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Comparative Structural and Thermal Elucidation of Cellulose and Kaolin as Sustainable Construction Materials

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Abstract

Rising demand for sustainable, energy-efficient construction materials has driven interest in alternatives such as cellulose and kaolin. This study compares their structural and thermal properties using Raman spectroscopy and TGA/DTA. Raman results show clear differences: cellulose exhibits characteristic polymer bands at ~1370–1400 cm^{-1} (CH bending) and ~1100 cm^{-1} (C–O–C stretching), while kaolin displays sharp lattice vibration peaks between 120 and 500 cm^{-1} associated with Si–O and Al–O bonds, indicating a more ordered crystalline structure. Thermal analysis highlights contrasting stability: cellulose shows minor moisture loss (~2.48%) below 120 °C but undergoes major degradation between 280 and 360 °C with ~85.92% weight loss, reflecting low thermal resistance. In contrast, kaolin experiences its main dehydroxylation stage between 450 and 650 °C and retains high residual stability. Overall, kaolin offers superior thermal stability and structural strength, while cellulose provides low density and good insulation but limited heat resistance. Their complementary properties make them suitable for developing hybrid cellulose–kaolin composites for sustainable, thermally optimized construction materials.t.

Keywords: Cellulose, Kaolin, Raman Spectroscopy, Thermal Properties, Sustainable Construction

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1. Introduction

The environmental impact of traditional materials such as cement and concrete is substantial, being among the top contributors to greenhouse gas emissions and resource depletion (Mora-Ruiz *et al*., 2025; Kallayil *et al*., 2025). Consequently, the global construction industry is moving towards sustainable, energy-efficient materials. Biopolymers, including cellulose, have become promising alternatives for their renewability, biodegradability, and tunable properties. In particular, cellulose shows strong mechanical performance and good thermal insulation, especially in nanostructured form or in composites, and thus is suitable for energy-efficient building components (Sumaila *et al*., 2020; Akartasse *et al*., 2022; Sumaila *et al*., 2022; Tabaght *et al*., 2023; Ali *et al*., 2024; Alwan *et al*., 2025; Amponsah *et al*., 2025;).

Conversely, mineral materials like kaolin are extensively utilized because of their availability, cheapness, and good physicochemical properties such as high thermal stability and structural strength (Azanfire *et al*., 2025; Mustapha *et al*., 2020; Sumaila *et al*., 2017). Performance of clay minerals such as kaolin and bentonite in composites depends on the changes in their crystal structure and thermal behaviour (Soliman and Shahat, 2026).

Due to these enhanced features, clay-based composites have received significant consideration for environmental remediation applications (Aboussabek *et al.,* 2026; Dehmani *et al*., 2026; Mouaki and Onescu, 2026). They have been effectively used in the adsorption and photocatalytic degradation of organic pollutants, predominantly textile dyes such as methylene blue, methyl orange, methyl red, and rhodamine B (Mokhtar *et al.,* 2024; Latifi *et al.,* 2025; Dawood *et al.,* 2025), as well as in the removal of lethal heavy metals including As^{3+}/As^{5+}, Cd^{2+}, Cr^{6+}, Cu^{2+}, Hg^{2+}, and $Pb^{2+}$from polluted water (Oladimeji *et al.,* 2024; Wang *et al.,* 2024). Also, these composites have shown potential performance in the treatment of pharmaceutical wastes, pesticides, phenolic compounds, and other emerging pollutants owing to their high specific surface area, abundant active adsorption sites, and improved photocatalytic activity when incorporated with metal oxides or nanomaterials (Kamel *et al.,* 2025; Hublikar *et al.,* 2026). These characteristics make kaolin-based composites sustainable, cost-effective, and environmentally friendly materials for wastewater treatment and pollution control, thus contributing meaningfully to the advances of safe water resources and an environment (Maia *et al*., 2025).

