

PAPER 51 – DEVELOPMENT OF SUSTAINABLE CONCRETING USING RHA BLENDED BIO SELF-COMPACTING CONCRETE INCORPORATING *Bacillus subtilis* AND DIFFERENT FILLERS

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ABSTRACT

Attaining a sustainable construction environment requires the use of readily available construction materials that are cheap and eco-friendly. This will make the attainment of the sustainable development goal of adequate mass infrastructure for all achievable. Self-Compacting Concrete is a special concrete that can be modified by the addition of fillers and supplementary cementitious materials to improve its overall properties and aid in its domestication in Nigeria. This research investigates the effect of the use of Rice Husk ash at 15% replacement of Portland Limestone Cement and incorporation of *bacillus subtilis* on the fresh state properties, and durability, measured using sorptivity and water absorption as well as the strength characterization at 7 and 28 days. The results showed an improvement in all the properties measured with the incorporation of bacteria and RHA. The use of fillers affected the microstructural characterization with the Limestone powder, crushed rock dust filler and cement kiln dust all having a positive impact on the microstructural and permeation properties of the SCC. It is concluded that the introduction of *bacillus subtilis*, into an RHA and LP, CKD or CRD ternary blended SCC improves its properties and its usage in concreting can impact positively sustainability in the built environment.

KEYWORDS: *bacillus subtilis*, Fillers, Rice Husk Ash, Self-Compacting Concrete, Sustainable Concreting

1. INTRODUCTION

Attaining a sustainable construction environment requires the use of readily available, affordable, and eco-friendly construction materials to achieve the sustainable development goal of providing adequate mass infrastructure for all, especially in less developed regions. Concrete is the most widely used construction material on earth, and there are continuous efforts to improve its strength and durability by incorporating materials that are readily available and can enhance its overall properties (Taku, et al 2021). One such special concrete that has revolutionized the construction industry is self-compacting concrete (SCC), which can be modified by adding fillers and supplementary cementitious materials to enhance its overall properties and facilitate its adoption in the Nigerian construction industry. Research has shown that the use of pozzolanic materials in the partial replacement of cement as well as the use of non-reactive fillers helps improve the basic properties of self-compacting concrete (Karatas, et al., 2020)

Ozawa and Maekawa (2001) studied the use of fly ash and limestone powder as supplementary cementing materials in self-compacting concrete, with a focus on the viscosity and hydration characteristics of the concrete and reported an overall improvement in the properties while. Khayat et al. (2003) investigated the performance of self-compacting concrete containing various supplementary cementing materials. Akbari and Ramezani pour (2017) investigated the performance of self-compacting concrete containing RHA in terms of its resistance to chloride ion penetration and Liu and Li (2019) conducted a comprehensive review on the use of rice husk ash (RHA) in self-compacting concrete, highlighting its potential as a filler material. Calcined clay, Limestone Powder, Cement Kiln Dust, and crushed rock dust have variously been used in self-compacting concrete with exciting results (Siddique, et al., 2015; Siddique et al. 2019; Taku et al., 2022; Babatunde, et al. 2022). The self-healing property of concrete can be enhanced by the adoption of Microbial induced calcite precipitation (MICP) technology in concrete, whereby a rhyolitic bacterium, in the presence of nutrients and moisture, deposits calcium calcite in the concrete pores, thereby improving the overall properties of concrete and enhancing self-healing (Adepegba & Adegbola, 2021). Recent research on SCC using *sporosarcina pasteurii* shows an improvement in the permeation characterization and strength of self-compacting concrete at the early and later ages of the concrete

(Taku et al., 2023). Other research using other bacteria also reported similar improvements in concrete properties (Subramanian & Bose, 2010; Vijay & Murma, 2018; Osinubi et al., 2019; Alisha, et al., 2020; Luhar, et al., 2022)

This research investigates the effect of incorporating RHA at 15% replacement of Portland Limestone Cement and *bacillus subtilis* bacteria on the properties of self-compacting concrete using different fillers, namely limestone powder, crushed rock dust, and cement kiln dust. The study evaluates the fresh state properties, durability (measured using permeation properties of sorptivity and water absorption), microstructure, and strength characteristics of the SCC at 7 and 28 days.

4. METHODOLOGY

Portland Cement of grade 42.5N was used for this research work and the properties conform to the provisions of BS 12 (1991).

The grading and particle shapes of aggregates are significant factors in the production of SCC. Thus, the aggregates were carefully chosen to fit into the specifications for aggregates for Self-compacting concrete as stipulated by EFNARC (2005). Consequently, River sand from River Benue and crushed rocks of maximum particle size 10mm were used as fine and coarse aggregates respectively.

Sandcrete SPR-300 Super-plasticizer, manufactured by the Wafa group of companies was used for this research. The specific gravity, pH and chloride content of the SP are 1.08, 6.5 and less than 0.1% respectively.

