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Experimental Investigations on Nano Graphene Coated Electrodes on Ceramic Materials for Energy Storage Applications

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Experimental investigations into nano-graphene-coated electrodes on ceramic materials focus on enhancing the performance of ceramic-based devices, such as sensors, fuel cells, capacitors, and batteries. Graphene, a two-dimensional carbon material with high electrical conductivity, mechanical strength, and chemical stability, is an ideal candidate for improving the properties of ceramic electrodes. The integration of nano-graphene coatings on ceramic materials has emerged as a promising advancement in enhancing the performance of ceramic-based electrodes. This paper explores the potential of nano-graphene- coated ceramic electrodes for energy storage applications, with a focus on super capacitors and lithium-ion batteries. Ceramics could benefit from graphene's large surface area and outstanding electrical conductivity, taking advantage of ceramics' mechanical strength and thermal stability. The research findings provide evidence of a smoother surface, a more stable interface, and fewer atomic-scale flaws in Al-Graphite. The study shows that the stress and voids at the C/Al interface were significantly reduced after sintering and cooling treatment. As a result, there is a significant opportunity to produce high-performance all-solid-state batteries; all that is needed is a straightforward method for obtaining an Al-graphite substrate with better physicochemical stability.

Keywords: Nano graphene, ceramic materials, energy storage applications.

1. Introduction

Energy storage technologies are critical to the performance and efficiency of modern electronic devices, renewable energy systems, and electric vehicles. Supercapacitors and lithium-ion batteries (LIBs) are two of the most popular energy storage devices, but several problems with their capacity, cycling stability, and energy density still need to be solved. Scientists are putting a lot of effort into creating new composite materials that combine the best characteristics of several substances because the electrode materials are so important to the effectiveness of these devices. Nanotechnology and materials science have come together to create new materials with exceptional properties. [1]. Nano graphene is one such substance that has been the subject of much research because of its huge surface area, high mechanical strength, and outstanding electrical conductivity. Superior performance electrodes for energy storage applications can be created by combining nano graphene with ceramic materials. Since 2004, a specific process has been employed in the laboratory of Manchester University to separate graphite sheets, resulting in graphene, a two-dimensional carbon atom crystal with an exceptionally stable structure. [2]. Many common benefits have been placed on graphene's impact on the modern materials world, depending on its outstanding physical and chemical characteristics. For their one-of-a-kind contributions to efficient and environmentally friendly energy solutions, batteries and super capacitors stand out in the field of energy storage research.[3]. Applications that need power that lasts a long time and has a high energy density in a small package rely heavily on batteries. Situations requiring fast bursts of energy are ideal for super capacitors due to their high power density and rapid charging capabilities. In addition to having an unrivalled cycle life, their reliability is second to none. The unique benefits of each technology emphasise how they work together to improve energy storage systems, which is crucial for the advancement of sustainable energy solutions. [4] So, for both long-term energy storage and short-term balancing, the two primary components are super capacitors and batteries with high power densities [5]. The energy conversion efficiency of fuel cells is rather high, however their longevity and durability are reduced. The development of novel electrode materials for use in batteries and super capacitors is an integral part of the race for maximum efficiency. Electrode electrochemistry and physical qualities are fundamentally related to the efficiency of these energy storage systems.

1.1 Applications

Nano graphene-coated ceramic electrodes have potential applications in various energy storage devices: a)Lithium-ion batteries: The high conductivity and large surface area of nano graphene can enhance the rate capability and energy density of lithium-ion batteries. b) Supercapacitors: Nano graphene-coated ceramic electrodes can provide high power density and long cycle life for super capacitor applications. C) Fuel cells: The conductive properties of nano graphene can improve the performance of fuel cell electrodes by facilitating electron transfer. d) Energy harvesters: Nano graphene-coated ceramic electrodes can be used in energy harvesting devices to capture and store energy from ambient sources.

1.2 Significance of research

The research into Nano graphene-coated ceramic electrodes for capacitor banks is significant because it has the potential to greatly enhance energy storage capacity and efficiency. This advancement could lead to more compact and powerful electronic devices, revolutionizing industries such as renewable energy and consumer electronics. This innovative approach can lead to higher capacitance and improved charge-discharge cycles, potentially revolutionizing the performance of electronic devices.

