregate for this experiment was 20mm. Water used for the mixture and curing of concrete in the experiment is potable water from drinking water tap confirmed to be free from impurities/injurious amount of deleterious materials that can lead to concrete distress. Coconut shell aggregate was obtained as a waste from a coconut seller in Gawon Nama area in Sokoto. The coconut shell was manually crushed into approximately equal sizes.

Batching and Mixing

The mix proportion which was obtained from the trail mix of water/cement ratio for the experiments was (1:2:4) by weight with a water/cement ratio of 0.5%. In this research, only 0%, 10%, 20% and 30% of the volume of the coarse aggregate was replaced by equivalent volume of coconut shell and mixing was manually done in the laboratory. The material mix proportion is as shown in (Table 1).

Specimen preparation and test methods

Split tensile strength test

The tensile strength properties of concrete were determined using splitting tensile test in accordance with ACI Manual-544.1R. Tensile strength for concrete specimen is defined as the tensile stresses developed due to application of the compressive load at which the concrete specimen may crack. The samples were cast in cylinder Mould of size 150 mm x 150 mm. Nine (9) specimens were prepared for each mix and subjected to water curing for a period of 28 days, and the Tensile strength was measured at 7, 14 and 28 days respectively. The split tensile strength of concrete is given as below.

$$T_{sp} = \frac{2F}{\pi} \cdot d \cdot l$$

Where F is value of load force at macro cracking, and a is length of cube edge,

Restrained drying shrinkage test

Preparation of moulds

To measure the restrained drying shrinkage that develops in concrete, the modification of ring test in accordance with AASHTO PP34-99 was used. A total of 36 specimens of 400 mm square column sections with ring at the Centre were prepared. The number of specimens for each mixture is 9. The mould was made from plywood where the thickness of the plywood is about 13mm. The mould has cross-section 400 mm x 400 mm and the height of column (H) is 150mm. Concrete is cast around the square plywood and a thick ring made from a sheet metal. Because the ring is stiffer than concrete, volume change of concrete is prevented to a certain extent which may induce stresses in the concrete and causes concrete to crack, which also depends on the ring's dimensions and properties of mix. Ring of different diameters namely 150mm, 250 mm and 350mm was used and glued at the Centre of specimen. The radial drying of square column specimens was conducted in the laboratory atmosphere with 85%RH and at 20°C. Drying was only allowed from the outer circumferential surface. The large depth-to-thickness ratio was chosen to provide uniform drying across the thickness (Table 2 and Figures 1 and 2).

Table 1: Concrete mix proportion for the experiment.

Ref.	Water/ cement ratio	Water (kg)	Cement (kg)	Fine Aggregate. (kg)	Coarse Aggregate. (kg)	Coconut shell Aggregate (CSA) Replacement by (volume).		
						8.05kg 10%CSA	16.10kg 20%CSA	24.15kg 30%CSA
Values	0.5	11.5	23	57.5	80.5			

Table 2: Number of specimens for restrained shrinkage cracks.

Dimension of Pipes		Concrete Mix				Total
		Mix 1	Mix 2	Mix 3	Mix 4	
Height (H) (mm)	Core Dia. (D) (mm)	Coconut shell 0%	Coconut shell 10%	Coconut shell 20%	Coconut shell 30%	
150	150	3	3	3	3	
150	250	3	3	3	3	
150	350	3	3	3	3	
Total		9	9	9	9	36

**Figure 1:** Modified ring setup for D350**Figure 2:** Different ring diameters

Shrinkage observation

After 24 hours, the wooden moulds were removed and the Rings remained, the crack was checked every day for the first week and once a week thereafter up to 10 weeks as well as recording the temperature and relative humidity of the environment.

Crack measurement

All the cracks appeared was measured in terms of length and width. The crack lengths were measured manually using thread and measuring tape and the crack width was measured using crack width ruler.

