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Suitabilitilty Of Sesame Plant Powder And Metakaolin On The Strength Properties Of Self Curing Concrete

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ABSTRACT: *Self-curing concrete offers a promising alternative by maintaining internal moisture for hydration without external curing, thereby achieving the required performance. Therefore, in this study, sesame plant powder (SPP) is obtained from fresh Sesamum indicum plants, dried, ground with a ball grinder, and sieved through a 150-micron sieve, while metakaolin (MTK) is obtained from Kaolin, calcined at 800 °C, sieved through a 150-micron sieve, and used as a partial replacement for cement. Results from the laboratory show that SPP has 27.60% SiO_2, 4.15% Al_2O_3, 2.50% Fe_2O_3, and loss of ignition 58.0%, while MTK has SiO_2 48.92%, Al_2O_3 43.46%, Fe_2O_3 0.51%,> 70%, and LOI 1.69%. Fine aggregates (FA) and coarse aggregates (CA) have fineness modulus of 2.01 and 6.55, respectively. Specific gravities FA is 2.67, CA is 2.68, for SPP is 2.18, and that for MTK 2.61. Cement was partially replaced with 0%, 10.5%, 11%, and 11.5% by weight of SPP and MTK, which are Control (C), R1, R2 and R3. The setting time and consistency for 0% to 11.5% mixes are initially 47min to 55min, and the final setting time was 262min to 302min, with consistencies of 27% to 30%. The slump test workability was low, while the compaction factor test result was 0.92 to 0.90. A 1:2:4 concrete mix by weight was used to produce 100x100x100mm cubes and 100x100x500mm beams; they were externally and self-cured at 7, 14, 28, 56, and 90 days. Results revealed that control concrete had the highest density and showed a steady increase in compressive strength from 19.09N/mm² at day 7 to 34.80N/mm² at 90 days, but R1 surpassed C at 90 days, with 35.01N/mm². R1 has the optimum flexural strength of 10.25N/mm² and at age 90. Therefore, optimum performance was observed at 0.5% SPP and 10% MTK. It enhances self-curing and promotes sustainable construction practices, providing a cost-effective solution for concrete production in arid and water-scarce sub-Saharan regions.*

KEYWORDS: *Compressive Strength, Metakaolin, Self-curing concrete, Sesame Plant Powder, Sustainable construction.*

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I. INTRODUCTION

Economic growth, social justice, and environmental protection are the three fundamental goals of sustainable development that countries worldwide have pledged to achieve (Hedayatinia, Delnavaz, & Emamzadeh, 2019). Cement and concrete are among the world's most significant manufactured materials and are crucial to these three fundamental goals. Concrete is a construction material widely used globally for its excellent properties, such as durability, workability, satisfactory strength, and the easy availability of raw materials (cement, aggregates, and water) used to produce it (Hilal, 2016). These properties, such as strength and durability, depend on adequate curing at an early age and a hardened state (Bazzar, Hafiane, & Alaoui, 2021). Water is essential for this curing and hydration because it is required to synthesize gel products and fill the micro-pores that occur between and within them as they are produced (ACI 308R-16, 2016). Curing is intended to maintain these favourable conditions for a continuous hydration process.

Curing, as defined in ACI 308R-16 (2016), is the process of maintaining moisture and temperature conditions in a freshly placed cementitious mixture to allow the hydration of hydraulic cement. If pozzolans are added, pozzolanic reactions develop the mixture's potential properties. When the qualities of the cast concrete equal or surpass the design properties, it is said to be appropriately proportioned and adequately cured. The American Concrete Institute (ACI, 2009) states that continuous pore spaces near the surface of concrete allow the ingress of harmful agents and may lead to several durability issues. In addition, early concrete drying can lead to microcracks or shrinkage cracks on the concrete surface, creating a pathway for durability problems (Khode, 2019; Yang, Weiss, & Olek, 2005). Consequently, concrete curing plays a significant role in developing an improved microstructure and pore structure, thereby improving its durability and performance.

