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Review on Diatomite for Sustainable Technology: Recent Advances in Functionalization, Composite Development, and Multi-Scale Applications

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Abstract

Diatomaceous earth (DE), or diatomite, constitutes the fossilized silica frustules of diatoms. Historically utilized as an industrial absorbent and filtration medium, it has recently garnered significant attention as an advanced material in nanotechnology and engineering. This transition is driven by its inherent physicochemical properties, which include a hierarchically porous architecture, high specific surface area, low density, and chemical stability, collectively rendering it an effective natural micro- and nano-structured scaffold. This review provides a systematic examination of the seminal scientific and engineering progress in diatomite research from 2014 to 2025. The analysis is structured around three primary themes: (1) the advancement of sophisticated chemical, physical, and biological strategies for surface activation and functionalization; (2) the rational design and fabrication of hybrid diatomite-based composites incorporating polymeric, metallic, metal oxide, and carbonaceous phases; and (3) the diversification of its application spectrum into domains including catalysis, energy storage (e.g., Li-ion batteries, supercapacitors), construction, environmental remediation, biomedical engineering (e.g., drug delivery, biosensing), and thermal/acoustic management. This work critically evaluates key performance indicators, synthesizes prevalent characterization techniques, and incorporates sustainability analyses from a life-cycle perspective.

Keywords: Diatomite; surface functionalization; diatomite-based composites; environmental remediation; energy storage materials; biomedical applications; sustainable materials.

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1. Introduction

Diatomite is a siliceous sedimentary rock made from the fossilized cell walls (frustules) of diatoms, a common unicellular algae found in aquatic ecosystems. These microorganisms biosynthesize frustules from hydrated silica ($SiO_2 \cdot nH_2O$) into species-specific, highly ordered nanoporous structures as a naturally occurring, cost-effective, and abundant template that can be utilized for advanced material synthesis[1]. Unique architecture of diatom frustules, with a multiscale pore network (micro-, meso-, and macropores) results in extremely attractive surface-area-to-volume ratios, usually in the range of 20-60 m^2/g post-calcination [2, 3]. Diatomite used in previous applications were strictly for filtration function, as a weakly abrasive and also as passive absorbing agent. However, the past decade has witnessed a paradigm shift, with research focused on transforming this naturally inert silica framework into a functionally active material with the aid of focused physical, chemical and biological manipulation [4]. The growing interest in sustainable and bio-inspired practices has also increased the attractiveness of diatomite since it requires considerably less energy to process compared to the synthesis of artificial porous materials like zeolites or mesoporous silica (e.g., MCM-41, SBA-15). (Diatom and Advanced Aspects of Material — The Material Path[5]

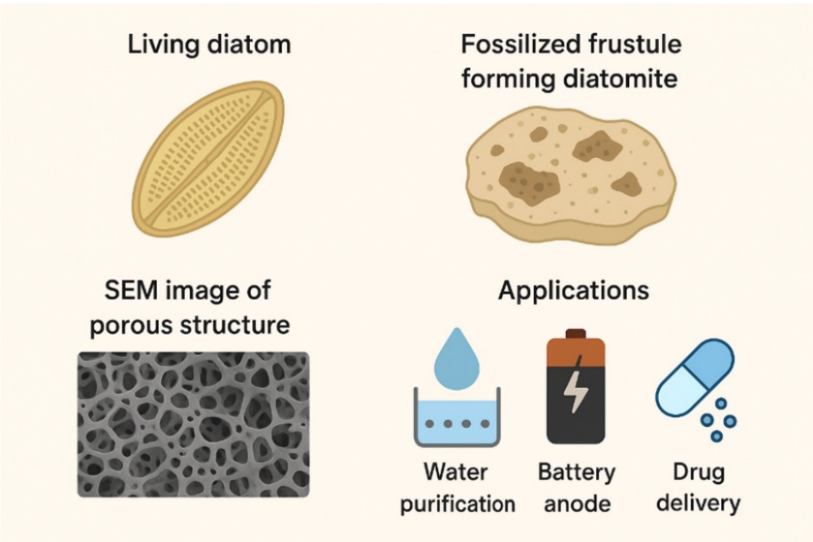

Figure 1. (a schematic drawing showing:(i) the form of a living diatom, (ii) fossilized frustule transforming diatomite, (iii) a SEM image of the porous structure, (iv) advanced applications such as water purification, battery anodes, and drug transport).