2. Literature Review

Loudiki et al [6] using an electrochemical exfoliation method on pencil graphite at room temperature to produce GO. Graphite electrode exfoliation using the new method has produced a multi-layer GO/rGO mixture that is stable. For a more even distribution, the exfoliated graphene solution was subjected to sonication for 35 minutes. Güler et al. [7] created multilayer graphene by combining graphite intercalated compound (GIC) with an acidic mixture and hexagonal graphite (HG). The expanded graphite (EG) is formed by heating the GIC to a temperature between 800 and 900 °C. Then, an organic solvent is dispersed in it using ultrasonication. Seville et al. [8] introduced a simple and eco-friendly synthetic method for making stable and processable graphene dispersions in water. In place of the more involved, risky, and detrimental classical chemical exfoliation treatments as the Hummers method, there is this route of study.Rosas-Laverde [9]With the inclusion of a graphene oxide (GO) nanomaterial before electrodeposition and its reduction degree, the properties of the polypyrrole coating were examined. Various imaging techniques were used to analyse the coatings' properties, including Fourier transform infrared spectroscopy, cyclic voltammetry, Raman spectroscopy, and field-emission scanning electron microscopy.Ramírez, C [10] Composites and hybrids of ceramics and graphene offer promising new materials for the production of smaller, lighter, and more efficient batteries. When problems associated with large-scale production, such as easy and standardised synthesis pathways, control of graphene agglomeration, and reprehensibility of homogeneous components, are resolved, product commercialisation will become a reality. Pisello et al. [11] studied the strain-sensing capacity, optical features, electrical characteristics, and thermal conductivity of CBC composites with varying carbon nanofillers at a 2 wt.% concentration. The authors found that GNP significantly increased thermal conductivity (46%), likely due to its ability to disperse thermal waves.Adaikalam, K et al [12] This research details the process of recovering nanographite from used batteries and transforming eggshell waste into calcium oxide through high-temperature calcination, both of which have potential uses in the energy storage industry. By employing XRD, SEM, TEM, and XPS techniques, the chemical, morphological, and structural compositions of CaO and CaO/graphite were characterised. Matios, E., Wang et al [13] The high interfacial charge transfer resistance between the solid electrolyte and the electrodes is a major obstacle to the development of solid-state sodium batteries. The interfacial resistance is reduced by a factor of ten using a new, scalable design method that involves growing a graphene-like interlayer over a Na+ superionic conductor (NASICON) ceramic electrolyte.Wang, Y et al[14] Researchers are concentrating on carbon-based materials, especially graphene, for energy storage because of its remarkable features. Electrodes made of graphene have enormous promise as components of energy storage systems like batteries and super capacitors due to its large surface area, high electrical conductivity, and remarkable chemical stability. Ramírez, C.[15] Graphene and its derivatives have been extensively utilised to create new materials that can store energy. An eco-friendly Na ion battery's electrode design is currently aiming towards decreased graphene oxide, which has demonstrated remarkable possibilities for more effective Na ion storage. Another driving force for additive manufacturing electrode development is the pursuit of more environmentally friendly and adaptable production methods.

3. Methodology

Ceramic electrodes coated with graphene are attracting interest as a potential energy storage medium because of the material's high electrical conductivity, mechanical strength, and thermal stability. The remarkable qualities of graphite-coated aluminium substrates, such as improved conductivity, resistance to corrosion, and thermal management abilities, have attracted considerable attention from a range of industries. The substrate is coated in a solution that contains graphite particles that are electrically charged. Particles settle onto a substrate when an electric field is presented.

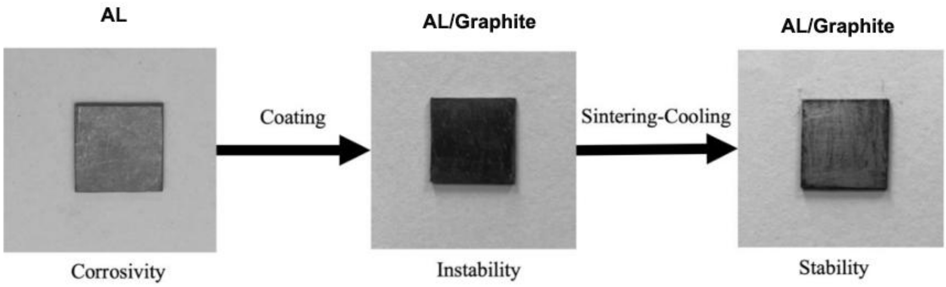

Figure 1 : The preparation process of graphite-coated AL substrate.