Split tensile strength

Figure 3 shows that the split tensile strength of concrete follows the same pattern with compressive strength, having tensile strength values as 2.46 Mpa, 2.25Mpa, 2.13Mpa and 2.04Mpa for 0%, 10%, 20% and 30% respectively. With the addition of 10%, 20% and 30% CS,

there is a decrease in split tensile strength values, representing 8.54%, 13.41% and 17.07% lower than the control concrete. The outcome of this findings is also in accordance with that of (Amarnath & ramachandrudu 2012; Trokon et al., 2021; Sunday et al., 2019; Sandeep et al., 2017; Alif et al., 2017; Jerim et al., 2016; Kalyanapu et al., 2015).

The effect of coconut shell on the restrained shrinkage behavior of concrete

It can be seen in (Table 3) that different diameter rings show different shrinkage behavior. In Concrete columns with diameter ring D150 and D250 for all the concrete mix, no cracks and shrinkage were observed throughout the 70 days observation period. And for the D350-0% and D350-10% no increase or decrease in volume was recorded but cracks appeared after a period of 28 and 42 days respectively, this shows that, inclusion of coconut shell has a significant effect on the appearance of cracks on

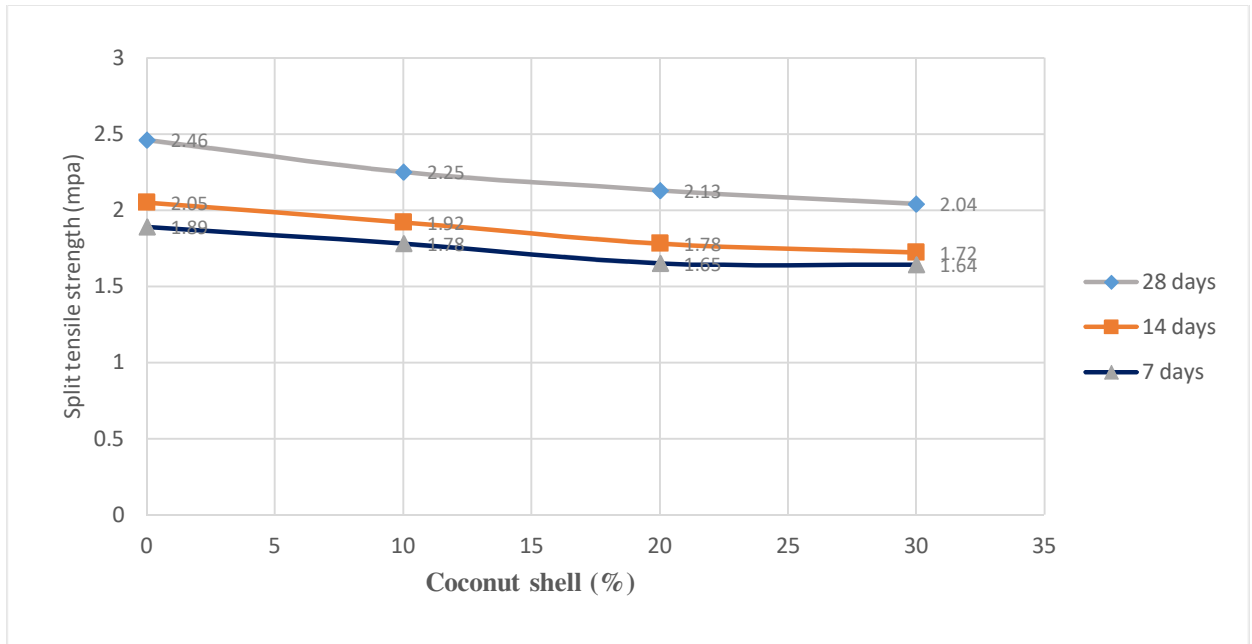


Figure 3: Split tensile strength versus coconut shell content

Table 3: List of specimens with the age of concrete when crack appeared.