The purpose of this review was to provide a detailed and critical overview of this transformational process and to show how diatomite went from a raw rock to a developed structure to meet some of the world's most critical human needs, such as that of energy, environmental, and health. The range of techniques to modify core components of a material ranges from the design of composite material systems to evaluating specific performance for applications. The future prospects and future viability of diatomite-based technologies are presented in a prospective review article.

2. Basic Characteristics of Raw Diatomite and Its Pre-Treatment.

2.1. Structural and chemical properties.

Diatomite is geologically regulated by its origins. The specific species of diatom, the age of the deposit and the conditions of fossilization influence the shape, purity and intrinsic porosity of the given material. The frustule shapes include the cylindrical, discoid, pinnate and triangular shapes of the pore size and the surface geometry [3]. From a chemical standpoint, raw diatomite consists primarily of amorphous silica (80–95%) and clay minerals, iron oxides and alkaline earth metals are the major impurities [6]. The surface, formed by silanol groups (Si-OH), serves as the dominant sites of chemical interaction and functionalization.

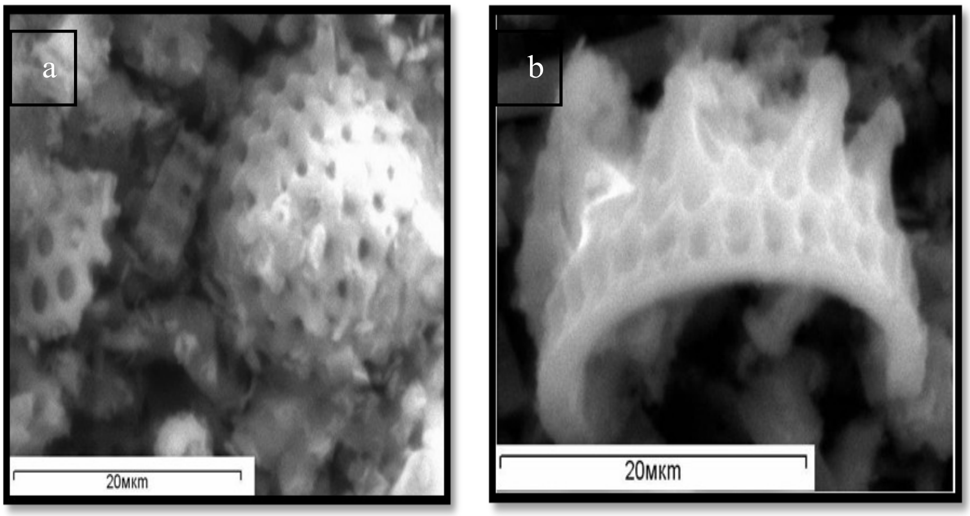

Figure 2. shows: (a) raw diatomite, (b) diatomite calcinated at 900oC[3].

2.2. Beneficiation and Purification

Raw diatomite ore often requires beneficiation to remove inherent impurities that can undermine its efficiency for advanced solutions Pre-treatment protocols are typically the following:

- **Crushing and Milling:** To reach a desired particle size distribution.
- **Calcination (500-900°C):** Eject organic matter and consolidate silica matrix. It can be processed in flux-calcination mode with sodium carbonate to sinter fine particles thereby improving filtration quality or non-flux mode since native structure is kept for functional applications [7, 8].

- **Acid Washing (e.g., with HCl or H_2SO_4):** To dissolve soluble metal oxides and carbonates, thus increasing the silica and the surface purity[8, 9].

Table 1: Common Preparation of Raw and Purified Diatomite [6, 10].

Component	Raw Diatomite (wt.%)	Acid-Purified Diatomite (wt.%)
SiO_2	80 - 90	> 98
Al_2O_3	3 - 6	< 1
Fe_2O_3	1 - 3	< 0.5
CaO + MgO	0.5 - 2	< 0.2
Loss on Ignition	4 - 8	< 2

3. Modification and Activation Strategies

As a result of the silica surface of diatomite being naturally rich in silanol (Si-OH) groups, it provides a versatile platform for chemical functionalization. The introduction of modification strategies is essential to either improve intrinsic properties (e.g., sorptive capacity) or introduce newly developed functionalities (e.g., magnetism, catalytic activity, hydrophobicity).