Production of concrete incorporating self-curing agents represents a new trend in concrete construction in the current millennium. Self-curing process is achieved by employing admixtures (AC1 308R-16, 2016; Mousa, Mahdy, Abdel-Reheem, & Yehia, 2015; Sundharam, 2016) or by employing pre-saturated lightweight aggregates that readily release water needed for hydration or replace moisture lost through evaporation or self-desiccation (Evangeline, 2014; ACI 308R-16, 2016; Sundharam, 2016). Self-curing is a method used in the production of special concretes that mitigate insufficient curing caused by environmental conditions and unforeseen circumstances. It is also used to checkmate human negligence in quality control, scarcity of water in arid areas, inaccessibility of structures under challenging terrains, and places where the presence of fluorides in water will negatively affect the characteristics of concrete (Kumar, Srikanth, & Rao, 2012).

Recently, the use of Sesame mucilage was found to be effective in producing concrete (Orame, Abdulazeez, & Kolawole, 2020). The application of sesame mucilage powder (Sesamum indicum) as an admixture can improve concrete properties, offering significant benefits to the construction industry (Orame et al., 2020; Zakka et al., 2021). Sesamum is an annual flowering plant that grows 500 to 1000mm tall. It is called Karkashi in Hausa; its flowers vary in colour, ranging from white to blue to purple. Sesame plants are grown in many parts of the world. The largest producers of the crop are India, China, Myanmar, Sudan, Ethiopia, Uganda, and Nigeria. However, twenty-six percent of these crops are grown in Africa (Hansen, 2011). The sesame plant is widely grown in the Middle Belt and Northern Nigeria as a minor crop initially in 1974 (NAERLS, 2010). Sesame contains compounds such as sesamin, sesamol, gamma-tocopherol, cephalin, and lecithin, and has pharmacological properties (Joseph, 2016). However, there are few studies on the application of sesame plant technology in construction and concrete fields.

Research has shown that incorporating pozzolanic materials helps achieve self-curing concrete. This includes self-curing agents such as fly ash, silica fume, limestone powder, and rice husk ash (Selvamony, Ravikumar, Kannan, & Gnanappa, 2010; Mousa et al., 2015; Bhosale, Shingade, & Patil, 2016). Metakaolin, which effectively serves as a filler, is meant to speed up cement hydration and exhibits high pozzolanic reactions with calcium hydroxide products in concrete (Ghrici, Kenai, & Said-Mansour, 2007; Sidek, Johari, Arshad, & Jaafar, 2013); despite excess liberation of heat, which influences the heat of hydration (Khode, 2019).

Therefore, this study focuses on investigating the influence of sesame mucilage powder as a water-retaining admixture. Metakaolin will be used as a cement replacement to influence the properties of self-curing concrete.

A. Sesame Mucilage

The original domestication of sesame is unclear, but it was probably first cultivated in Asia or India (Zakka et al., 2021). It has been known and used for more than 5,000 years in India and is documented as a crop in Babylon and Assyria 4,000 years ago (Borchani et. al., 2010).

Today, the use of sesame plant mucilage as a concrete admixture would benefit the Nigerian construction industry. The admixture is obtained from the sesame plant (Sesamum indicum), extracted, and processed for concrete production. Research by Orame et al. (2020) and Zakka et al. (2021) revealed that the chemical compositions of qualifies it as an admixture.

II. MATERIALS AND METHODS

The research design used for this study is the quantitative design. Coarse aggregates used is of size 14mm retained on a 10mm sieve in conformity with BS EN 933-5 (1998), while the fine aggregate is subjected to sieve analysis and passed through a sieve size of 4.75mm conforming to BS EN 933-1 (1997). A type I Portland Cement grade was used in conformity with BS EN 197-1: 2011, and the water used for the study is portable water that conforms to BS EN 1008-2 (2002). Metakaolin to be used for this research will be obtained from kaolin sourced from Bauchi, Kano road, Bauchi State, Nigeria. It is then calcined at 650 °C in a kiln at the Industrial Design Department, ATBU Bauchi, sieved through a 150-micron sieve at the Building Department Material Laboratory, ATBU Bauchi, as shown in Fig. 2. On the other hand, Sesamum Plant Powder (SPP) was obtained from the fresh plant (Sesamum Indicum) dried, ground using a ball grinder at Nigerian Metallurgical Development Centre (NMDC), Jos, as shown in Fig.s 1 and 2, after which it is stored in an air-tight plastic container ready for use.

