FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 21, November, 2026, pp 258 – 263
DOI: https://doi.org/10.33003/fjs-2026-1021-6182

Water Absorption and Sulphuric Acid Resistance of Metakaolin–Sisal Fibre Concrete

[*1]Giwa Zainab Tolu, [2]Ajamu Solomon Olalere

[1]Department of Civil and Environmental Engineering, Kwara State University, Malete, Kwara State, Nigeria
[2]Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria

*Corresponding authors' email: zainab.giwa@kwasu.edu.ng

Received: 07 Oct. 2026
Accepted: 02 Nov. 2026
Published: 02 Nov. 2026

ABSTRACT
This study investigated water absorption and sulphuric-acid resistance of metakaolin (MK) and alkali-treated sisal fibre (SF) concrete using a Grade 50 reference mixture. Nineteen experimental runs represented 14 unique formulations and five repeated design points, covering 0–30% MK replacement and 0–3% SF addition by binder mass at a constant water-to-binder ratio of 0.28. Three specimens per formulation were assigned to each acid-exposure period. The 28-day pre-exposure compressive strengths ranged from 15.60 to 52.04 MPa across the formulations. Water absorption was determined at 28 days using a 24-h room-temperature immersion procedure based on ASTM C642-13, while acid resistance was evaluated after 28, 56 and 112 days of exposure to 5% (v/v) H_2SO_4 using mass loss, residual compressive strength and percentage strength loss. Water absorption increased from 3.90% in the control to 6.67% for MK30-SF3. MK7.5-SF0.75 recorded the highest residual compressive strengths at 28 and 56 days, with values of 44.40 and 38.40 MPa, respectively, whereas MK0-SF3 recorded the highest 112-day residual strength at 28.24 MPa. Although MK30-SF3 recorded a relatively low 112-day mass loss of 7.08%, its residual strength was only 8.00 MPa. The results show that durability ranking depended on mixture composition, exposure duration and the indicator considered under the tested acid-exposure conditions. Mass loss and residual compressive strength should therefore be considered together when assessing prolonged sulphuric-acid exposure.

Keywords: Metakaolin; Sisal Fibre; Water Absorption; Sulphuric Acid; Residual Strength

INTRODUCTION

Durability is an important consideration in high-strength concrete, as achieving high compressive strength does not always mean that the concrete will perform well when exposed to moisture or aggressive chemicals (Poon et al., 2001). One way of improving its long-term performance is to replace part of the Portland cement with supplementary cementitious materials. According to Badogiannis and Tsivilis (2009), these materials can affect the hydration process and alter concrete's pore structure, thereby influencing the flow of water and other hazardous pollutants through the material. Because of its high pozzolanic reactivity, metakaolin is very beneficial in this context. It can contribute to a denser matrix by reacting with the calcium hydroxide created during cement hydration to create higher-quality cementitious products. However, the benefits of metakaolin are not the same at all replacement levels. Its performance depends on factors such as the amount used, water demand, admixture dosage and how well the concrete is compacted (Mobasher et al., 2010; Dinakar et al., 2013).

Sisal (*Agave sisalana*) fibre has attracted interest as a natural reinforcement for cement-based materials because of its low density and potential to contribute to crack control (Melo Filho et al., 2013; Okeola et al., 2018). However, sisal fibre is hydrophilic and may undergo dimensional changes, while prolonged exposure to the alkaline cement environment can contribute to fibre degradation (Fode et al., 2024; Wei & Meyer, 2014; de Klerk et al., 2020). Consequently, fibre treatment, dosage and dispersion can influence its interaction with the cement matrix and the resulting composite performance (Castoldi et al., 2022; Liang et al., 2025; Okeola et al., 2018).

When metakaolin and treated sisal fibre are used together, their effects on concrete are not necessarily straightforward. Metakaolin can react with calcium hydroxide and alter the pore structure of the cement matrix, while sisal fibre, when used in a suitable amount, can help control the development and spread of cracks. These benefits, however, depend on the proportions used. A high metakaolin content may increase water demand and reduce workability, while too much fibre can make mixing and compaction more difficult and may introduce additional voids or poorly bonded regions within the concrete. Therefore, increasing the amount of either material does not automatically result in better performance. The durability response depends largely on the mixture proportions and the conditions to which the concrete is exposed.