The Bacteria (*bacillus subtilis*) was obtained from the soil while the calcium lactate was obtained at a local chemicals store in Makurdi. Both the Bacteria culture and preparation of the cementation reagent were carried out at the Microbial Laboratory in the Department of Microbiology, Joseph Sarwuan Tarka University Makurdi.

a. Fresh State Properties of Self-Compacting Concrete

The fresh state properties of the SCC were determined using the procedure stipulated in EFNARC (2005) to determine the flow time, the time taken to reach a diameter of 500mm, the flow diameter and the V-Funnel flow, while the L box and J rings were used to determine passing and filling ability of the concrete

b. Permeation and Strength properties

The permeation properties of the Self-Compacting Concrete were determined in accordance with the provisions of BS 1881-122 for sorptivity and water absorption of concrete. The test for sorptivity was carried out at 7 and 28 days for each mix to evaluate the effects of the bacteria, rice husk ash and filler on the rate of water absorption through interconnected capillary pores. The compressive and split tensile strengths were determined using 100x100x100mm³ cubes and 100x200mm³ respectively in accordance with the procedure set out in BS EN 12390-9 and BS EN 12390-10

c. Microstructural Characterization

The microstructural characterization was carried out using SEM and EDX at the Department of Chemical Engineering, Ahmadu Bello University Zaria

5. RESULTS AND DISCUSSION

a. Oxide Composition of Filler Materials

Table 1 gives the oxide composition of the materials used in the research. It can be seen that it is RHA and CRD has a combined SiO₂ + Al₂O₃ + Fe₂O₃ of over 70%, however, only the RHA is pozzolanic since the silica, aluminate and ferrite in the RHA exists in the amorphous state. The CRD exists in crystalline form and so the SiO₂ is non-reactive and hence does not possess pozzolanic properties (Kibriya & Tahir, 2017). LP and CKD contain more non-reactive calcite. Thus, while RHA is suited as a cement replacement material, CRD, CKD and LP can only serve as non-reactive fillers.

Table 1. Oxide Composition of Materials

| Oxide | SiO ₂ | Al ₂ O ₃ | Fe ₂ -O ₃ | CaO | MgO | Na ₂ O | K ₂ O | SO ₃ | LOI | Surface Area (cm ² /g) | Specific gravity |
|-------|------------------|--------------------------------|---------------------------------|-------|------|-------------------|------------------|-----------------|------|-----------------------------------|------------------|
| RHA | 77.19 | 6.19 | 3.65 | 52.88 | 1.45 | - | 1.82 | 0.16 | 5.43 | 2400 | 2.20 |
| OPC | 10.41 | 6.10 | 3.18 | 70.26 | 4.09 | 0.57 | 1.17 | 3.04 | 6.72 | 3200 | 3.15 |

| | | | | | | | | | | | |
|------------|-------|------|------|-------|------|-------|------|------|------|------|------|
| LP | 8.97 | 1.02 | 0.37 | 46.77 | 2.38 | 0.02 | 0.13 | - | 39.5 | 1300 | 2.76 |
| CKD | 22.07 | 4.33 | 4.10 | 67.16 | 1.08 | 0.096 | 0.18 | 0.29 | 0.69 | 2065 | 1.15 |
| CRD | 58.4 | 15.9 | 8.1 | 3.42 | 1.98 | 4.14 | 2.82 | - | 2.82 | 2870 | 2.59 |

2.2 Fresh State Properties

The filling and passing ability, as well as the flowability characteristics of the ternary blended Bio-SCC were carried out to determine the effect of the RHA, Fillers and bacteria on the fresh state properties of the SCC. The result is presented in Tables 2 and 3 for filling and passing ability testing and flowability testing respectively

Table 2. Filling and Passing Ability Testing

| L-Box Test results | | | | | | | J-Ring Tests results | | | |
|--------------------|-----------------|----------------|----------------|--------------------------------|----------------------|----------------------|----------------------|--------------------|----------------------|--|
| ID mark | Filler Material | H ₁ | H ₂ | H ₂ /H ₁ | T ₂₀₀ (s) | T ₄₀₀ (s) | d _{Jx} mm | d _{Jy} mm | SF _J (mm) | |
| T1 | 0 | 7.7 | 7.4 | 0.96 | 0.80 | 1.93 | 630 | 630 | 630 | |
| T2 | CRD | 7.6 | 7.4 | 0.97 | 0.53 | 1.86 | 697 | 700 | 699 | |
| T3 | CKD | 7.3 | 7.2 | 0.99 | 0.40 | 1.13 | 700 | 700 | 700 | |
| T4 | LP | 7.4 | 7.1 | 0.96 | 0.67 | 1.40 | 700 | 706 | 703 | |