Although there are many individual studies, there is no systematic comparison between cellulose and kaolin, particularly regarding thermal insulation, microstructural evolution, and energy efficiency in buildings. Knowledge of these differences is important for the design of environmentally friendly materials with optimised thermal and structural performance. Such comparisons may help steer the development of sustainable building solutions that successfully balance insulation, strength, and thermal stability.

2. Materials and methods

Plant-based commercial microcrystalline cellulose (≥99% purity) was purchased from Sigma-Aldrich. The kaolin clay was sourced from a local deposit in Doko, Niger State, Nigeria. Samples were prepared using distilled water, cleaned and dispersed using analytical grade ethanol, and homogenised using a mortar and pestle, sieves, and an ultrasonic bath.

Cellulose powder was air-dried for 24 h to remove moisture. Both cellulose and kaolin samples were ground in a mortar and pestle and sieved with a 75µm sieve to ensure homogeneity.

Structural characterizations of the samples were carried out by Raman Spectroscopy with a laser wavelength of 532 nm, power: 5–10 mW, and scanning range of 100–2000 cm^{-1}. Thermogravimetric Analysis (TGA) was used to evaluate the thermal stability, decomposition temperatures, and residual mass of the samples at a heating rate of 10°C/min from 25°C to 800°C under a nitrogen atmosphere.

3. Results and discussion

Raman spectroscopy measures the vibrational modes of molecules and crystals, producing distinct "fingerprint" spectra for different materials (**Figure 1**). Each peak corresponds to a specific bond vibration or lattice mode, where the peak position (in cm^{-1}) identifies the vibrational mode, and higher peak intensity indicates stronger light scattering by that vibration.

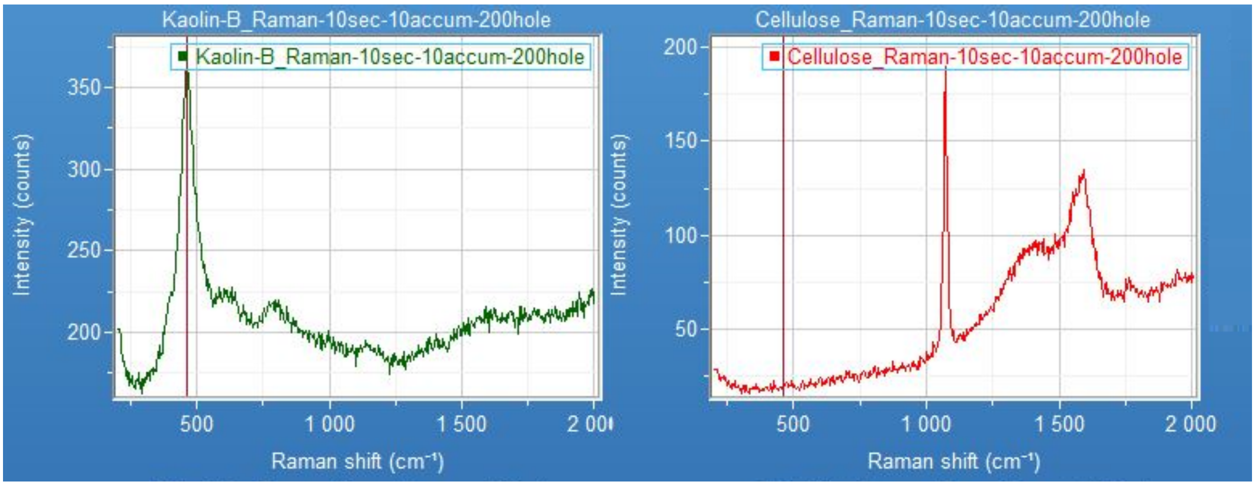

Fig 1: Raman Spectra of Cellulose and Kaolin

Cellulose exhibits characteristic Raman bands around ~1370–1400 cm^{-1} (CH bending/deformation) and a prominent ~1100 cm^{-1} band from glycosidic C–O–C stretching, widely used as a key marker, along with a broad 1000–1200 cm^{-1} region linked to strong glycosidic vibrations (Guo *et al*., 2025; Sumaila *et al*., 2020; Tofanica *et al*., 2025). These features reflect its semi-crystalline polymer structure, with broad vibrational bands arising from diverse bond types, including C–H and backbone C–O–C linkages, rather than sharp phonon peaks typical of crystalline materials.