This becomes particularly important when the concrete is exposed to sulphuric acid. Sulphuric acid can attack the products formed during cement hydration, gradually weakening the cement matrix. As the attack continues, the concrete may lose material, develop cracks and eventually suffer a considerable reduction in strength (Bassuoni & Nehdi, 2007; Usman & Sam, 2017; Wang et al., 2022; Xiao et al., 2022). The rate and extent of this deterioration can vary considerably between mixtures because the resistance of the concrete depends on its composition, pore structure and initial quality.

Previous research has examined metakaolin and sisal fibre both separately and in combination. Abdullahi and Duna (2017) investigated metakaolin in sisal-fibre-reinforced concrete, with emphasis on compressive and flexural strength, while Melo Filho et al. (2013) examined degradation and ageing mechanisms in sisal-fibre cement composite systems. These studies provide useful evidence on the

behaviour of the two materials, but they do not address the combined durability response of the present mixture system using water absorption, mass loss, residual compressive strength and percentage strength loss across prolonged sulphuric-acid exposure. Accordingly, the present study examines how these indicators respond to changes in MK and SF contents and exposure duration.

MATERIALS AND METHODS

Constituent Materials

The primary binder was Portland limestone cement (PLC), strength class 42.5R. The Nigerian Building and Road Research Institute (NBRRI), located in Sango Otta, Ogun State, produced metakaolin by calcining kaolin from Ado-Ekiti, Nigeria, at 800 °C for two hours in a gas-powered furnace. X-ray fluorescence analysis gave 72.48% SiO_2, 20.32% Al_2O_3 and 1.10% Fe_2O_3, corresponding to a combined SiO_2 + Al_2O_3 + Fe_2O_3 content of 93.90%. Metakaolin replaced PLC at 0-30% by binder mass.

Sisal fibre was sourced locally in Ilorin, Nigeria. The fibres were washed with clean water, immersed in 5% NaOH solution for 4 h, washed thoroughly with distilled water, dried and stored under dry conditions until use. The treated fibres were cut to a nominal length of 30 mm and incorporated at 0-3% by weight of binder. Natural river sand from the Asa-Dam River was used as fine aggregate, while crushed granite passing the 12.5 mm sieve and retained on the 4.75 mm sieve was used as coarse aggregate. Clean water was used for mixing and curing. COSTAMIX 200R high-range water-reducing admixture was used at 1.8% by weight of cement.

Concrete Mixture Design and Experimental Matrix

Grade 50 concrete was used as the reference mixture, with the mix proportions determined in accordance with the Council for the Regulation of Engineering in Nigeria (COREN) Concrete Mix Design Manual (2017). The reference mix contained 550 kg/m³ of binder, 678.4 kg/m³ of fine aggregate, 1017.6 kg/m³ of coarse aggregate and 154 kg/m³ of water, giving a water-to-binder ratio of 0.28. Metakaolin replaced Portland limestone cement (PLC) at 0–30% of the binder mass, whereas sisal fibre was incorporated as an addition at 0–3% of the binder mass. The superplasticizer was used at 1.8% of the actual cement mass; therefore, its absolute dosage decreased as the proportion of PLC replaced by MK increased. Design-Expert Version 13 (Stat-Ease, Minneapolis, USA) was used to generate an Optimal Custom Design using an I-optimal point-exchange algorithm for the mixture–process system. Nineteen experimental runs represented 14 unique formulations and five repeated design points. The repeated runs were Run 11 = Run 9, Run 12 = Run 9, Run 14 = Run 4, Run 17 = Run 6 and Run 18 = Run 3. Table 1 summarises the experimental framework adopted for the production and evaluation of metakaolin–sisal fibre concrete. The complete run-level matrix and the corresponding pre-exposure and 28-day response values are provided in Supplementary Table S1.