Table 3: Flowability Testing – Slump Flow and V-funnel Testing

| ID mark | Filler Material | t ₅₀₀ (s) | Viscosity class | t _{flow} (s) | Slump flow (mm) | SCC class | V _{funnel} time (s) |
|---------|-----------------|----------------------|-----------------|-----------------------|-----------------|-----------|------------------------------|
| T1 | 0 | 3.42 | VS1/VF1 | 3.64 | 655 | SF2 | 6.90 |
| T2 | CRD | 4.72 | VS1/VF1 | 4.48 | 710 | SF2 | 8.30 |
| T3 | CKD | 3.62 | VS1/VF1 | 4.63 | 710 | SF2 | 7.85 |
| T4 | LP | 3.78 | VS1/VF1 | 4.60 | 670 | SF2 | 7.60 |

EFNARC (2005) specifies the following limits for the fresh state properties; Slump: 650 to 800mm; T₅₀₀: 3 to 7 seconds; V_{funnel}: 8-12 seconds; H₂/H₁: Closer to 1. It can be seen that all the samples met the flowability, passing ability and filling ability criteria, irrespective of the filler material used. Generally, the fines content and cementitious content determine the fresh state properties of the SCC. Research has shown that the bacterial content does not affect the fresh-state properties (Taku et al 2023). It can also be seen that even though all the samples met the specifications of EFNARC (2005), the higher the surface area of the particles of the filler, the less the flowability as the water demand is generally higher.

2.3 Permeation Characterization

The permeation properties were measured in terms of the water absorption and sorptivity in water and acidic environment. Figs. 1.0 presents the result of the Variation of water absorption with age for SCC containing the various filler. It can be seen that the water absorption decreased with age irrespective of the filler used. The same applies even when no filler was used. The absorption of water into the concrete depends on the pore spaces in the concrete. As the concrete ages, those spaces are filled up by the products of hydration, the products of the pozzolanic reaction, the calcium calcite precipitated by the bacteria and also the filler effect. Apart from filling the pore spaces, the fillers bring better packing and improve concrete durability (Kibriya & Tahir, 2017; Diagne, et al., 2021).

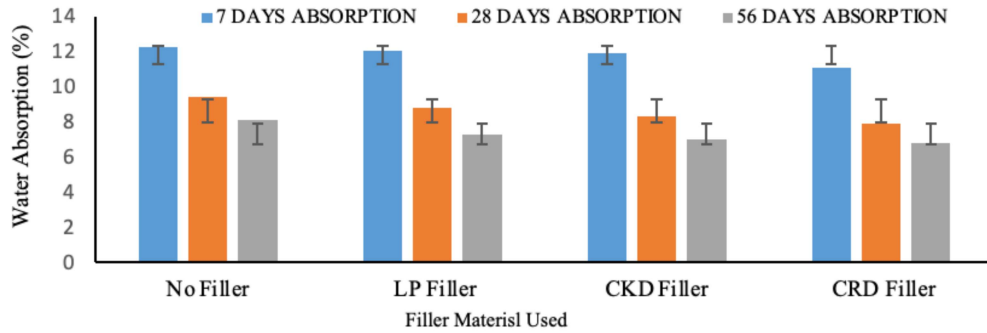


Figure 1: Variation of Water Absorption with Curing Age

The result of the Sorptivity behaviour of the ternary blended SCC in a normal curing environment and the acidic medium at different ages is given in Figure 2, where 7D-W, 14D-W, 28D-W, 56 D-W stands for curing age in days in normal water and 7D-A, 14D-A, 28D-A, 56D-A represents curing in acidic medium respectively.