A mix ratio of 1:2:4 by weight was used to eliminate bulking of sand and variable moisture content, with 4.75mm and 14mm coarse aggregate sizes respectively as per BS 1881-125 (1986), and a water-cement ratio of 0.5 as per IS 456-2000. SPP and MTK was partially to replace cement at C0%, R1 (SPP 0.5%-MTK10%), R2 (SPP 1.0%-MTK10%), and R3 (SPP 1.5%-MTK10 %). Sieve analysis of aggregates was determined according to the procedures specified in BS 882:1965, BS 812:1975, and ASTM C 136-92. Specific gravity and bulk density, and void tests procedures were conducted following BS 812. 1975. Consistency tests were conducted in accordance with BS EN 196-3 (1995). The slump and compaction factor tests were conducted in accordance with BS EN 12 350-2:2009.

The densities of the concrete samples were determined in accordance with BS EN 12390-7 (2000). Compressive strength test of cube samples was conducted as per BS 1881: Part 116 (1983), while flexural test of beam samples was carried out following BS1881: Part 4 crushed at day. Water absorption of the concrete specimens was conducted according to BS 1881-122 (1983).

Fig. 1: Ball grinding machine

Fig. 2: Metakaolin and Sesame Plant Powder

(a) Metakaolin (b) Sesame Plant Powder

III. RESULT AND DISCUSSION

3.1 Chemical Properties of Material

3.1.1 Chemical Properties of Sesame Plant Powder (SPP)

Chemical properties of Sesame Plant Powder (SPP) results obtained from the Nigerian Institute of Mining and Geosciences Chemistry Laboratory, Jos, using an XRF technique, are shown below in Table 1. Results from previous researchers' studies on Sesame Mucilage Powder (SMP) and Sesame Plant Powder (SPP) indicate notable variations in their chemical compositions. The result shows Silicon Dioxide (SiO_2) content is 27.60%, which suggesting improved pozzolanic properties that could enhance concrete strength and durability. Aluminum Oxide (Al_2O_3) recorded a value of 5.055%, which may influence the setting time and workability of the concrete mix. Iron Oxide (Fe_2O_3) a value of 2.50%, which could affect colour and mechanical strength. Calcium Oxide (CaO) content has a value of 0.78%, indicating a potential increase in cementitious properties and hydration capacity. Magnesium Oxide (MgO) has a value of 4.81%, which could influence expansion properties and overall durability. Sodium Oxide (Na_2O) and Potassium Oxide (K_2O) shows a value of 0.09% and 0.27%, respectively. However, K_2O, raises concerns about potential alkali-silica reactions that may affect concrete stability. Loss on Ignition (LOI) indicate a value of 58.0%, suggesting a reduced presence of volatile compounds, which may influence the material's stability and performance in concrete. Titanium Dioxide (TiO_2) was detected at 0.06%, which may have minor implications for color stability and ultrviolet (UV) resistance. The result from this studies is consistent with that of Orame et al. (2020) and Zakka et al. (2021).

Table 1: Chemical constituents of sesame plant powder (SPP)

	Percentage (%) Composition								
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**LOI**	**TiO_2**
SSP	27.60	5.06	2.50	0.78	4.81	0.09	0.27	58.0	0.06

3.2 Chemical Properties of Metakaolin (MTK)

The percentage composition of metakaolin (MTKis presented in Table 2, compared with those of Agboola et al. (2024) and the ASTM C618-05 limits, shows key variations that affect its pozzolanic reactivity and suitability as a supplementary cementitious material. The Silicon Dioxide (SiO_2) content is 47.84%, confirming its strong pozzolanic potential. The Aluminium Oxide (Al_2O_3) content is 45.14%, enhancing early strength gain. The Iron Oxide (Fe_2O_3) content is 0.48%, with minimal impact on color or strength. Calcium Oxide (CaO) is 0.61%, reducing expansion risks. Potassium Oxide (K_2O) and Sodium Oxide (Na_2O) at 0.18% and 0.19%, indicate low alkali content, minimizing alkali-silica reaction risks. Sulphur Trioxide (SO_3) is 0.03%. Magnesium Oxide (MgO) content is 0.098% and Manganese Oxide (MnO) at 0.02% indicating stability. Titanium Dioxide (TiO_2) is at 0.57%. The Loss on Ignition (LOI) is 1.69%, which is well below ASTM C618-05's 3% limit, confirming low organic impurities. Overall, the laboratory results meet the ASTM C618-05 requirements and align with those of Agboola et al. (2025), confirming metakaolin's suitability as a supplementary cementitious material.