Table 1: Experimental Framework for Metakaolin–Sisal Fibre Concrete

Parameter	Value/range	Role
Reference concrete	Grade 50	Baseline
Binder content	550 kg/m³	Constant binder quantity
Water-to-binder ratio	0.28	Constant across mixtures
Metakaolin replacement	0-30% of binder	SCM factor
Sisal fibre content	0–3% of binder mass	Natural-fibre factor
Sisal fibre length	30 mm	Constant geometry
Superplasticizer	1.8% of binder mass	Workability control
Experimental runs	19 (14 unique; 5 repeated)	Combined MK-SF design space
Initial water curing	28 days	Pre-exposure conditioning
H_2SO_4 concentration	5% (v/v)	Accelerated acid environment
Acid exposure	28, 56, 112 days	Time-dependent deterioration
Repeated runs	11=9; 12=9; 14=4; 17=6; 18=3	Design repetition

Note: The 14 unique formulations and all 19 experimental runs are listed in Supplementary Table S1. The 28-day pre-exposure compressive strengths ranged from 15.60 to 52.04 MPa. Grade 50 refers to the reference mix designation and target, not to a requirement that every modified formulation achieved 50 MPa.

Mixing, Casting and Curing

All mixtures were prepared in a mechanically driven concrete mixer using the same sequence. Portland limestone cement and metakaolin were first combined, followed by the fine and coarse aggregates and the treated sisal fibre. The constituents were dry-mixed to promote uniform distribution. Water was then added, followed by the superplasticizer, and mixing continued until a visually homogeneous fresh concrete was obtained. Exact mixing durations were not recorded in the retained laboratory records. The fresh concrete was placed in the moulds and compacted, then allowed to set for approximately 24 h before demoulding. After demoulding, the specimens were transferred to water for curing. The curing-water temperature was not recorded in the retained laboratory records. Concrete cubes measuring 100 × 100 × 100 mm were used for the compressive-strength-related durability tests. Specimens designated for sulphuric-acid exposure were water-cured for 28 days before transfer to the acid-exposure containers.

Water Absorption

Water absorption was determined at 28 days using a 24-h room-temperature immersion procedure based on ASTM C642-13 (ASTM International, 2013). Specimens were oven-dried at 105 ± 5 °C until a consistent mass was attained and the dry mass (W_d) was recorded. The dried specimens were then immersed in room-temperature water for 24 h. After immersion, excess surface water was removed using a damp cloth, and the specimens were immediately weighed to obtain the wet mass (W_w). Water absorption was calculated using Eq. (1).

$$Water\ absorption\ (\%) = \frac{Ww - Wd}{Wd} x\ 100 \qquad (1)$$

Sulphuric-Acid Exposure and Durability Indices

Following 28 days of water curing, the specimens were immersed in a 5% (v/v) H_2SO_4 solution in 25-L paint containers. Nine 100 × 100 × 100 mm concrete cubes were used for each mixture, with three specimens assigned to each exposure period of 28, 56 and 112 days. The specimens were completely immersed in the acid solution throughout the designated exposure period. The acid solution was not replaced as the exposure duration increased, and its pH was not monitored. The exact volume of acid solution used per container was not recorded in the retained experimental records; therefore, no numerical acid-volume-to-specimen ratio is reported.

$$Mass\ loss\ (\%) = \frac{Mo - Mt}{Mo}\ x\ 100 \qquad (2)$$

At the end of each exposure period, the designated specimens were removed from the acid solution and rinsed with water to remove residual acid from the specimen surfaces before the relevant measurements were performed. The retained records did not specify a fixed rinsing volume or duration. Mass loss was determined using Eq. (2). Residual compressive strength was measured using the compression-testing principle of BS EN 12390-3:2009 (British Standards Institution, 2009) at a loading rate of 6 kN/s. Percentage compressive-strength loss was determined using Eq. (3), with the corresponding 28-day pre-exposure compressive strength used as the denominator.

$$Compressive\ strength\ loss\ (\%) = \frac{f0 - ft}{f0}\ x\ 100 \qquad (3)$$

Data Interpretation

The durability assessment used four complementary indicators: 28-day water absorption, acid-induced mass loss, residual compressive strength and percentage compressive-strength loss. Design-Expert Version 13 was used to generate the Optimal Custom Design, and the repeated design points were retained in the dataset as generated by the design. Because the retained dataset contains run-level values rather than individual specimen-level observations, replicate standard deviations, error bars and inferential comparisons could not be calculated without introducing unsupported values. The analysis therefore focuses on recorded mixture-level trends, exposure-time effects and differences in the rankings produced by the individual durability indicators. Where mechanisms are discussed, they are presented as possible explanations rather than as directly demonstrated causes unless they were measured in the present study.