3.1. Thermal Activation

In addition to traditional calcination, specialized thermal processing techniques are now established:

- **Controlled Atmosphere Calcination:** Calcination for a given period under an inert atmosphere (e.g. N_2, Ar) can preserve carbonaceous residues from the pore network to generate carbon-silica composites with improved adsorption of organic contaminants [11].
- **Magnesification:** This procedure is specific and involves the thermal treatment of diatomite (for instance, at 500–700°C), impregnated with magnesium salts (including $MgCl_2$). This can produce reactive magnesia (MgO) nanoparticles on the silica surface, resulting in composites with excellent adsorption capability for anions such as phosphate, arsenate, fluoride from aqueous media [12].

- **3.2. Chemical Functionalization**

3.2.1. Acid/Base Treatment: While acid washing serves a purifying function, controlled alkaline treatment (e.g., with NaOH) can be employed to selectively etch the silica surface. This process increases the surface area and generates a higher density of reactive silanol sites for subsequent grafting reactions.

Table 2. Comparison of the effects of different purification HCl concentrations on the specific surface area, total pore volume, t-*graph volume, and average pore diameter of diatomite[13].*

Sample	BET surface area (m2/g)	Total pore volume (cm3 g−1)	T-plot micropore volume (cm3 g−1)	BJH averagepore diameter (nm)
Raw diatomite	**5.530**	**0.0013**	**0.00076**	**0.9261**
10%	**5.711**	**0.0012**	**0.00132**	**0.8700**
15%	**7.920**	**0.0020**	**0.00106**	**0.9972**
20%	**8.062**	**0.0021**	**0.00108**	**0.9963**
25%	**8.145**	**0.0020**	**0.00109**	**0.9322**

3.2.2. Surface Silylation: This is a basic process for the functionalization of diatomite. Organosilane molecules, such as (3-aminopropyl)triethoxysilane (APTES) or vinyltriethoxysilane (VTES), are chemically grafted onto surface silanol groups through hydrolysis and condensation reactions. Si-OH + X-Si-R → Si-O-Si-R + HX (where X is a hydrolysable group like $-OCH_3$, and R is an organic functional group such as $-NH_2$, -SH, $-CH=CH_2$).

This strategy is important for hydrophobicity, polymeric matrix compatibility and specific functional group assignment to anchor both catalysts or biomolecules [14].

3.2.3. In-situ Precipitation and Coating: These processes are the fundamental basis of the preparation of most composite materials[15].

- **Sol-Gel Coating:** A precursor (e.g., titanium isopropoxide for TiO_2) is hydrolyzed in the presence of diatomite to obtain a homogeneous metal oxide coating on the frustule surface.
- **Layer-by-Layer (LbL) Assembly:** Because oppositely charged polyelectrolytes or nanoparticles adsorb sequentially, a controlled thickness and composition of coating is easily achieved [16].
- **Precipitation Methods:** Direct precipitation from aqueous solution (e.g., by metal salts such as $FeCl_3$/$FeCl_2$ for magnetite, Fe_3O_4) is a common and scalable method for depositing nanoparticles in diatomite pores [17].

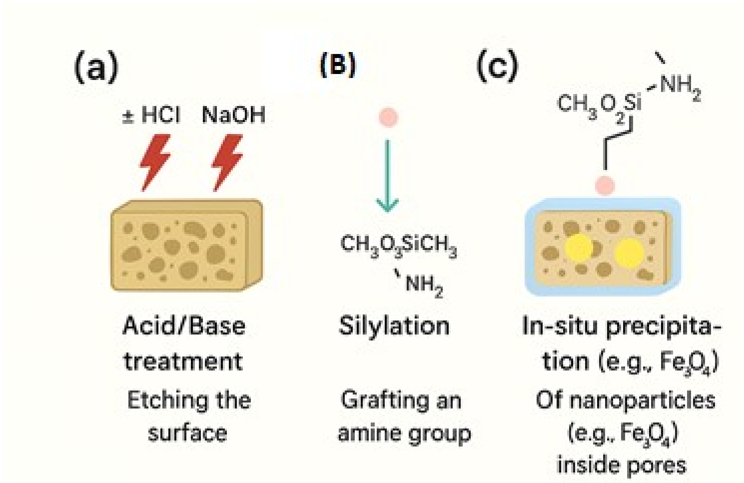

Figure 3. schematic shows: (a) etching of the surface through acid or base treatment, (b) silylation via APTES grafting an amine group, (c) In situ precipitation of nanoparticles (e.g., Fe_3O_4) in pores; Metal oxide with sol-gel coating (e.g., TiO_2).