Table 2: Chemical Constituents of Metakaolin

S/N	**Chemical constituents**	**MTK (%)**
1	Silicon Oxide (SiO_2)	47.84
2	Aluminium Oxide (Al_2O_3)	45.14
3	Iron Oxide (Fe_2O_3)	0.48
4	Calcium Oxide (CaO)	0.61
5	Potassium Oxide (K_2O)	0.18
6	Sodium Oxide (Na_2O)	0.19
7	Sulphur trioxide (SO_3)	0.03
8	Magnesium Oxide (MgO)	0.098
9	Manganese Oxide (MnO)	0.02
10	Titanium oxide (TiO_2)	0.57
11	Loss of Ignition (Loi)	1.69

3.2 Physical Properties of Material

3.3.1 Sieve analysis

Table 3 displays the sieve analysis results for fine and coarse aggregates used to calculate the fineness modulus. The result, 2.01, is consistent with the literature review by Garba (2008) and falls within the fineness modulus range of 2.0 to 3.5 (± 0.2).

The sieve examination of coarse aggregates yields a fineness modulus of 6.55. Therefore, the coarse aggregates utilized in this study were in accordance with the literature as evaluated by Garba (2008) because the fineness modulus of coarse aggregates should be between 5.5 and 8.0 (± 0.2).

Table 3: Sieve Analysis

S/N	Material	Fineness modulus	Range
1	Fine Aggregates	2.01	2.0 to 3.5 (± 0.2)
2	Coarse Aggregates	6.55	5.5 and 8.0 (± 0.2)

3.2.2 Specific gravity

The result from Table 4, fine aggregate's specific gravity of 2.67, falls well within the typical acceptable range of 2.60 to 2.70 and is consistent with several local and international research findings. This demonstrates that the aggregate is dense, high-quality, and appropriate for normal-weight concrete production.

The result in Table 4 for coarse aggregate specific gravity is 2.68, which is consistent with both local and international research values and falls within the generally accepted range of 2.60 to 2.90. It guarantees good strength and long-term performance by indicating that the aggregate is dense, resilient, and appropriate for structural concrete applications.

Table 4 specific gravity test result of Same Plant Powder (SPP) is 2.18, which is higher than most gel-based plant admixtures with Specific gravity of 1.0 to 1.5 (Attar & Kolase, 2025; Bedada, Nyabuto, Kinoti, & Marangu, 2023; Malathy, Selvam, & Prabakaran, 2023), with the SG sesame mucilage value of 2.25 (Orame et al., 2020; Zakka et al., 2021), that suggest suitability to be used as self-curing agent where density aids stability, though it may limit absorption compared to lighter agents under ASTM C1761, supporting its use for strength (10–15% gains) and having potential moisture retention in concrete.

Though there is no range of values on specific gravity limit, metakaolin, as a pozzolan (ASTM International, 2019), still the value of 2.61 is within the standard range of 2.50–2.65, as revealed by (Bedada et al., 2023; Kamal et al., 2024; Murana, Olowosulu, & Ahiwa, 2014; Noor, Tuan, Sultan, & Shah, 2022). Despite being lighter than cement (3.15), it aligns with published values and suggests a pozzolanic material with high reactivity, capable of partially replacing cement and thereby enhancing the strength, sustainability, and durability of concrete.