In contrast, kaolin's Raman spectrum is governed by crystal lattice vibrations and Si–O structural modes rather than polymeric bonds (Soliman and Shahat, 2026; Mustapha *et al*., 2020). It typically shows a strong band around 120–145 cm^{-1} from O–Si–O and O–Al–O bending, additional bands between ~400 and 1200 cm^{-1} from Si–O stretching, and a prominent sharp peak near 400–500 cm^{-1} characteristic of lattice vibrations, with broader features at higher shifts due to its layered silicate structure (Onutai, Osugi, and Sone, 2023). This results in a distinctly sharper, low-wavenumber-dominated spectrum compared to the broader, polymeric profile of cellulose.

Additionally, cellulose and kaolin exhibit a typical multi-stage thermal degradation behavior in TGA/DTA analysis (**Figure 2**), consistent with lignocellulosic biopolymers

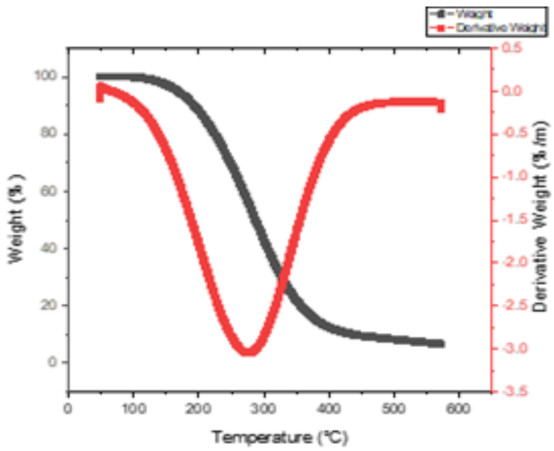

Fig 2: TGA/DTA Curves of Cellulose

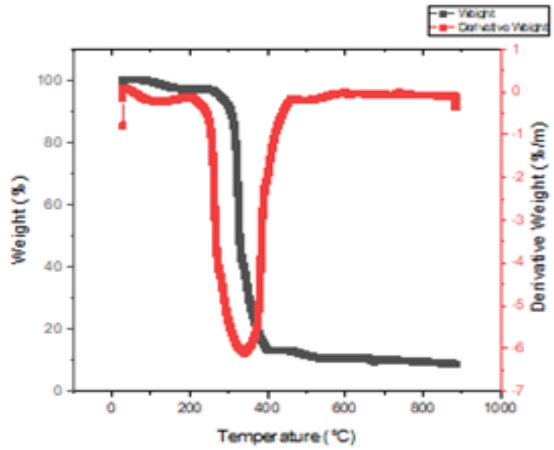

Fig 3: TGA/DTA Curves of Kaolin

The TGA/DTA analysis shows that cellulose undergoes an initial 2.48% weight loss below 135 °C due to the removal of physically adsorbed moisture, associated with a weak endothermic DTA peak from evaporation of hydrogen-bonded water (Kavitha *et al*., 2024; Song *et al*., 2025; Sumaila *et al*., 2023; Sumaila *et al*., 2022). The decomposition occurs at 277.76 °C, where the maximum mass loss rate is observed, corresponding to depolymerisation, cleavage of β-1,4-glycosidic bonds, and formation of volatile products. This stage involves simultaneous bond scission and char formation, reflected by an endothermic–exothermic transition. Consistent with the literature, cellulose typically decomposes around 280 °C depending on crystallinity and polymerisation degree (Lupidi *et al*., 2023; Stanciu *et al*., 2025). A relatively sharp DTA peak suggests a homogeneous cellulose structure with minimal impurities (Wang *et al*., 2022). Beyond 400 °C, mass stabilises, leaving about 6.67% residual char at 572.95 °C, indicating limited thermal stability and flame resistance, which constrains its use in high-temperature applications (Sumaila *et al*., 2023).