Coconut Shell Volume (%)	Height (mm)	Core Dia. (mm)	Age (Day) 1 st Crack	Age (Day) 2 nd Crack
0%	150	150	-	-
	150	250	-	-
	150	350	28	28
10%	150	150	-	-
	150	250	-	-
	150	350	42	42
20%	150	150	-	-
	150	250	-	-
	150	350	-	-
30%	150	150	-	-
	150	250	-	-
	150	350	-	-

concrete, as it increases the time of crack appearance from 28 to 42 days when 10% of normal aggregate was replaced with coconut shell aggregate. And for 20% and 30% replacement, no crack was recorded for the whole period of observation. This shows that addition of 20% and 30% coconut shell was able to arrest a crack in this concrete mix. Therefore, the bigger surface area of restrained will leave smaller section for concrete, which means that the concrete section is the thinnest/smallest. Large, thick concrete members dry out more slowly than

small/thin sections. As a result, for the same drying period, shrinkage of large-size members is lower than the smaller-size ones which can dry out to their cores more quickly. This conformed to the work of Gunasekaran and Kumar (2018) which found out that coconut shell plays a significant role in reducing the shrinkage cracks in the concrete compared with conventional concrete constituents.

Varying the core diameter on shrinkage was found to have very little effect provided that there is no cracking



Figure 4: shows a crack appeared on D350-0%



Figure 5: shows a crack appeared on D350-10%

taking place. But with the larger core diameter and therefore a much thinner shell, cracking and positive strains (expansion) are more likely. For the largest core diameter of D350 as shown in (Figures 4 and 5), as the coconut shell contents is added the duration for the appearance of crack is increased and the crack length and width decreased for D350-10%, For the smallest core diameter and medium core diameter of D150 and D250,

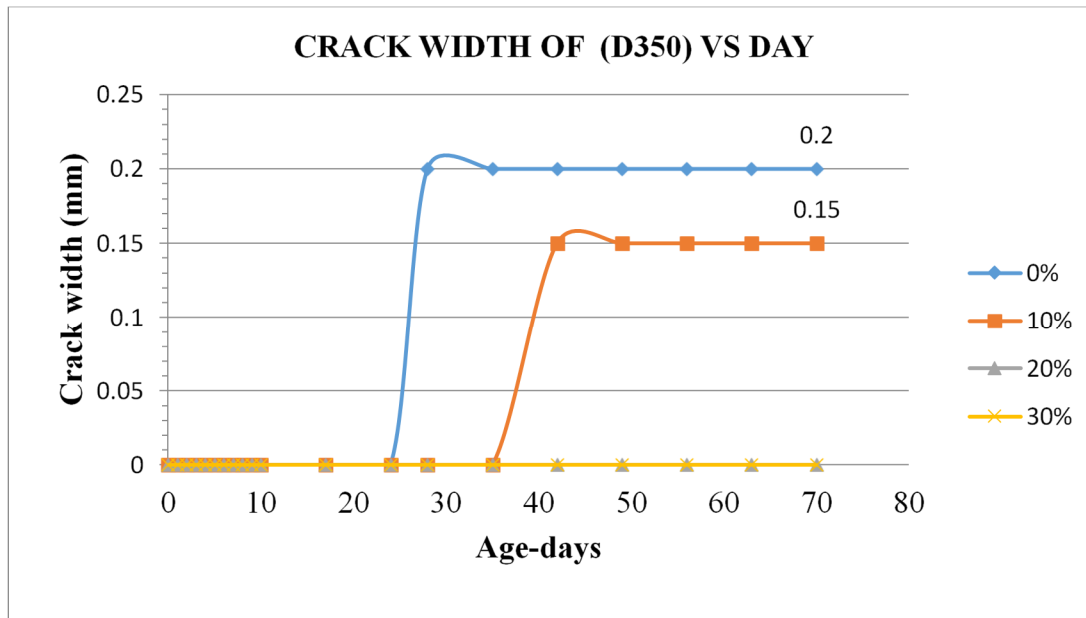
no signs of shrinkage or cracking appeared, and the inclusion of coconut shell at 20% and 30% actually prevented cracking.