3.1 Ceramic Materials in Energy Storage

Ceramic materials, such as titanium dioxide (TiO_2), silicon carbide (SiC), and aluminum oxide (Al_2O_3), are known for their high thermal stability, structural robustness, and chemical inertness. These properties make ceramics suitable for extreme environments, but their poor electrical conductivity has limited their use in energy storage devices. Coating ceramics with graphene can overcome this limitation by providing conductive pathways for efficient charge transfer.

3.2 Preparation of Nano graphene Using Electro chemical Exfoliation process:

Nano graphene is a two-dimensional carbon substance that possesses remarkable qualities like enormous surface area, mechanical strength, and great electrical conductivity. The unusual properties of this material make it highly desirable for use in electronics, energy storage, and composites, among additional possible applications. Graphite can be transformed into nano graphene by electrochemical exfoliation, a well-liked process. When ions are intercalated into the graphite lattice, the layers expand and eventually exfoliate into individual sheets of graphene.

3.2.1 Preparation of Electrolyte

Dissolve the chosen electrolyte (e.g., H_2SO_4, Na_2SO_4) in distilled water to prepare the solution. The concentration of the electrolyte can vary, but a common choice is 0.1 M.

- Place the graphite electrode (anode) and the counter electrode (cathode) in the electrolyte solution within a beaker.
- Ensure the electrodes are positioned parallel to each other to allow uniform electric field distribution.
- Connect the electrodes to the power supply.
- Use a steady voltage, usually between 5 and 20 volts. The electrolyte and the quality of graphene that is desired determine the exact voltage.

- Exfoliation occurs when electrolyte ions intercalate into graphite layers due to the voltage, which reduces the strength of the van der Waals forces.
- As a natural part of the exfoliation process, you could see bubbles forming (the result of oxygen evolution at the anode).
- The graphene that has been exfoliated is distributed throughout the electrolyte solution. Use a magnetic stirrer to improve the dispersion.
- Turn off the power source once the exfoliation time has elapsed, which is often 30 minutes to a few hours.
- Use filter paper or a centrifuge to separate the electrolyte from the graphene solution.
- Repeatedly washing the gathered graphene with pure water will eliminate any remaining electrolyte.
- To determine the sheets' size, thickness, and quality, dry the graphene using a hoover or moderate heating.

3.2.2 Electrolysis process nano graphene:

Graphene on a nanoscale, or nano-graphene, can be synthesized using the electrolysis process in a number of different ways. To produce graphene and its derivatives is by electrochemical exfoliation of graphite. Give me a rundown of the steps:

- Material: The starting material is usually graphite, which consists of stacked layers of graphene.
- Electrolyte: An electrolyte solution, often a mixture of ionic liquids or acidic solutions, is used. Common electrolytes include sulfuric acid (H_2SO_4), sodium sulfate (Na_2SO_4), or ammonium sulfate ($(NH_4)_2SO_4$).
- Electrodes: The graphite is used as the anode, and a suitable counter electrode, like platinum or graphite, is used as the cathode.
- Voltage Application: Electrodes are subjected to a voltage, causing ions to intercalate into graphite layers from the electrolytes. This intercalation reduces the van der Waals forces holding the layers together.
- Graphene Formation: The applied voltage induces the exfoliation of graphene layers from the graphite. The process can be controlled to yield single-layer or few-layer graphene, depending on the conditions.