4. Development of Diatomite-Based Composites

Synergistic composites derived from the combination of diatomite with other substrates, in which a diatomite functions as a scaffold structure, which provides mechanical stability, high surface area and special morphology in the hybrid.

4.1. Polymer-Diatomite Composites

Diatomite works as a strong reinforcing filler and functional additive in polymeric matrices.

- **Thermoplastics (e.g., Polypropylene, Polyethylene):** The use of diatomite increases mechanical properties (tensile and flexural modulus), improves thermal stability and reduces flammability by acting as a char promoter[18, 19]. Studies deals with the effect of the Diatomite (D) microcomposite with and without chemical modification in a polypropylene (iPP) blend.
- **Thermosets (e.g., Epoxy, Polyurethane):** addition of diatomite provides better stiffness, more toughness with fracture, and lower thermal degradation[20].
- **Biopolymers (e.g., Polylactic Acid - PLA):** Besides reinforcement, diatomite can modify the gas barrier behavior of packaging films and work as a nucleating agent for crystallization to promote thermo-mechanical performance improvement[21, 22].
- **Stimuli-Responsive Composites:** Functionalized diatomite can be integrated with hydrogels or shape-memory polymers to form composites to be utilized in smart packaging, controlled release, or self-healing applications [23].

Table 3: Summary of Key Polymer-Diatomite Composite Systems and Properties.

Polymer Matrix	Key Findings	Improvement Over Neat Polymer	Reference
Polypropylene (PP)	20 wt.% DE increased tensile modulus by ~50% and reduced peak heat release rate by 25%.	Enhanced stiffness and flame retardancy.	[18]
Epoxy	10 wt.% aminopropyl-functionalized DE improved fracture toughness by 80%.	Enhanced mechanical durability.	[20]
Polylactic Acid (PLA)	5 wt.% DE increased crystallization temperature and oxygen barrier properties by 30%.	Improved processability and packaging performance.	[21]
Polyurethane Foam	DE incorporation enhanced sound absorption coefficients across a broad frequency range.	Superior acoustic insulation.	[24]
		DE = Diatomaceous Earth	

4.2. Metal/Metal Oxide-Diatomite Composites

This category is one of the most researched domains within diatomite composites scientific research.

- **TiO_2/DE Photocatalysts:** Diatomite is an ideal support for TiO_2 NPs, and it blocks dyes' aggregation to promote the photon absorption by internal scattering by the scattering of light ("light-trapping" effect) as well as supporting the simple catalyst recovery and reuse in water purification (degradation of dyes, pharmaceuticals) and air treatment [25, 26]. This study demonstrates the effectiveness of the diatomite and TiO nanoparticles composite in photodegrading methylene blue, achieving up to 80% efficiency in 270 min under sunlight. The high surface area and porosity of diatomaceous earth improve the dispersion of TiO nanoparticles[26].