In contrast, kaolin ($Al_2Si_2O_5(OH)_4$) exhibits significantly higher thermal stability due to its inorganic crystalline structure (Mustapha *et al*., 2020; Sumaila *et al*., 2017). It shows a minor 2.23% mass loss below 150 °C from the removal of surface-adsorbed water, accompanied by a weak endothermic DTA peak. The thermal transformation occurs between 450 and 650°C, corresponding to the dehydroxylation of kaolin:

$$Al_2Si_2O_5(OH)_4 \rightarrow Al_2Si_2O_7 + 2H_2O$$

The dehydroxylation of kaolin produces metakaolin, an amorphous aluminosilicate phase, accompanied by a ~2.54% weight loss consistent with the removal of structural hydroxyl groups. This transformation is marked by a strong endothermic DTA peak at 342.21 °C and is well documented for its importance in cementitious and geopolymer applications (Xue *et al*., 2023; Buyondo *et al*., 2024; Polcowñuk Iriarte *et al*., 2025; Mustapha *et al*., 2020). Minimal additional weight loss above 700°C indicates strong thermal resistance, while further heating beyond 900°C may induce structural reorganisation toward mullite formation.

A comparison highlights fundamental differences between cellulose and kaolin. Cellulose, as an organic biopolymer, undergoes rapid thermal degradation between 280 and 360°C, resulting in substantial weight loss (~85.92%) and minimal residue, reflecting low structural and thermal stability (Sumaila *et al*., 2024; Mustpha *et al*., 2019). In contrast, kaolin, an inorganic aluminosilicate, shows much higher resistance to thermal degradation, with its main transformation (dehydroxylation to metakaolin) occurring at higher temperatures and total weight loss limited to about 12–15%, primarily due to removal of water. Its high residual mass and stability up to 600–900 °C confirm its superior thermal resistance (Mustapha *et al*., 2020).

These differences make kaolin suitable for high-temperature and structural applications, while cellulose is better suited for low-temperature insulation and lightweight composites. Thermally, cellulose decomposition involves complex endothermic–exothermic processes linked to polymer chain scission and char formation, whereas kaolin is dominated by endothermic dehydroxylation without structural collapse. Hybrid cellulose–kaolin composites offer a promising balance between insulation and thermal stability and are increasingly explored for improved fire resistance and mechanical performance in sustainable materials (Alvarado *et al*., 2024; Przybek *et al*., 2025; Sumaila *et al*., 2019; Mustapha *et al*., 2023).

Hence, TGA/DTA results confirm that cellulose exhibits typical biopolymer degradation with major mass loss and little residue, while kaolin retains significant mass and structural integrity at elevated temperatures, demonstrating their complementary roles in sustainable building material design.

Conclusion

This study was a comparison of kaolin and cellulose to gain knowledge about their structural and thermal behavior for sustainable construction. The Raman spectra indicated that cellulose has a flexible semi-crystalline polymer structure, while kaolin is a rigid, well-ordered crystalline aluminosilicate. Thermogravimetric analysis indicated that cellulose has low thermal stability and high mass loss, making it suitable for lightweight insulation, whereas kaolin has high thermal resistance and low mass loss, making it appropriate for structural and fire-resistant applications. Rather than one being better than the other, the research points to their complementary properties, such as cellulose being renewable and an insulator, and kaolin providing strength and heat resistance, which suggests that hybrid composites of the two could enhance sustainable construction materials.

Conflict of Interest

The authors declare no conflict of interest.