RESULTS AND DISCUSSION

Water Absorption

Figure 1 presents the 28-day water absorption results. Water absorption increased from 3.90% for the control mixture (MK0-SF0) to 6.67% for MK30-SF3, representing an increase of about 71.0%. Among the fibre-free mixtures, absorption increased from 3.90% in the control to 4.28%, 4.81% and 5.38% at 7.5%, 15% and 30% MK, respectively. This differs from reports of reduced water absorption with metakaolin through pozzolanic activity and pore refinement (Badogiannis & Tsivilis, 2009; Mobasher et al., 2010). Under the mixture conditions used here, the increase with MK may be related to higher replacement levels and associated changes in water demand and workability, which could have affected consolidation.

Sisal fibre also increased water absorption. At 0% MK, absorption rose from 3.90% without fibre to 4.52% and 4.94% at 1.5% and 3% SF, respectively. The hydrophilic nature of sisal may contribute to water uptake, while higher fibre contents can make dispersion and compaction more difficult (Toledo Filho et al., 2000; de Klerk et al., 2020; Castoldi et al., 2022). The slump reduction from 45 mm for the control to 18 mm for MK30-SF3 supports the change in workability as the combined MK–SF content increased.

Water absorption therefore increased rather than decreased as MK and SF contents increased under the conditions investigated. The result suggests that the use of these materials to improve durability needs to be considered alongside their effects on workability and compaction.

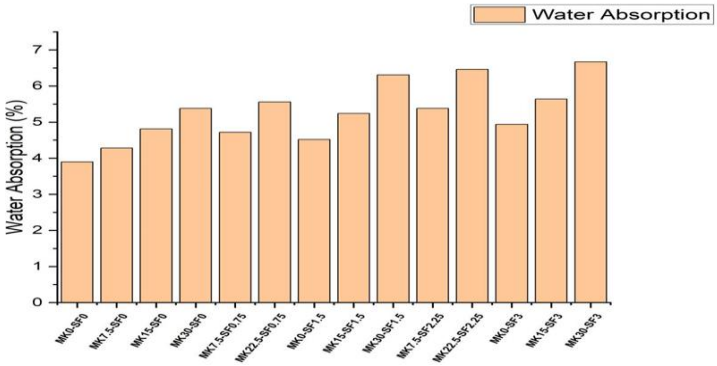


Figure 1: 28-Day Water Absorption of the Concrete Mixtures. Source: Authors' Experimental Data

Mass Loss under Sulphuric-Acid Exposure

Figure 2 presents the mass loss of the concrete mixtures after exposure to 5% H_2SO_4 for 28, 56 and 112 days. The control mixture (MK0-SF0) recorded mass losses of 6.73%, 7.55% and 9.85% at 28, 56 and 112 days, respectively. The increase with exposure duration indicates progressive deterioration of the concrete as the acid continued to react with the cementitious matrix and weakened the exposed material. Similar increases in mass loss with prolonged sulphuric acid exposure have been reported by Bassuoni and Nehdi (2007), Usman and Sam (2017), and Wang et al. (2022).

The incorporation of metakaolin (MK) did not result in a consistent reduction in mass loss. At 112 days, the fibre-free mixtures containing 7.5%, 15% and 30% MK recorded mass losses of 10.06%, 9.63% and 10.04%, respectively, compared with 9.85% for the control. Although the 15% MK mixture recorded a slightly lower mass loss than the control, the 7.5% and 30% MK mixtures recorded slightly higher values. Increasing MK replacement therefore did not produce a progressive improvement in resistance to sulphuric acid attack.