Table 4: Specific gravity

S/N	Material	Fineness modulus
1	Fine Aggregates	2.67
2	Coarse Aggregates	2.68
3	Sesame Plant Powder (SPP)	2.18
4	Metakaolin (MTK)	2.61

3.3 Properties of Fresh Concrete

3.3.1 Consistency

Table 5 below shows the setting time and consistency results. Sesame plant powder and metakaolin at 10.50% and 11.50% increase the initial setting time from 47 min to 55 min, the final setting time from 262 min to 302 min, and the consistency from 27% to 30%, suggesting a retarding effect and a higher water demand.

Table 5: Setting of Cement

Setting time	0%	10.50%	11.00%	11.50%
Initial	47mins	47mins	53mins	55mins
Final	262mins	274mins	290mins	302mins
Consistency	27%	28%	29%	30%

3.3.2 Workability

The laboratory results in table 6 show that it complies with the ASTM general use. For a self-curing concrete, the values support internal hydration without excessive flow, which is generally adequate.

Table 6: Workability of Concrete

Definition	Mixes	Slump	Degree of workability	Compaction factor	Degrees of workability
C	0%	30	Low	0.92	Medium
R1	10.5% (SPP/MTK)	30	Low	0.93	Medium
R2	11.0% (SPP/MTK)	40	Low	0.94	Medium
R3	11.5% (SPP/MTK)	55	Low	0.94	Medium

3.4 Properties of Hardened Concrete

3.4.1 Density

The density results in Fig. 3 show the effects of Sesame Plant Powder (SPP) and Metakaolin (MTK) on the density development of concrete at curing ages of 7, 14, 28, 56, and 90 days. The control mix (C), containing no replacement materials, exhibited the highest density across all curing periods, ranging from 2351 to 2395 kg/m³. These values fall within the typical range for normal-weight concrete (2200–2500 kg/m³) as reported by Neville & Brooks (2010). The slight reduction in density over time may be due to continued hydration and the evaporation of excess water within the matrix. For the modified mixes containing both SPP and MTK, a progressive decrease in density was observed with increasing SPP content. The mix with 0.5% SPP and 10% MTK (R1) recorded densities of 2322-2341 kg/m³, only slightly lower than the control. This indicates that a small proportion of SPP has minimal influence on bulk density, while MTK contributes to maintaining compactness due to its high fineness and pozzolanic reactivity (Sabir et al., 2001). At 1.0% SPP (R2), density values ranged from 2314 to 2265 kg/m³, reflecting the lighter nature of SPP compared to cement. The reduction is consistent with findings by Obilade (2014), who reported that incorporating agricultural by-products tends to decrease density due to increased internal porosity and lower particle density. The mix with 1.5% SPP (R3) exhibited the lowest density values (2299–2193 kg/m³), yet these still lie within the acceptable range for normal-weight concrete (Neville & Brooks, 2010). The decline can be attributed to the higher organic content of SPP, which introduces more voids and entrapped air into the matrix.

Nevertheless, the inclusion of 10% MTK likely contributes to pore structure refinement and improves particle packing. Beyond 28 days, the mixes exhibit relatively stable densities, revealing that the hydration and microstructural densification processes had largely stabilized. On a note, shell density decreases as SPP content increases; however, it remains within structural concrete limits. Therefore, partial cement replacement with 1.5% SPP and 10% MTK can produce a normal-weight and environmentally sustainable concrete mix. Thus, the use of SPP and MTK offers a balance between density reduction and adequate microstructural integrity, making it a viable option for sustainable construction.