References

Aboussabek A., Boukarma L., Aziam R., ... Soudani A., Chiban M. (2026). Hybrid clay mineral-based photocatalysts for sustainable water treatment: structural modifications, mechanisms, and future perspectives, *Scientific African,* 33, e03526, https://doi.org/10.1016/j.sciaf.2026.e03526

Akartasse N., Azzaoui K., Mejdoubi E., Hammouti B., Elansari L.L., Abou-salama M., Aaddouz M., Sabbahi R., Rhazi L. and Siaj M. (2022), Environmental-Friendly Adsorbent Composite Based on Hydroxyapatite/Hydroxypropyl Methyl-Cellulose for Removal of Cationic Dyes from an Aqueous Solution, *Polymers,* 14(11), 2147; https://doi.org/10.3390/polym14112147

Ali, A., Issa, A., & Elshaer, A. (2024). A Comprehensive Review and Recent Trends in Thermal Insulation Materials for Energy Conservation in Buildings. *Sustainability,* 16(20), 8782. https://doi.org/10.3390/su16208782

Alvarado, C., Martínez-Cerna, D., & Alvarado-Quintana, H. (2024). Geopolymer Made from Kaolin, Diatomite, and Rice Husk Ash for Ceiling Thermal Insulation. *Buildings,* 14(1), 112. https://doi.org/10.3390/buildings14010112.

Alwan, N. T., Tarish, A. L., Yaqoob, S. J., Bajaj, M., & Zaitsev, I. (2025). Enhancing energy efficiency in buildings using sawdust-based insulation in hot arid climates. *Scientific reports,* 15(1), 8349. https://doi.org/10.1038/s41598-025-92924-7.

Amponsah, O., Nopuo, P. S. A., Manga, F. A., Catli, N. B., & Labus, K. (2025). Future-Oriented Biomaterials Based on Natural Polymer Resources: Characteristics, Application Innovations, and Development Trends. *International journal of molecular sciences*, 26(12), 5518. https://doi.org/10.3390/ijms26125518.

Azanfire, B.-E., Bulgariu, D., Cimpoeşu, N., & Bulgariu, L. (2025). Efficient Removal of Toxic Heavy Metals on Kaolinite-Based Clay: Adsorption Characteristics, Mechanism and Applicability Perspectives. *Water*, 17(13), 1938. https://doi.org/10.3390/w17131938.

Buyondo, A. K., Kasedde, H., Kirabira, J. B., & Bongomin, O. (2024). Characterization and treatment effects on Mutaka kaolin for additive in coatings: Mineral composition, thermal and structural modifications. *Heliyon*, 10(1), e24238. https://doi.org/10.1016/j.heliyon.2024.e24238.

Dawood, I., Zyoud, A. H., Zyoud, S., Amireh, A., Zyoud, S. H., & Kim, T. W. (2025). Sustainable water treatment using thermally stable natural clay: dual adsorption-thermolysis approach for organic pollutants and nitrate removal. *Scientific reports*, *15*(1), 29888. https://doi.org/10.1038/s41598-025-12148-7.

Dehmani Y., Bentahar I., Lgaz H., El-Kordy A., Aldalbahi A., Alrashdi A.A., Dehbi A., Lamhasni T., Hammouti B., Sadik A. (2026), A critical review of natural clay minerals: Structural characterization, textural properties, and adsorption mechanisms for sustainable wastewater treatment, *Materials Today Advances,* 29, 2026, 100682, ISSN 2590-0498, https://doi.org/10.1016/j.mtadv.2025.100682

Guo, J., Jiang, S., Lu, B., Zhang, W., Zhang, Y., Hu, X., Yang, W., Feng, H., & Xu, L. (2025). Exploring the potential of microscopic hyperspectral, Raman, and LIBS for nondestructive quality assessment of diverse rice samples. *Plant methods*, 21(1), 25. https://doi.org/10.1186/s13007-025-01345-0.

Hublikar, L. V., Nivedhitha, K. S., Chikkatti, B. S., Sajjan, A. M., Banapurmath, N. R., Palaniswamy, D., Beena, T., Hegde, P., Mishra, S. K., & Ravulapati, K. (2026b). Functionalized biochar–metal oxide nanocomposites for the catalytic degradation of recalcitrant pollutants in wastewater treatment. *RSC Advances*, *16*(14), 12186–12214. https://doi.org/10.1039/d5ra07670f.