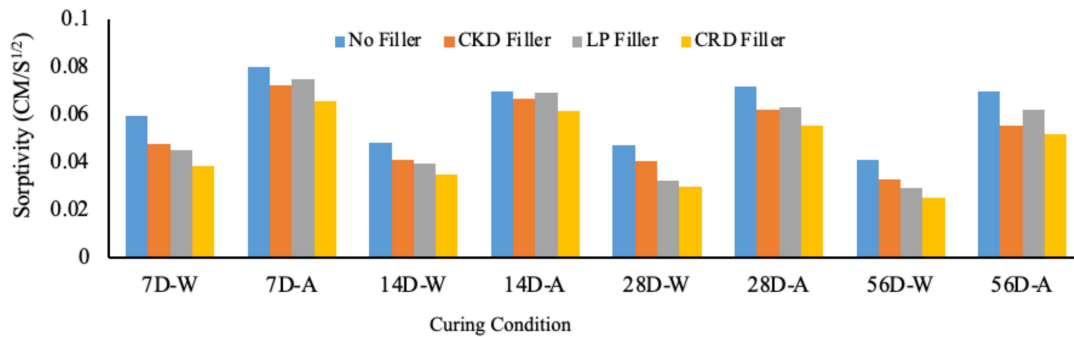


Figure 2: Variation of Sorptivity with Filler Type and Curing Condition

The sorptivity decreased with age as all the samples showed better permeation as they aged. The sorptivity performance for samples cured in the water proved better than that in Acid. This is a result of the inhibition of the calcite precipitation by the bacteria as well as the deterioration of the concrete matrix which leaves it more porous. The performance of the SCC incorporating filler is better than that without filler due to the filling of the pore spaces by the filler as well as the filler effect. Overall, CRD blended SCC showed better performance in normal conditions and acidic curing conditions. The result agrees with the works by El-Gamat, et al., (2012); Vaezi et al (2019) and Kaur et al (2021).

2.4 Strength Characterization

The effect of the RHA, *bacillus subtilis* and different fillers on the compressive, flexural and tensile strength was determined by testing samples at 7-, 28- and 56-days curing age for compressive strength and 7 and 28 days for split tensile and flexural strength. The result of compressive strength testing is presented in Figure 3.

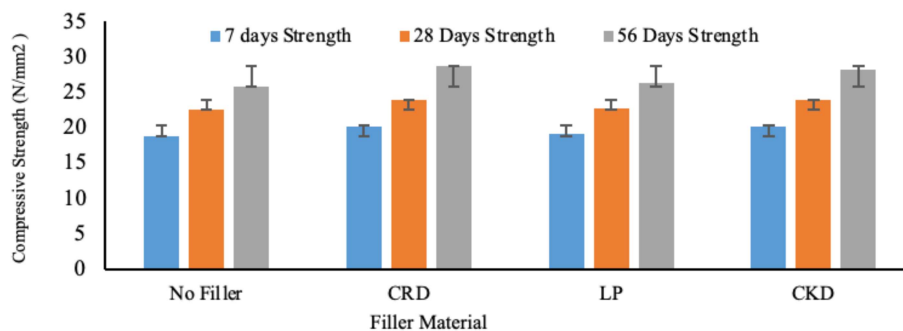


Figure 3: Variation of Compressive Strength with Age

The strength increased with age and the presence of filler, with the SCC containing the fillers showing higher strength development at all ages as compared to the without filler. Generally, the pozzolanic reaction, the hydration reaction and calcite deposition by the bacteria all contribute to strength development. In the case of the concrete with fillers, however, the fillers not only affect the porosity and microstructure of the concrete but also the reaction of cement. According to Moosberg-Bustnes et al (2004) and Diagne et al (2021), Fillers are materials whose function in concrete is based mainly on size and shape and they can interact with cement to improve particle packing and give the fresh concrete other properties, and even to reduce the amount of cement in concrete without loss of strength.

The result of split tensile and flexural strengths presented in Table 4 shows a similar pattern as the compressive strength.

Table 4. Flexural and Split-Tensile Strength Data

| Mix | Filler Material | Flexural Strength (N/mm ²) | | Tensile Strength (N/mm ²) | |
|-----|-----------------|--|---------|---------------------------------------|---------|
| | | 7 Days | 28 Days | 7 Days | 28 Days |
| T1 | No Filler | 3.04 | 3.33 | 2.14 | 3.42 |
| T2 | CKD | 3.11 | 3.38 | 2.17 | 3.44 |
| T3 | LP | 3.07 | 3.35 | 2.22 | 3.48 |
| T4 | CRD | 3.15 | 3.42 | 2.25 | 3.52 |

2.5 Microstructural Characterization

The Microstructural evolution of the SCC with the addition of RHA, *bacillus subtilis* and fillers was investigated using Standard Electronic Microscopy (SEM) analysis and the result for the microstructure at 28 days of curing is presented in Figure 5.



Figure 5: SEM Result for (a) CRD @ 28 days (b) LP at 28 days (c) CKD at 28 days

Figure 5 shows that the microstructural evolution of the SCC with the different fillers have distinct microstructures, due to the differing effect of each filler. This is due to the differences in particle sizes of the fillers as well as the effect on cement hydration.

6. CONCLUSION

The research shows that sustainable concreting can be achieved by the use of Rice Husk ash at 15% in replacement of Cement; the application of Microbial induced calcite precipitation and the use of readily available materials like limestone powder, Cement Kiln Dust and Crushed rock dust in Self-compacting concrete to improve the permeation and strength of SCC while also minimizing cost and ensuring environmental preservation. The SCC

properties are optimized by the combined pozzolanic action of RHA, the calcite precipitation by bacillus subtilis and the filler effect of the different fillers. It is also concluded that irrespective of the filler used, the filler particle size and shape are the determining factors of the level of effect the filler will have on the concrete properties.

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