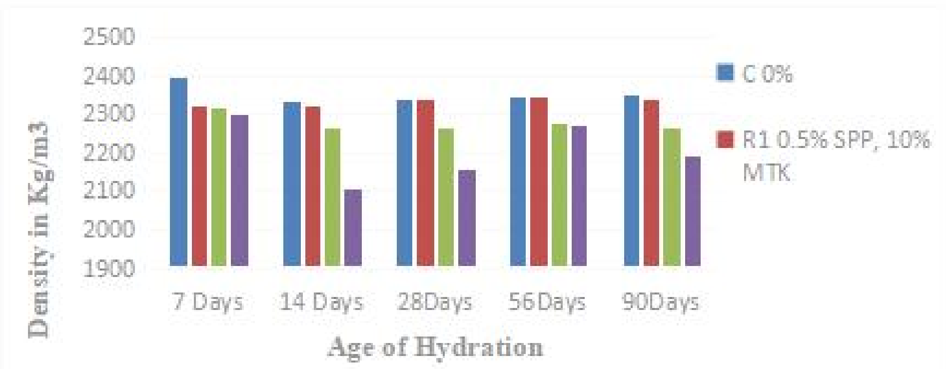

Fig.3: Density of Concrete

3.4.2 Compressive strength

Fig. 4 above shows the compressive strength results incorporating Sesame Plant Powder (SPP) and Metakaolin (MTK) as partial replacements for cement, revealing a trend in strength development with curing age. C shows a steady increase from 19.01 N/mm² at 7 days to 34.80 N/mm² at 90 days, due to better hydration and strength gain. R1 0.5% SPP + 10% MTK showed the same pattern of compressive strength values, progressing from 18.02

N/mm² at 7 days to 35.01 N/mm² at 90 days, with C surpassing it slightly at later ages. This improvement can be due to the pozzolanic reaction of MTK with calcium hydroxide, which forms additional calcium silicate hydrate (C–S–H), refining the microstructure and enhancing strength (Gunasekaran et al., 2020). The result shows that at R1, with 0.5% SPP and 10% MTK replacement in concrete, the mix's optimal strength is comparable to C, suggesting that the level of modification supports beneficial hydration and pore refinement. Moreso, R2 with 1% SPP + 10% MTK exhibited moderate compressive strength development, of 16.28 N/mm² at 7 days to 27.53 N/mm² at 90 days, falling below the C and R1 mixes, revealing that excessive SPP content can interfere with cement hydration or weaken the bond between paste and aggregate due to high organic content in SPP or increased porosity (John, 2023). R3 exhibits the lowest performance, with a 1.5% SPP + 10% MTK mix, achieving 11.71 N/mm² at 7 days and 16.79 N/mm² at 90 days. Neville & Brooks (2010); Falade et al., (2024) and Abah, Ndububa, & Ikpe (2018) reported that the water-to-binder ratio, aggregate quality, and the use of fine fillers can influence the compressive strength of concrete.

However, organic additives above 0.5% delay cement hydration, thereby increasing porosity and reducing strength. Moreover, the strength development trend is consistent with literature reports indicating that metakaolin at 5–15% enhances compressive strength, whereas higher organic contents can reduce bonding (Al-Akhras, 2017; Agboola et al., 2024b; Kumar & Dhaka, 2020). R1 and C mixes produced the most favorable results, exceeding R2 and R3, which are below acceptable values. ASTM C39 (2018) and BS EN 206 (2016) state that concrete with a compressive strength of 25 N/mm² to 35 N/mm² falls within the range of regular structural-grade concrete suitable for beams, slabs, and foundations.