The addition of sisal fibre produced a more varied response. MK30-SF3, for example, recorded mass losses of 0.53%,

2.71% and 7.08% after 28, 56 and 112 days, respectively. Its mass loss at 112 days was lower than that of the control and the corresponding fibre-free mixture. The relatively low mass loss may be associated with fibre bridging, which could have helped to retain weakened surface material and limit its detachment from the specimen. The hydrophilic nature of sisal fibre and its interaction with the cementitious matrix may also have influenced the response to prolonged acid exposure.

The results indicate that the incorporation of MK and sisal fibre did not produce a simple or consistent reduction in mass loss under 5% H_2SO_4 exposure. The response varied with the combination of MK and SF contents and became more pronounced as the exposure period increased.

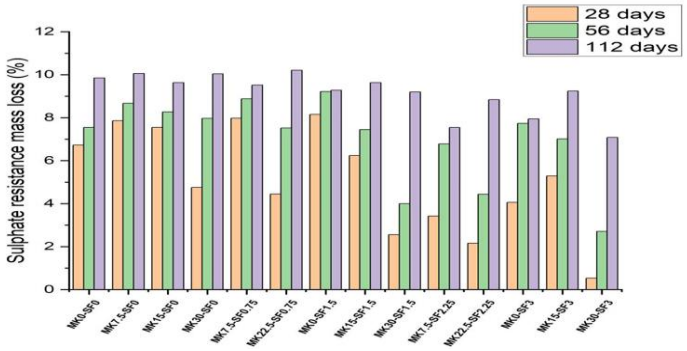


Figure 2: Mass Loss Under Sulphuric-Acid Exposure. Source: Authors' Experimental Data

Residual Compressive Strength

Figure 3 presents the residual compressive strength of the concrete mixtures after exposure to 5% H_2SO_4 for 28, 56 and 112 days. The control mixture (MK0-SF0) recorded residual strengths of 40.53, 30.20 and 19.11 MPa at 28, 56 and 112 days, respectively, compared with its pre-exposure strength of 51.73 MPa. The reduction in residual strength with exposure duration shows the continuing effect of sulphuric acid on the concrete.

MK7.5-SF0.75 recorded the highest residual compressive strengths at 28 and 56 days, with values of 44.40 and 38.40 MPa, respectively. The relatively high residual strength may be linked to the combination of 7.5% MK and 0.75% sisal fibre, which appears to have provided a favourable balance between the two materials at the early exposure periods. This benefit was less evident as the exposure period increased.

At 112 days, MK0-SF3 recorded the highest residual compressive strength, retaining 28.24 MPa. Its strength remained relatively stable between 56 and 112 days compared with several of the other mixtures, indicating a comparatively strong long-term load-bearing response under the acid exposure.

The combined use of MK and sisal fibre produced different responses at different proportions. MK22.5-SF2.25 maintained higher residual strength than MK22.5-SF0.75 throughout the exposure period, indicating that fibre dosage affected the response at the same MK level. In contrast, MK30-SF3 retained approximately 13.00 MPa after 28 days and only 8.00 MPa after 112 days. Its low residual strength contrasts with the relatively low mass loss recorded for the same mixture.

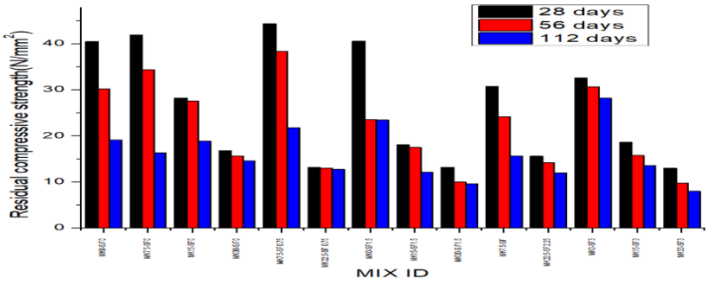


Figure 3: Residual Compressive Strength Under Sulphuric-Acid Exposure. Source: Authors' Experimental Data

Percentage Compressive-Strength Loss

Figure 4 presents the percentage compressive-strength loss of the concrete mixtures after exposure to 5% H_2SO_4 for 28, 56 and 112 days. The control mixture recorded strength losses of 21.65%, 41.62% and 63.06% at 28, 56 and 112 days, respectively. Strength loss therefore increased as the exposure period increased, although the magnitude of deterioration varied among the mixtures.