Cracks appearance

The number of cracks appeared on the concrete specimens as shown in (Table 4) indicated that, the

Table 4: Number of cracks appeared on each mix

Coconut shell volume	Number of Cracks per day		
	28 days	42 days	70 days
CS-00	8	8	8
CS-10	4	4	4
CS-20	0	0	0
CS-30	0	0	0

**Figure: 6** Effect of CS on crack width for concrete restrained with D350 core diameter ring.

coconut shell aggregate has a direct influence on the appearance of cracks on concrete, it reduces the number of cracks from 8 in CS-00 to 4 in CS-10. While in CS-20 and CS-30 no crack appeared. And the number of cracks remained the same up to the end of the seventy (70) days observation period.

Crack width and length

Increased in crack width and crack length on the concrete with respect to time of ageing as shown in (Figures 6 and 7) explained that there is no expansion in the concrete D350. At 28 days, the crack appeared due to drying process of the concrete, but small increase in width and reduction in length of the crack shows that the mixture composition of the concrete and material properties are good.

The restrained shrinkage cracking of concrete containing CS appeared to be less than that of control concrete. Cracking with CS was delayed to later ages and resulted in smaller crack width and length, this is possible according to ACI 213R-14 as a result of internal curing effect of coconut shell as light weight aggregate, it has a

porous particle that act as water reservoirs releasing moisture slowly and hydration continues internally, reducing early-age stress. Coconut shell aggregates are softer than conventional aggregate and absorbs energy through microcracks formed at CS-cement interfaces, the weak interfacial Transition Zone around CS particles distributes stresses and prevents localized cracking.

The single factor analysis of variance (ANOVA) was conducted to examine the influence of coconut shell aggregate (CSA) replacement on the shrinkage crack width of concrete. The computed F-value (24.92) was markedly higher than the critical F-value (2.56), indicating that the mean crack widths differed significantly among the concrete mixes containing varying percentage of CSA. The corresponding p-value (2.19×10^{-11}) was far below the 0.05 level of significance, confirming that the observed differences were statistically significant and not due to random variation.

This implies that the percentage replacement of coarse aggregate with coconut shell had a significant effect on the development of shrinkage cracks. In particular, mixtures with higher coconut shell content exhibit lower crack widths, demonstrating that the incorporation of coconut