Kallayil, A., Patadiya, J., Kandasubramanian, B., Adamtsevich, A., Kchaou, M., & Aldawood, F. K. (2025). Adaptive Smart Materials in Architecture: Enhancing Durability and Sustainability in Modern Construction. *ACS Omega*, 10(22), 22305–22322. https://doi.org/10.1021/acsomega.4c04943.

Kamel, A. H., Abd-Rabboh, H. S. M., Abd El-Fattah, A., Boudghene Stambouli, G., & Adeida, L. (2025). Metal oxides and their composites for the remediation of organic pesticides: advanced photocatalytic and adsorptive solutions. *RSC Advances*, *15*(9), 6875–6901. https://doi.org/10.1039/d4ra08149h.

Kavitha, S. A., Priya, R. K., Arunachalam, K. P., Avudaiappan, S., Saavedra Flores, E. I., & Blanco, D. (2024). Experimental investigation on strengthening of Zea mays root fibres for biodegradable composite materials using potassium permanganate treatment. *Scientific reports*, 14(1), 12754. https://doi.org/10.1038/s41598-024-58913-y.

Latifi S., Saoiabi S., Alanazi M. M., Boukra O., Krime A., El Hammari L., Azzaoui K., Hammouti B., Hanbali G., Jodeh S., Saoiabi A., Sabbahi R., Algarra M., Abidi N. (2025), Low-Cost Titania-Hydroxyapatite (TiHAp) nanocomposites were synthesized for removal of Methylene blue under Solar and UV irradiation, *Next Materials,* 8, 100859, ISSN 2949-8228, https://doi.org/10.1016/j.nxmate.2025.100859

Lupidi, G., Pastore, G., Marcantoni, E., & Gabrielli, S. (2023). Recent Developments in Chemical Derivatization of Microcrystalline Cellulose (MCC): Pre-Treatments, Functionalization, and Applications. *Molecules (Basel, Switzerland)*, 28(5), 2009. https://doi.org/10.3390/molecules28052009.

Maia, M. B., do Nascimento, J. L. A., da Silva, A. S., & dos Santos, I. M. G. (2025). Kaolin Waste Applied as Support for Photocatalytic Materials. *Sustainability*, *17*(4), 1605. https://doi.org/10.3390/su17041605.

Mokhtar, A., Asli, B., Abdelkrim, S., Hachemaoui, M., Boukoussa, B., Sassi, M., Viscusi, G., & Abboud, M. (2024). Polymer/Clay Nanocomposites as Advanced Adsorbents for Textile Wastewater Treatment. *Minerals*, *14*(12), 1216. https://doi.org/10.3390/min14121216.

Mora-Ruiz, V., Soto-Paz, J., Attia, S., & Mejía-Parada, C. (2025). Sustainable Earthen Construction: A Meta-Analytical Review of Environmental, Mechanical, and Thermal Performance. *Buildings*, 15(6), 918. https://doi.org/10.3390/buildings15060918.

Mouaki Benani, M., & Onescu, I. (2026). Clay-Based Composite Materials: A Review of Structural Advantages, Sustainability and Applications. *Buildings*, *16*(9), 1711. https://doi.org/10.3390/buildings16091711,

Mustapha, S., Jimoh Oladejo, T., Rabi, E., Muhammed Binin, E., Azeezah Taiwo, A., Damola Taye, S., Abdulmumuni, S., Adekunle Jelili, O., Hassana Ladio, A., Saka Abdulkareem, A., Muhammed Muhammed N. (2023). Photocatalytic degradation and defluorination of per- and polyfluoroalkyl substances (PFASs) using biosynthesized TiO_2 nanoparticles under UV–visible light. *Engineering Proceedings*, 37(10), 1–7. https://doi.org/10.3390/ECP2023-14630

Mustapha, S., Ndamitso, M. M., Abdulkareem, A. S., Tijani, J. O., Shuaib, D. T., & Mohammed, A. K. (2019). Adsorption isotherm, kinetic and thermodynamic studies for the removal of Pb (II), Cd (II), Zn (II) and Cu (II) ions from aqueous solutions using Albizia lebbeck pods. *Applied Water Science*, 9, 142.