MK15-SF0 recorded the lowest percentage strength losses during the early exposure periods, with 2.76% loss at 28 days and 5.03% at 56 days. At 112 days, the loss increased to 34.89%. The mixture therefore retained a large proportion of its initial strength during the first 56 days, but the advantage became less pronounced with prolonged exposure.

MK7.5-SF0.75 recorded strength losses of 14.68%, 26.21% and 58.11% at 28, 56 and 112 days, respectively. In comparison, MK0-SF3 recorded lower losses of 10.93%, 16.09% and 22.84% over the same periods, giving it the lowest proportional strength loss at 112 days. The mixture with the highest early residual strength was therefore not the mixture with the best long-term proportional retention.

The combined use of MK and sisal fibre also produced different levels of strength retention. MK22.5-SF2.25 recorded strength losses of 9.30%, 17.44% and 30.23% at 28,

56 and 112 days, respectively, whereas MK22.5-SF0.75 recorded much higher losses of 60.24%, 60.84% and 61.45%. The difference between these mixtures, despite their identical MK content, shows that fibre dosage influenced proportional strength retention at this MK level.

MK30-SF3 recorded strength losses of 16.67%, 37.18% and 48.72% at 28, 56 and 112 days, respectively. Its increasing strength loss with exposure duration shows that the combined use of high MK and high fibre content did not prevent progressive deterioration under prolonged sulphuric acid exposure.

The percentage strength-loss results provide a different basis for comparing the mixtures because they express deterioration relative to each mixture's initial strength. This is particularly relevant because the mixtures differed in their initial compressive strengths. MK15-SF0 showed the lowest strength losses during the first 56 days, whereas MK0-SF3 recorded the lowest loss at 112 days. The response to sisal fibre also depended on the MK content, indicating that improved strength retention was associated with particular MK–SF combinations rather than simply increasing the content of either material.

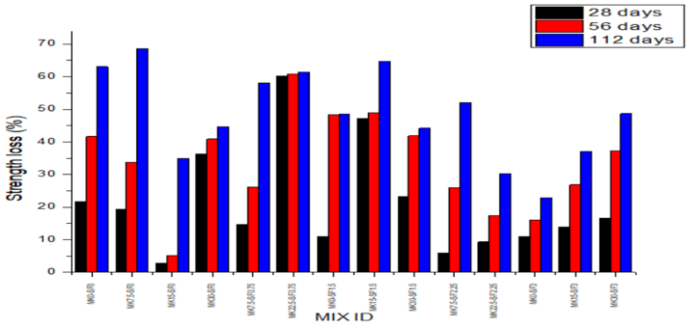


Figure 4: Percentage Compressive-Strength Loss Under Sulphuric-Acid Exposure

Indicator-Dependent Durability Ranking

The durability indicators did not rank the mixtures in the same order. For example, MK30-SF3 recorded the lowest mass loss at 112 days (7.08%), yet its residual compressive strength was only 8.00 MPa. This difference indicates that limited material loss from the specimen surface did not necessarily correspond to better retention of load-bearing capacity. Similar differences between mass loss and strength deterioration have been reported for concrete exposed to sulphuric acid (Bassuoni & Nehdi, 2007).

The exposure periods provide different stages for assessing the response of the mixtures. The 28-day results represent the early response following the initial curing period, 56 days provides an intermediate stage, while 112 days shows the longer-term trend within the laboratory exposure condition. Changes in mixture ranking across these periods demonstrate that performance at an early stage may not necessarily be maintained with prolonged acid exposure. The results should therefore be interpreted within the conditions of the experiment rather than as direct equivalents of field service periods.