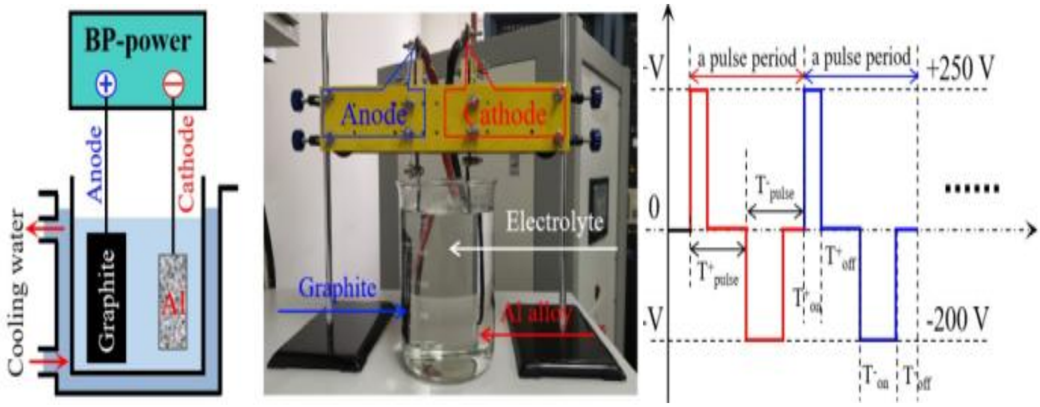

Figure:2 Deposition of grphene on AL substrate

Experimentation setup and deposition methods shown in the figure 2 and the pulse on period for the process T_{pulse} is 13.34 and 6.67milli seconds, T_{on} time is0.67 to 4 milli seconds and T_{off} is 2.67 to 6 milli seconds.

4. Results And Discussions

Nano-graphene coated ceramic electrodes have emerged as promising candidates for energy storage devices due to their exceptional properties such as high surface area, excellent electrical conductivity, and mechanical stability.

Morphological Characterization of Graphite-Coated Al Substrates

Morphological characterization is essential to understand the surface structure and coating quality of graphite-coated aluminum substrates. It helps identify defects, measure coating thickness, and assess the uniformity of the graphite layer shown in figure3.

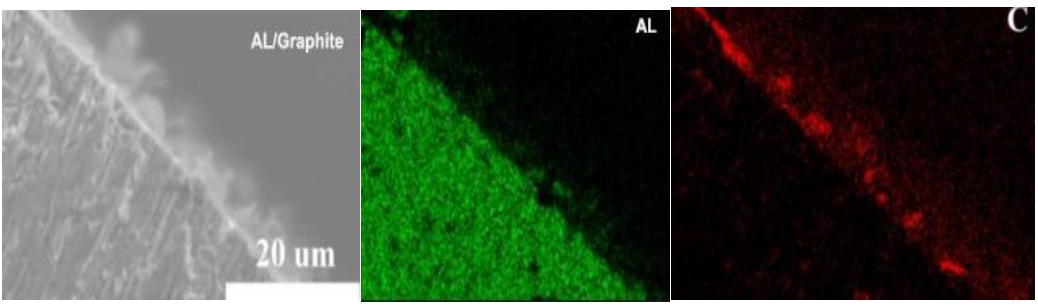

Figure:3 Morphological characterization: side view of (a) AL/Graphite

The composition and form of the Al-Graphite composite's constituent elements. Possible improvements in mechanical characteristics, electrical conductivity, and thermal conductivity may result from the graphite's layered arrangement within the aluminum matrix.

✓ SEM Image: A scanning electron microscopy (SEM) photograph of a sample of an Al-Graphite combination in monochrome. Twenty micrometers is the length indicated by the scale bar.

✓ EDS Map Al: An elemental map that displays how the composite contains aluminum (Al). Red is used to indicate regions having higher amounts of aluminum.

✓ EDS Map C: The composite's carbon (C) distribution can be seen on an elemental map. In this case, green indicates regions with higher carbon concentrations.