Mustapha, S., Ndamitso, M. M., Abdulkareem, A. S., Tijani, J. O., Shuaib, D. T., Mohammed, A. K., & Sumaila, A. (2019). Comparative study of crystallite size using Williamson-Hall and Debye-Scherrer plots for ZnO nanoparticles. *Advances in Natural Sciences: Nanoscience and Nanotechnology*, 10, 045013.

Mustapha, S., Tijani, J. O., Ndamitso, M. M., Abdulkareem, A. S., Shuaib, D. T., Mohammed, A. K., & Sumaila, A. (2020). The role of kaolin and kaolin/ZnO nanoadsorbents in adsorption studies for tannery wastewater treatment. *Scientific Reports*, 10, 13068. https://doi.org/10.1038/s41598-020-69808-z

Oladimeji, T., Oyedemi, M., Emetere, M., Agboola, O., Adeoye, J., & Odunlami, O. (2024). Review on the impact of heavy metals from industrial wastewater effluent and removal technologies. *Heliyon*, *10*(23), e40370. https://doi.org/10.1016/j.heliyon.2024.e40370.

Onutai, S., Osugi, T., & Sone, T. (2023). Alumino-Silicate Structural Formation during Alkali-Activation of Metakaolin: In-Situ and Ex-Situ ATR-FTIR Studies. *Materials*, 16(3), 985. https://doi.org/10.3390/ma16030985.

Polcowñuk Iriarte, I. A., Mocciaro, A., Rendtorff, N. M., & Richard, D. (2025). Dehydroxylation of Kaolinite: Evaluation of Activation Energy by Thermogravimetric Analysis and Density Functional Theory Insights. *Minerals*, 15(6), 607. https://doi.org/10.3390/min15060607.

Przybek, A., Piątkowski, J., Romańska, P., Łach, M., & Masłoń, A. (2025). Low-Carbon Insulating Geopolymer Binders: Thermal Properties. *Sustainability*, 17(15), 6898. https://doi.org/10.3390/su17156898.

Soliman, W., & Shahat, M. A. (2026). Chemical activation of kaolin-based clay bricks as a sustainable route to enhanced mechanical and thermophysical properties. *Scientific reports*, 16(1), 4720. https://doi.org/10.1038/s41598-026-35471-z.

Soliman, W., & Shahat, M. A. (2026). Chemical activation of kaolin-based clay bricks as a sustainable route to enhanced mechanical and thermophysical properties. *Scientific reports*, 16(1), 4720. https://doi.org/10.1038/s41598-026-35471-z.

Song, L., Li, Y., Lei, T., Yang, Y., Shen, Y., Yang, M., Wang, Y., & Zheng, H. (2025). Research on the water absorption diffusion model and kinetics of pretreated straw. *Scientific reports*, 15(1), 9927. https://doi.org/10.1038/s41598-025-94157-0.

Stanciu, M.-C., Tanasă, F., & Teacă, C.-A. (2025). Crystallinity Changes in Modified Cellulose Substrates Evidenced by Spectral and X-Ray Diffraction Data. *Polysaccharides*, 6(2), 30. https://doi.org/10.3390/polysaccharides6020030.

Sumaila, A., Aliyu, A. O. C., Abdullahi, A. S., & Usman, A. O. (2024). Adsorption isotherm, kinetic, and thermodynamic studies for the removal of Pb (II) and Zn (II) ions from mining wastewater using chitosan (CH) and chitosan-copper oxide nanocomposite (CMP). *Moroccan Journal of Chemistry*, 12(2), 696–713.

Sumaila, A., Nana, B. I., Izom, I. I., Mamuda, A., Muhammad, A., & Abbas, A. M. (2017). Determination of physicochemical properties of electric transformer oil extracted from selected plant seeds in Nigeria. *International Research Journal of Engineering and Technology,* 4(9), 760–767.

Sumaila, A., Ndamitso, M. M., Iyaka, Y. A., Abdulkareem, A. S., & Tijani, J. O. (2019). Sequestration of copper (II) and iron (II) ions from electroplating effluent using crab shells chitosan stabilized silver nanocomposite. *Iranian Journal of Energy and Environment*, 10(1), 1–9.