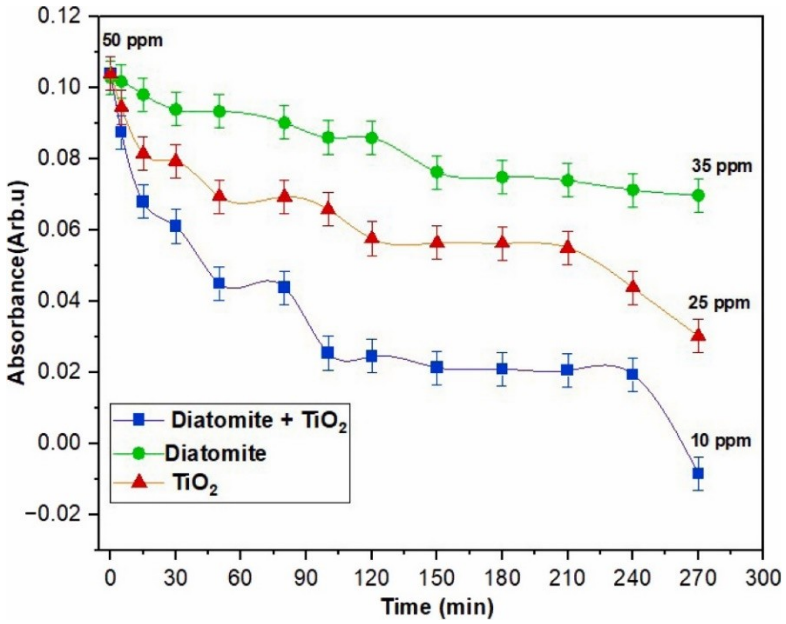

Fig. 4. (a) Photodegradation of Diatom, (b) Photodegradation of TiO nanoparticles, (c) Photodegradation of Diatom loaded with TiO2.[26]

- **Magnetic DE Composites (e.g., Fe_3O_4/DE):** Inclusion of magnetic nanoparticles like magnetite and maghemite enables fast and effective magnetic separation even after application in adsorption or catalytic processes. This property is attractive for large-scale applications where the low-cost operation and the prevention of secondary pollution are crucial[17, 27].
- **Noble Metal/DE Composites (e.g., Ag/DE, Au/DE):** Silver-based composites supported on diatomite possess powerful broad-spectrum antibacterial activity, which is beneficial for the disinfection in both water and antimicrobial coatings[28]. Gold/diatomite composites have also been evaluated for catalytic oxidative reactions and surface-enhanced Raman scattering (SERS)-based sensing applications[29].

4.3. Carbon-Diatomite Composites

The process of conversion of the intrinsic organic matter in diatomite through pyrolysis, or deposition of carbon layers[30] (e.g., chemical vapor deposition or sucrose carbonization), results in conductive composites

- **Diatomite-Derived Porous Carbon:** Complemented by a silica template (used either by NaOH or HF) to be removed following carbonization, a porous carbon equivalent to the diatom structure with a very high surface area (>1000 m^2/g) is obtained[31].
- **Carbon-Coated Diatomite:** Retaining the silica core gives strength to the mechanical behaviour. These materials combine the high surface and electrical behavior of carbon with the structural stability of the diatomite scaffold and are suitable as electrode materials for energy storage applications[32].

5. Multifunctional Applications

5.1. Adsorbs and catalyst supports DE-based composites have excellent adsorbing and environmental remediation capacities.

- **Heavy Metal Removal:** Composites functionalized with chelating groups (e.g., $-NH_2$, -SH) or coated with metal oxides (e.g., MnO_2, FeO) show high capacity, and selectivity for heavy metals e.g., Pb(II), Cd(II), Cu(II), and Cr(VI)[33-35].

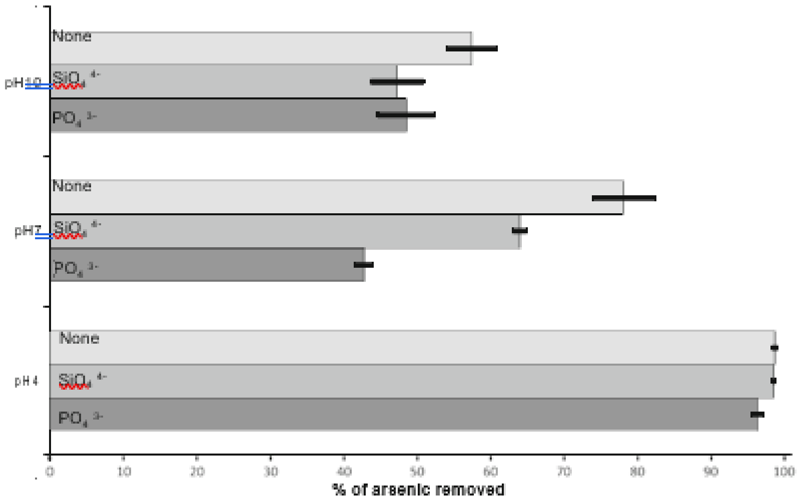

Fig. 5 Effect of competitive ions (phosphate, 10 mg L−1; silicate, 10 mg L−1) in arsenic (V) (10 mg L−1) adsorption onto D-Fe (0.1 g of D-Fe 17 %)[35]

The incorporation of iron into the diatomite matrix in- creased the performance in both batch and column experi-ments. In order to enhance the potential of low cost diatomite based adsorbents to remediate arsenic contaminated water, it is recommended that further studies are carried out to optimize methods of coating these adsorbents with iron and other metal oxides.