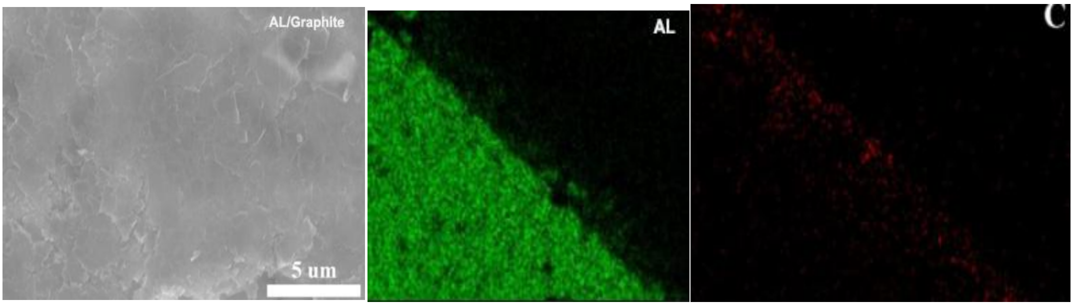

Figure: 4Morphological characterization AL-Graphite with EDS, top view

✓ SEM Image: A scanning electron microscopy (SEM) image of an Al-Graphite composite is shown in black and white. The scale bar indicates a length of 5 micrometers.

✓ EDS Map: Al: An elemental map showing the distribution of aluminum (Al) in the composite. The areas with higher concentrations of aluminum appear in red.

✓ EDS Map: C: An elemental map showing the distribution of carbon (C) in the composite. The areas with higher concentrations of carbon appear in green.

The distribution, size, and orientation of the graphite particles inside the aluminum matrix may be learned through the morphological characterization of Al-Graphite composites using Energy-Dispersive X-ray Spectroscopy (EDS). Electrochemical dispersive spectroscopy (EDS) is an effective method for microscopic analysis of a sample's elemental makeup. The enormous promise of ceramic electrodes covered with nanographene for use in energy storage. Their adjustable characteristics, synergistic effects, and improved electrochemical performance make these materials appealing for use in batteries and super capacitors. To reach their maximum potential, though, we must overcome obstacles with respect to scalability, affordability, and uniform coating.

4.1 Structural and electro chemical characterization of AL/Graphite

A correlation between the Al/Graphite composite's microstructure and its electro chemical performance can be established using the findings of evaluation.Graphite's electrical conductivity and specific capacitance can be enhanced with a uniform distribution of particles, while mechanical characteristics and corrosion resistance can be improved with a strong interfacial contact between graphite and aluminum as shown in figure 5.

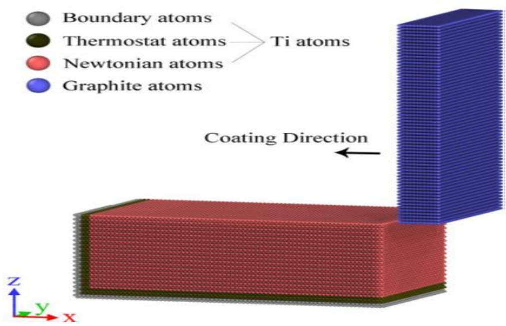

Figure 5: Model for molecular dynamics simulation

Atomic-level simulation: The picture shows the coating process down to the atomic level, which helps to clarify the diffusion mechanisms and the interactions between the surfaces as shown in figure6.

Graphite deposition: Coating the aluminum substrate are the blue spheres, which stand for graphite atoms.

Boundary and thermostat atoms: The gray and black spheres likely represent boundary atoms and thermostat atoms used in the simulation to control the temperature and boundary conditions.

Newtonian atoms: The red spheres represent Newtonian atoms, which follow classical Newtonian mechanics.