Each indicator provided a different aspect of durability performance. Water absorption reflects water uptake before acid exposure, mass loss measures material physically lost during acid attack, residual compressive strength represents the load-bearing capacity retained after exposure, and percentage strength loss expresses deterioration relative to the pre-exposure strength. Considering these indicators together provides a broader assessment of the MK–SF mixtures than any single measure. Table 2 summarises the contrasting performance of selected mixtures, while the complete run-level baseline and 28-day response data are provided in Supplementary Table S1.

Table 2: Comparative Durability Performance of Selected MK–SF Mixtures, Including Pre-Exposure Strength

Mixture	Main durability advantage	Main limitation	Engineering interpretation	28-day pre-exposure compressive strength (MPa)
MK0-SF0	Lowest water absorption (3.90%)	63.06% strength loss at 112 d	Low water absorption did not correspond to better long-term acid resistance.	51.73
MK7.5-SF0.75	Highest residual strength at 28 and 56 d (44.40 and 38.40 MPa)	58.11% strength loss at 112 d	Favourable residual-strength performance at early and intermediate exposure periods.	52.04
MK0-SF3	Highest 112-d residual strength (28.24 MPa)	Higher water absorption than control	Best long-term residual-strength performance among the mixtures tested.	36.60
MK15-SF0	Very low strength loss at 28 and 56 d (2.76% and 5.03%)	Strength loss increased to 34.89% at 112 d	Maintained a high proportion of its initial strength during earlier exposure.	29.03
MK30-SF3	Lowest 112-day mass loss (7.08%)	Residual strength of only 8.00 MPa	Low mass loss did not correspond to high residual strength.	15.60

Note. Pre-exposure strengths are the corresponding 28-day values used as f_0 in Eq. (3). Complete 19-run data are provided in Supplementary Table S1.

CONCLUSION

Water absorption increased from 3.90% in the control mixture to 6.67% in MK30-SF3. Under 5% (v/v) H_2SO_4 exposure, compressive strength generally decreased as the exposure period increased, although the extent of deterioration varied among the mixtures. MK7.5-SF0.75 recorded the highest residual compressive strengths at 28 and 56 days, with values of 44.40 and 38.40 MPa, respectively, while MK0-SF3 retained the highest residual strength at 112 days (28.24 MPa). MK30-SF3 recorded the lowest mass loss at 112 days (7.08%), but its residual strength was only 8.00 MPa, showing that low physical mass loss did not necessarily correspond to better retention of load-bearing capacity. The durability performance of the mixtures therefore depended on the combination of MK and SF, the duration of acid exposure, and the indicator used for assessment rather than on increasing either material alone. These findings are limited to the accelerated 5% (v/v) H_2SO_4 immersion condition and the available run-level data; the proposed deterioration mechanisms were not directly characterised.

ACKNOWLEDGEMENTS

The authors acknowledge the technical support received during the laboratory preparation and testing of the concrete specimens.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

REFERENCES

Abdullahi, M., & Duna, S. (2017). Effect of metakaolin on the strength properties of sisal fibre reinforced concrete. Current Journal of Applied Science and Technology, 25(2), 1–12. https://doi.org/10.9734/CJAST/2017/36189

ASTM International. (2013). ASTM C642-13: Standard test method for density, absorption, and voids in hardened concrete.

Badogiannis, E., & Tsivilis, S. (2009). Exploitation of poor Greek kaolins: Durability of metakaolin concrete. *Cement and Concrete Composites*, *31*(2), 128–133. https://doi.org/10.1016/j.cemconcomp.2008.11.001

Bassuoni, M. T., & Nehdi, M. L. (2007). Resistance of self-consolidating concrete to sulfuric acid attack with consecutive pH reduction. *Cement and Concrete Research*, *37*(7), 1070–1084. https://doi.org/10.1016/j.cemconres.2007.04.014

British Standards Institution. (2009). Testing hardened concrete—Compressive strength of test specimens (BS EN 12390-3:2009).