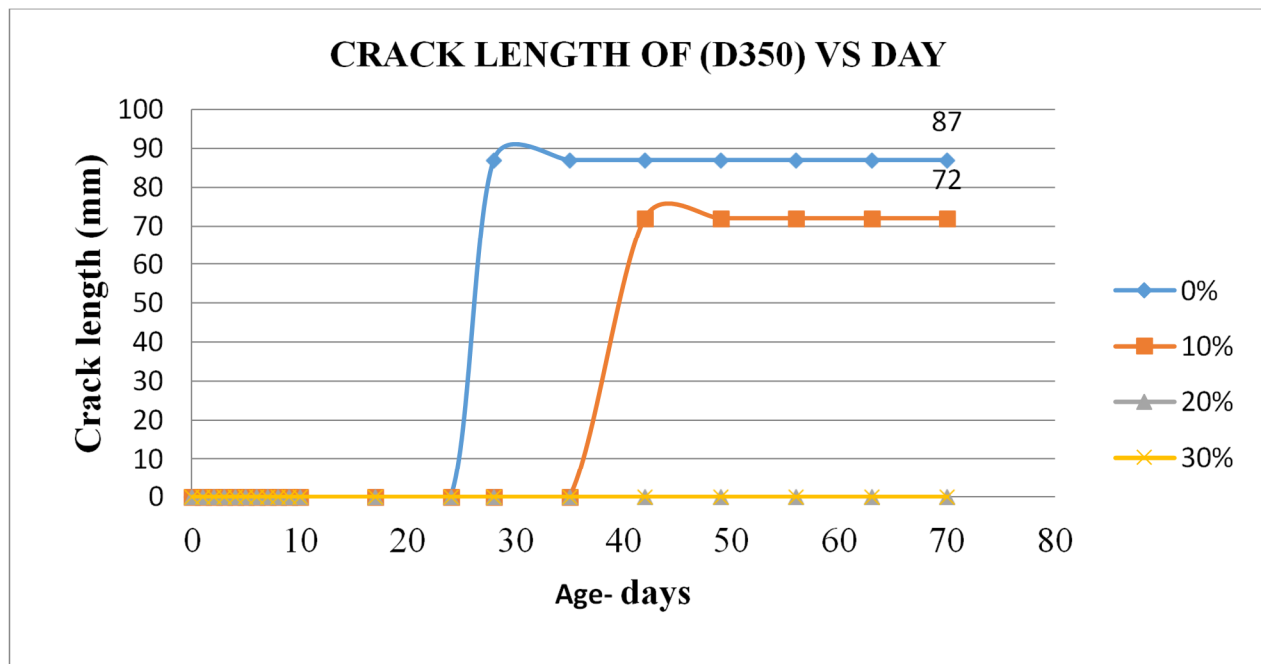


Figure 7: Effect of CS on crack length for concrete restrained with D350 core diameter ring.

shell aggregate reduces shrinkage cracking tendencies. This outcome is consistent with earlier studies reporting that lightweight aggregates with higher water absorption capacity can mitigate tensile stress buildup and delay crack initiation in concrete (ACI 231R-14). Mixtures with internal curing reduced risk of cracking and reduced chloride ingress, internal curing is just one of many tools that might increase the sustainability of concrete elements. Internal curing has the potential to improve the durability and reduce the life-cycle costs of concrete structures. The service lives of theoretical higher-performance concrete bridge decks with and without internal curing was compared and it was assumed that higher performance concrete deck without internal curing exhibit early-age autogenous and thermal cracking while concrete with internal curing was assumed not to exhibit such early-age cracking. Based on these assumptions, service life of conventional concrete was estimated to be 22 years, 40 years for higher-performance concrete without internal curing and 63 years for higher-performance concrete with internal curing (ACI 231R-14).

Finally, coconut shell acts as a shrinkage-reducing admixture. At 10% CS, cracks are delayed and smaller due to internal curing and ductility. At 20%-30% CS, the percolation network of pores and weak ITZ fully dissipates shrinkage stresses and eliminating cracks. This aligns with global research on bio-waste fiber and bio-aggregates and offers a sustainable path to crack-resistance concrete (ACI 231R-14). As reported by zakiah et al., 2010 that increase in the content of oil palm trunk fiber (OPTF) has resulted

in reduction in drying shrinkage as well as controlling the cracking. Also, Gunasekaran and Kumar (2013) reported that plastic shrinkage crack area of coconut shell concrete is reduced as the percentage of coconut shell is increased. Research carried out by Gunasekaran and Kumar (2018). On the shrinkage of coconut shell concrete hollow blocks, found out that coconut shell plays a significant role in reducing the shrinkage cracks in the concrete compared with conventional concrete constituents.

Conclusion

Coconut shell aggregate significantly influences the restrained drying shrinkage and cracking behavior of concrete. Increasing CSA content reduced crack formation and delayed crack initiation from 28 days (control) to 42 days at 10% CSA. At 20% and 30% CSA replacement, no cracks were observed during the 70-day period. Crack width reduced from 0.2mm in control concrete to 0.15mm at 10% CSA replacement while the crack length reduced from 87mm in control concrete to 72mm at 10% CSA replacement. Although tensile strength decreased slightly with CSA inclusion, the benefits in cracking resistance and sustainability outweigh this limitation.

Recommendation

Use CSA replacement levels of 20%-30% for structures prone to shrinkage cracking and future studies should

investigate long-term durability, microstructural behavior, and field-scale applications of CSA concrete to further validate its suitability as a sustainable construction material.

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