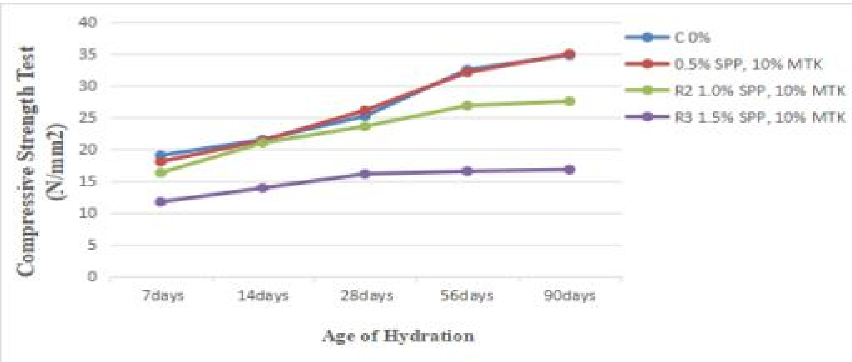

Fig. 4: Compressive Strength of Concrete

3.4.3 Flexural strength

Fig. 5 presents the flexural strength results for concrete beams C, R1, R2 and R3 obtained at 90 days. The flexural strength increases from 5.55 N/mm² at 28 days to 10.18 N/mm² at 90 days, indicating an enhancement in concrete's mechanical properties resulting from continuous and adequate hydration and matrix densification (Neville, 2011). R1 = 5.63 N/mm² at age 28, which increases to 10.25 N/mm² at day 90, outperforming C, indicating that superplasticizers (SPP) at low dosage with metakaolin (MTK) can improve strength performance through particle dispersion and pozzolanic reactions (Alsadey & Omran, 2022). R2 initial strength is 2.50 N/mm² at 28 days and then rises to 6.72 N/mm² at 90 days. R3 mixes exhibit the lowest flexural strength, ranging from 2.17 N/mm² to 4.82 N/mm² at 28 to 90 days, suggesting that high SPP content may cause segregation or weaken the interfacial transition zone, as supported by the literature (ACI Committee 212, 2010). The mixes show an upward trend in flexural strength with hydration age, with the most notable gains between 28 and 56 days, stabilizing by 90 days, consistent with the age-related strength improvement of concrete (Orame et al., 2020; Zakka et al., 2021). The results, therefore, indicate that an optimal SPP at 0.5% with 10% MTK maximizes flexural strength, while higher SPP levels reduce it (Zahabi & Aly, 2021).

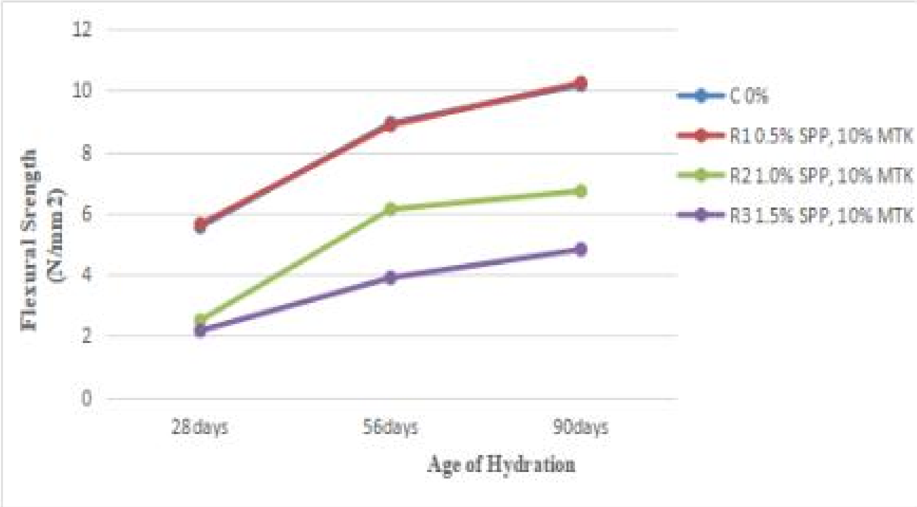

Fig.5: Flexural Strength of Concrete

IV. CONCLUSION AND RECOMMENDATONS

In conclusion, the study revealed that sesame plant powder (SPP), as a plant-based admixture, when used with metakaolin (MTK) as a partial replacement for cement, can be used to produce self-curing concrete in the sub-Saharan region. Their use as an internal self-curing agent improves curing efficiency, reducing over-reliance on external water curing. When the 0.5% SPP and 10% MTK mix is used, it produces superior, balanced workability and compressive and flexural properties of concrete compared to the control mix (C). Therefore, when SPP and MTK are combined in self-curing concrete production, it provides a viable, eco-friendly, and cost-effective alternative for sustainable concrete production, suitable for water-scarce regions such as sub-Saharan Africa.

RECOMMENDATIONS:

1. The 0.5% SPP and 10% MTK replacement levels are recommended for practical applications to achieve optimal performance in self-curing concrete production.
2. SPP and MTK should be promoted as sustainable materials, as they reduce cement consumption in concrete production and, most importantly, reduce CO_2 emissions.
3. The use of SPP as an internal self-curing technique should be adopted when external water curing is not feasible or expensive.
4. Standardization bodies such as SON and NIS, and other research institutes such as NBRRI, should, as needed, develop guidelines for the use of organic-based admixtures, such as SPP, for various types of concrete production.
5. Adequate quality control mechanisms should be provided and maintained in the production processes of SPP and MTK, and the calcination should be performed to ensure optimal consistency in performance.

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