- **Organic Pollutant Removal:** Removal — The material effectively adsorbs dyes, pesticides, and new contaminants like pharmaceuticals and per- and polyfluoroalkyl substances (PFAS)[36, 37].
- **Advanced Catalytic Degradation:** Diatomite enhances the degradation efficiency of persistent organic pollutants via Advanced Oxidation Processes (AOPs) as a catalyst support [15, 38] , for instance, TiO_2 in photocatalysis and Fe-based catalysts in Fenton-like reactions.

5.2. Energy Storage

It is based on active energy materials on diatomite is an ideal scaffold due to its 3D porous structure.

Lithium-Ion Batteries (LIBs): Silicon-diatomite anodes take advantage of the natural porosity, allowing such a large volume expansion of silicon during lithiation (~300%) to be accommodated and increasing cycling stability as well as capacity retention. Diatomite-derived porous silicon and carbon are also emerging as desirable anode materials[39]. successfully synthesized nanosilicon from diatomaceous earth (DE) using magnesiothermic reduction and subsequently applied a carbon coating to it. Electrochemical Performance gives that Following 50 cycles at a rate of C/5 (0.2 C), the anode demonstrated a specific (reversible) discharge capacity of approximately 1102.1 mAh/g.In the rate capability assessments, which ranged from C/30 to 4C, the retention of capacity for each block of 10 cycles was as follows:

- At C/30, the anode retained 67.4% of its initial capacity.

- At C/10, it retained 90.4%.

- At C/5, the retention was 98.3%.

- At C/2, it maintained 95.0%, and so on.

At a rate of 4C, the anode maintained a capacity of about 654.3 mAh/g, which is significantly higher than graphite's theoretical capacity of 372 mAh/g. Interpretation: The intrinsic porous architecture of diatomite, which is preserved in the reduced silicon, combined with the carbon coating, acts as a buffer to mitigate the substantial volume expansion of silicon. This structural advantage enhances both the capacity and the cycling stability of the anode[40].

Supercapacitors: Diatomite-derived porous carbon and metal oxide/DE composites (e.g., MnO_2/DE, Co_3O_4/DE) are possible electrodes with enhanced specific capacitance due to their large surface area and effective ion transport pathways [31, 41].

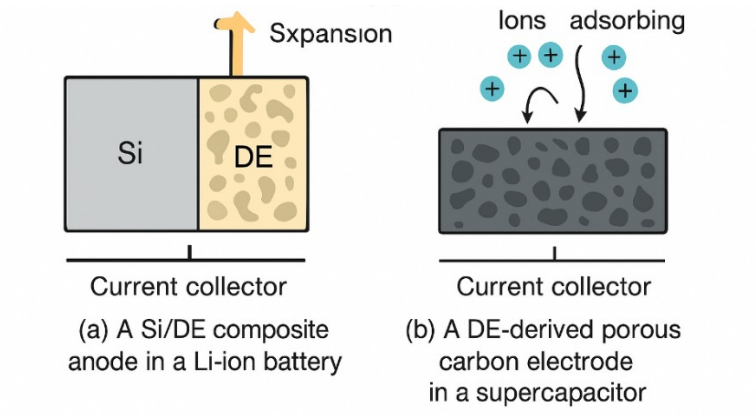

Figure 6: Diagram of Diatomite in Energy Storage Applications

5.3. Construction Materials

Diatomite improves the properties of building materials.

Cement and Concrete: A high-performance micro-filler and pozzolanic material, it reacts with calcium hydroxide (portlandite) to form additional calcium silicate hydrate (C-S-H) gel, the principal strength-bearing phase in cement and concrete. This increases the compressive strength and lowers permeability, improving durability[42, 43]. Diatomite has been proposed as a replacement for fly ash in lightweight engineered cementitious composites, and its effects on mechanical performance, shrinkage behavior, and microstructural development have been systematically evaluated. The findings indicate that incorporating diatomite leads to reductions in compressive strength, tensile strength, and tensile strain capacity. These decreases are primarily attributed to the lower degree of cement hydration and the higher porosity introduced by the diatomite particles. When additional mixing water is incorporated together with the diatomite, the hydration reactions are enhanced and the resulting matrix becomes more compact. As a result, specimens containing diatomite with added water exhibit higher compressive and tensile strengths, though their tensile strain capacity remains lower than that of mixtures without the added water. In addition, relative to the reference mixture, the autogenous shrinkage of the diatomite-modified composite increases because of the reduced amount of available mixing water.