Castoldi, R. S., de Souza, L. M. S., Souto, F., Liebscher, M., Mechtcherine, V., & de Andrade Silva, F. (2022). Effect of alkali treatment on physical–chemical properties of sisal fibers and adhesion towards cement-based matrices. *Construction and Building Materials*, *345*, 128363. https://doi.org/10.1016/j.conbuildmat.2022.128363

Council for the Regulation of Engineering in Nigeria. (2017). Concrete mix design manual (1st ed., Special Publication No. COREN/2017/016/RC).

de Klerk, M. D., Kayondo, M., Moelich, G. M., de Villiers, W. I., Combrinck, R., & Boshoff, W. P. (2020). Durability of chemically modified sisal fibre in cement-based composites. *Construction and Building Materials*, *241*, 117835. https://doi.org/10.1016/j.conbuildmat.2019.117835

Dinakar, P., Sahoo, P. K., & Sriram, G. (2013). Effect of metakaolin content on the properties of high strength concrete. *International Journal of Concrete Structures and Materials*, *7*(3), 215–223. https://doi.org/10.1007/s40069-013-0045-0

Fode, T. A., Jande, Y. A. C., Kivevele, T., & Rahbar, N. (2024). A review on degradation improvement of sisal fiber by alkali and pozzolana for cement composite materials. *Journal of Natural Fibers*, *21*(1), 2335327. https://doi.org/10.1080/15440478.2024.2335327

Liang, J., Wang, X., Fu, Z., Li, Z., Liang, L., Luo, Q., & Long, W. (2025). Enhancing the applicability of sisal fibers in cement-based materials through alkali treatment and penetrating crystallization. *Journal of Cleaner Production*, *490*, 144736. https://doi.org/10.1016/j.jclepro.2025.144736

Melo Filho, J. A., de Andrade Silva, F., & Toledo Filho, R. D. (2013). Degradation kinetics and aging mechanisms on sisal fiber cement composite systems. *Cement and Concrete Composites*, *40*, 30–39. https://doi.org/10.1016/j.cemconcomp.2013.04.003

Mobasher, B., Shekarchi, M., Bonakdar, A., Bakhshi, M., & Mirdamadi, A. (2010**).** Transport properties in metakaolin blended concrete. *Construction and Building Materials*, *24*(11), 2217–2223. https://doi.org/10.1016/j.conbuildmat.2010.04.035

Okeola, A. A., Abuodha, S. O., & Mwero, J. (2018). Experimental investigation of the physical and mechanical properties of sisal fiber-reinforced concrete. *Fibers*, *6*(3), 53. https://doi.org/10.3390/fib6030053

Poon, C. S., Lam, L., Kou, S. C., Wong, Y. L., & Wong, R. (2001). Rate of pozzolanic reaction of metakaolin in high-performance cement pastes. *Cement and Concrete Research*, *31*(9), 1301–1306. https://doi.org/10.1016/S0008-8846(01)00581-6

Toledo Filho, R. D., Scrivener, K., England, G. L., & Ghavami, K. (2000). Durability of alkali-sensitive sisal and coconut fibres in cement mortar composites. *Cement and Concrete Composites*, *22*(2), 127–143. https://doi.org/10.1016/S0958-9465(99)00039-6

Usman, J., & Sam, A. M. (2017). Acid resistance of palm oil fuel ash and metakaolin ternary blend cement mortar. *Sustainable Environment Research*, *27*(4), 181–187. https://doi.org/10.1016/j.serj.2017.02.003

Wang, X., Wang, W., Liu, Q., Wang, S., Luo, H., Ji, S., & Zhu, J. (2022). Effects of metakaolin on sulfate and sulfuric acid resistance of grouting restoration materials. *Construction and Building Materials*, *349*, 128714. https://doi.org/10.1016/j.conbuildmat.2022.128714

Wei, J., & Meyer, C. (2014). Improving degradation resistance of sisal fiber in concrete through fiber surface treatment. *Applied Surface Science*, *289*, 511–523. https://doi.org/10.1016/j.apsusc.2013.11.024

Xiao, J., Long, X., Qu, W., Li, L., Jiang, H., & Zhong, Z. (2022). Influence of sulfuric acid corrosion on concrete stress–strain relationship under uniaxial compression. Measurement, 187, 110318. https://doi.org/10.1016/j.measurement.2021.110318

©2026 This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International license viewed via https://creativecommons.org/licenses/by/4.0/ which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is cited appropriately.