Sumaila, A., Ndamitso, M. M., Iyaka, Y. A., Abdulkareem, A. S., & Tijani, J. O. (2020). The role of chitosan (CHS) and chitosan-silver nanoadsorbents (COMP) in adsorption of Cu (II) and Fe (II) ions from electroplating wastewater. *Advances in Environmental Studies*, 4(2), 318–330. https://doi.org/10.36959/742/228

Sumaila, A., Ndamitso, M. M., Iyaka, Y. A., Abdulkareem, A. S., Tijani, J. O., & Idris, M. O. (2020). Isolation and characterization of selected biopolymers from maize cobs and crab shells obtained in Niger State, Nigeria. *Research Journal of Material Sciences, 8(*1), 1–10.

Sumaila, A., Ndamitso, M. M., Iyaka, Y. A., Abdulkareem, A. S., Tijani, J. O., & Idris, M. O. (2020). Extraction and characterization of chitosan from crab shells: Kinetic and thermodynamic studies of arsenic and copper adsorption from electroplating wastewater. *Iraqi Journal of Science*, 61(9), 2156–2171. https://doi.org/10.24996/ijs.2020.61.9.2

Sumaila, A., Onyirioha, N. N., Erhabor, D. O., & Muhammad, H. B. (2023). Thermal and morphological studies on biosynthesized chitosan-silver nanocomposites. *Journal of Materials and Environmental Science*, 14(6), 678–688. https://www.jmaterenvironsci.com/Document/vol14/vol14_N6/JMES-2023-14065-Sumaila.pdf

Sumaila, A., Sumaila, A. O., Abdullahi, A. S., Usman, A. O., & Ekwoba, L. (2022). Application of chitosan-silver nanocomposites for heavy metals removal: A review study. *Journal of Materials and Environmental Science*, 13(8), 869–883.

Sumaila, A., Sumaila, A. O., Usman, A. O., Abdullahi, A. S., & Abdullahi, Z. (2022). Thermal degradation and particle size distribution studies of activated carbon obtained from coconut shells. *Journal of Materials and Environmental Science*, 12(7), 739–746. https://www.jmaterenvironsci.com/Document/vol13/vol13_N7/JMES-2022-13060-Sumaila.pdf

Tabaght FE., Azzaoui K., El Idrissi A., Jodeh S., Khalaf B., Rhazi L., Bellaouchi R., Asehraou A., Hammouti B., Sabbahi R., Synthesis, characterization, and biodegradation studies of new cellulose-based polymers, *Scientific reports,* 13 (2023) 1673, https://doi.org/10.1038/s41598-023-28298-5

Tofanica, B. M., Callone, E., Ungureanu, E., Ungureanu, O. C., & Popa, V. I. (2025). Structure of Cellulose Isolated from Rapeseed Stalks. *Polymers,* 17(8), 1032. https://doi.org/10.3390/polym17081032.

Wang, N., Xu, B., Wang, X., Lang, J., & Zhang, H. (2022). Chemical and Structural Elucidation of Lignin and Cellulose Isolated Using DES from Bagasse Based on Alkaline and Hydrothermal Pretreatment. *Polymers*, 14(14), 2756. https://doi.org/10.3390/polym14142756.

Wang, P., Shen, X., Qiu, S., Zhang, L., Ma, Y., & Liang, J. (2024). Clay-Based Materials for Heavy Metals Adsorption: Mechanisms, Advancements, and Future Prospects in Environmental Remediation. *Crystals*, *14*(12), 1046. https://doi.org/10.3390/cryst14121046.

Xue, H., Dong, X., Fan, Y., Ma, X., & Yao, S. (2023). Study of Structural Transformation and Chemical Reactivity of Kaolinite-Based High Ash Slime during Calcination. *Minerals*, 13(4), 466. https://doi.org/10.3390/min13040466.

(2026); www.mocedes.org/ajcer