- **Lightweight and Insulating Materials:** Its high porosity offers low thermal conductivity, which makes it suitable for lightweight aggregates, insulating bricks, and plasters in energy-efficient buildings[44, 45].

5.4. Biomedical Applications

Biocompatibility, high surface area and tunable surface chemistry for biomedical applications diatomite are exploited.

- **Drug Delivery:** The inherent pores of diatomite can be loaded with drugs in a controlled and sustained manner (e.g. anticancer drugs, antibiotics). Surface functionalization allows for selective delivery [46]. The potential of diatomaceous earth (DE) in various applications can be significantly augmented by integrating nitric oxide (NO) technology, known for its role in regulating important physiological processes. The advancement of NO-releasing diatomaceous earth offers a novel strategy for delivering adjustable quantities of NO, with promising applications in polymer chemistry, tissue engineering, drug delivery, and wound healing.
- **Biosensing:** The photonic crystal features of diatom frustules are used for label-free biosensing. The binding of a target biomolecule to a functionalized frustule surface leads to a measurable change in its reflectance or photoluminescence spectrum [47].
- **Bone Tissue Engineering:** Diatomite-derived silica has bioactivity and can promote the adhesion and growth of bone cells (osteoblasts). It is being investigated as a scaffold for bone regeneration purposes [48].

5.5. Thermal and Acoustic Management

The highly porous and hollow microstructure of diatomite frustules imparts exceptional thermal insulation and sound absorption properties.

- **Thermal Insulation:** Diatomite-based composites, aerogels, and plasters in buildings reduce heat transfer for energy conservation [49].
- **Acoustic Absorption:** The interconnected pore network of diatomite effectively dissipates sound energy, making it useful in noise suppression applications [24].

Table 4 Representative some thermal & acoustic values for diatomite-based materials.

Material / Form (source)	Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	Acoustic performance (sound absorption)	Key result / test conditions
Diatomite-based aerogel [50]	**0.041** (density ≈0.114 $g \cdot cm^{-3}$, porosity ≈91.5%).	Not reported in that paper (thermal focus).	Very low k competitive with polymer foams; excellent for insulation.
Porous diatomite ceramic [51]	**~0.0984** (reported for a sample with ~57.9% porosity) and other porous diatomite ceramics in literature: **0.061–0.123** (high-porosity fired samples).	Not acoustic-focused.	Good thermal insulation for a mineral ceramic; properties depend strongly on porosity and firing.
Diatomite-based thermal insulation mixture / dry mix [52]	**0.128–0.152** (reported range for dry construction mix).	Not reported.	Practical construction mixture; higher k than aerogels but still useful for lightweight insulation.
Diatomite-impregnated PCM (myristic acid) [53]	**~0.36** for raw diatomite-based PCM (value depends on PCM loading).	N/A (thermal energy storage focus).	Diatomite acts as support for PCM; thermal conductivity increases compared with pure PCM but thermal storage benefits are improved.
Diatomite / polyurethane porous composite [54]	Thermal conductivity not central in that paper (composite focus).	**Peak absorption >0.9 at ~1600 Hz** for a sample with **65 wt.% diatomite**; absorption coefficient >~0.56 across a >2000 Hz band.	Very good mid-frequency sound absorption when diatomite is used as filler in porous polymer matrices.
Diatomite-based composite PCMs (review / 2020 Renene) — (vacuum-impregnated lauric-stearic acid)[55]	Effective thermal properties depend on loading — many diatomite-PCMs show improved thermal stability and thermal conductivity up to **~0.2–0.5** W/m·K depending on PCM and loading.	N/A	Diatomite improves shape stability and heat transfer vs. pure PCM.

6. Characterization Techniques

A multi-faceted analytical approach is vital in characterizing modified diatomite and its composites.

- **Microscopy:** Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) are indispensable for characterizing detailed microstructure characteristics, frustule morphology, and distribution of nanoparticles on the composite surface.

- **Surface Area and Porosity:** Specific surface area and porosity were determined using the Brunauer-Emmett-Teller (BET) method by nitrogen adsorption-desorption isotherms. The Barrett-Joyner-Halenda (BJH) method for mesopores or Non-Local Density Functional Theory (NLDFT) models for a full range of pore size distribution determine the distribution [56].
- **Chemical Analysis:** Fourier-Transform Infrared Spectroscopy (FTIR) detects functional groups (Si-OH, C-H, N-H post-modification). X-ray Diffraction (XRD) reveals the diatomite crystallinity (an amorphous halo), along with any deposited crystalline phase(s), such as anatase TiO_2, magnetite Fe_3O_4. Quantitative surface elemental composition and chemical state details were obtained by X-ray Photoelectron Spectroscopy (XPS) [57].
- **Thermal Analysis:** Thermogravimetric Analysis (TGA), which quantifies thermal stability, organic content, and composite composition at varying temperatures, through mass loss with respect to temperature [58].

7. Sustainability, Challenges, and Future Directions

7.1. Challenges

Despite the dramatic improvement, several challenges remain:

1. **Source Variability:** Natural diatomite sources have been reported to be quite variable in terms of composition, purity, and microstructure, which lead to differences in batch-to-batch consistency and performance predictability [59].
2. **Scalability:** Engineering and translation of laboratory synthesis technologies for making composites, as in the case of sol-gel, LbL, and similar methods, into industry at scale without compromise of cost-efficiency and uniformity as well as following green chemistry is a major challenge.
3. **Long-Term Stability and Safety:** Preserving the long-term stability of composites (e.g., avoiding nanoparticle leaching from magnetic and Ag/DE composites) in environmental and biomedical settings is essential for overall risk assessment [60].
4. **Life-Cycle Assessment (LCA):** For most novel diatomite applications, complete LCAs are missing, which prevents arriving at strong and accurate sustainability claims [61].

7.2. Sustainability Considerations

Diatomite, a natural and inexpensive resource, can be used for environmental remediation and energy-saving technologies, contributing to sustainable development goals. In the near future, focus should be shifted to environmentally friendly modification pathways (e.g., aqueous-based approaches, benign chemicals) and the reduction of energy consumption during processing, together with the development of materials with easy recovery, recycling, and biodegradability, wherever achievable[62].

7.3. Future Directions

1. **Bio-inspired Design:** Building on fossilized diatoms has been proposed to mimic the biosilica synthesis of the diatom (bio-silicification) to prepare novel hybrid materials for low-energy synthesis with genetically programmable architectures [63].
2. **Advanced Multi-functional Composites:** Design of "smart" composites that combine multiple functional aspects, e.g., self-cleaning building material, which can be composite with photocatalysis (TiO_2/DE) acting together with thermal insulation, or wound dressing which can combine antibacterial property (Ag/DE) working with drug release [64].
3. **Precision Medicine:** Design of diatomite frustules with specialized surface chemistries and pore geometries for targeted drug delivery, gene therapy, and advanced diagnostic (theranostic) platforms [65].
4. **Energy Conversion:** The role of diatomite as a catalyst support in energy conversion technologies such as photocatalysis for hydrogen production, electrochemical CO_2 reduction, and fuel cells is considered in recent directions[66, 67].
5. **Circular Economy:** Designing effective regeneration protocols for spent diatomite adsorbents and catalysts. Moreover, investigating direct recycling of diatomite from waste streams from industrial production (i.e., beverage filtration) to produce high-value products to close the material loop [68, 69].

8. Conclusion

During 2010-2025, diatomite has been established as a versatile, sustainable, and high-potential material for advanced materials engineering. By making strategic improvements: thermal activation, chemical grafting, and in situ composite formation have opened up far wider application possibilities beyond its traditional uses. The naturally occurring, hierarchical, and unique structure of diatomite is a viable platform for addressing environmental science, energy storage, biomedicine, and sustainable building challenges. Diatomite's progression from a simple filter aid to a component in advanced technologies such as lithium-ion batteries and targeted drug delivery systems clearly defines a successful convergence between materials science and bio-inspiration. Overcoming scalability issues, designing for multifunctionality, embracing bio-inspired synthesis, and following circular economy principles will be critical avenues of future research efforts. Such initiatives will cement diatomite's position in the design of next-generation, high-performance, and truly sustainable materials.

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