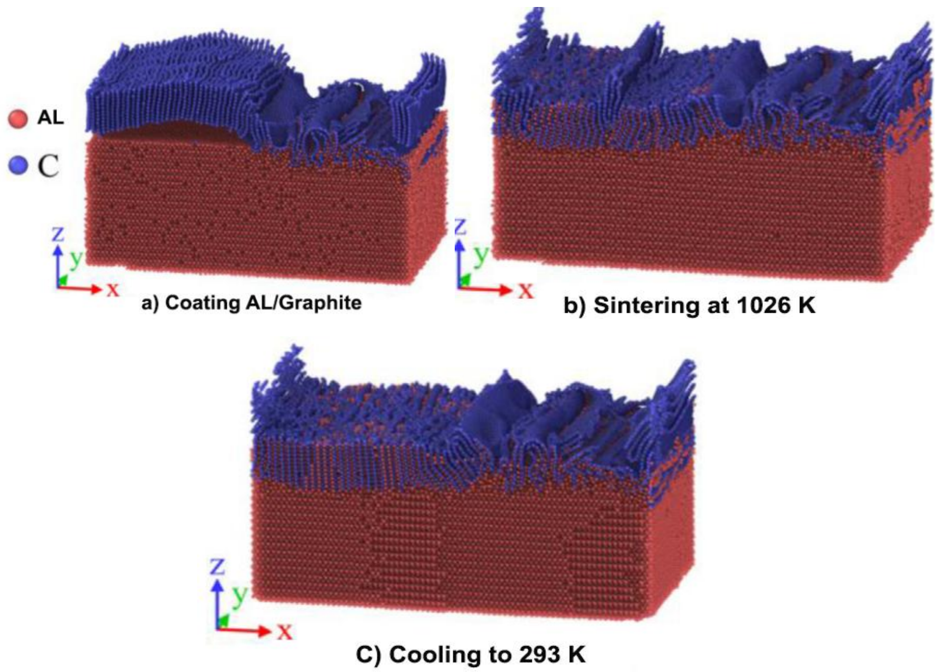

Figure 6: The graphite-coated Aluminium on different processes: (a) completed coating, (b)

sintering at 1026 K, and (c) cooling to 293 K.

a) Coating AL/Graphite: This initial stage depicts the composite after the graphite coating has been applied to the aluminum substrate. The graphite layer is shown in blue, while the aluminum substrate is shown in red.

b) Sintering at 1026 K: This figure represents the composite after undergoing a sintering process at a temperature of 1026 K. The graphite layer appears to have diffused into the aluminum matrix, forming a more interconnected structure.

c) Cooling to 293 K: This final figure shows the composite after being cooled to room temperature (293 K). The micro structure may have undergone further changes during the cooling process as shown in figure 7.

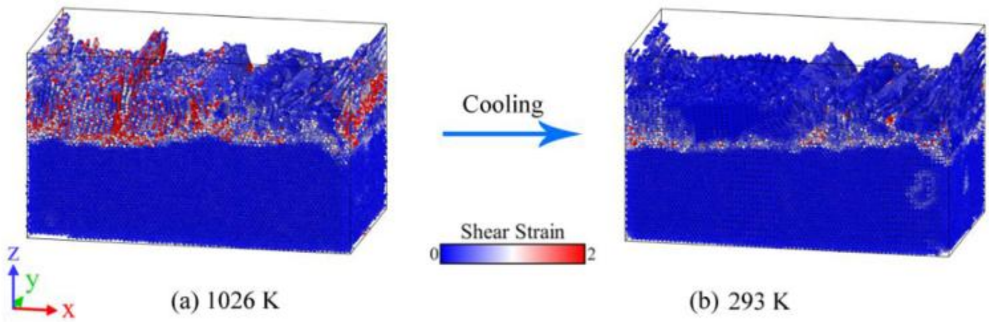

Figure 7: Stress distribution of the model at (a) 1026 K and (b) 293 K

The stress distribution of the model throughout the annealing procedures is depicted in the figure7. The AL substrate has a low stress value since the melting point of AL has not been reached even at 1026 K. When the model was sintered at 1026 K, the carbon-titanium mixed layer shows signs of significant stress. Heat increases the atomic thermal motion, which in turn increases the strains due to interactions between carbon atoms in graphite and AL atoms on the surface of the substrate.

5. Conclusion

The experimental investigations into Nano- graphene- coated electrodes on ceramic materials reveal promising advancements in the field of high-performance materials. In conclusion, experimental and modeling methods were used to examine the effects of graphite coating on the aluminum substrate and the subsequent annealing process. To create a graphite-coated AL substrate (AL-Graphite) with a robust interface, the AL substrates used in the studies had their surfaces annealed at 1026 K. Prior to annealing, the surface of an aluminum plate substrate is made up of several micron-sized flakes. This surface is rough, contains numerous faults and voids, and fails to provide a sufficient protective layer for the Aluminium substrate. These hybrid materials demonstrate considerable potential in both super capacitors and lithium-ion batteries, offering improvements in energy density, power density, and long-term stability.Structural and electro chemical characterization are indispensable tools for understanding the properties and performance of Al/Graphite composites. By combining these techniques, researchers can optimize the micro structure and composition of the composite to achieve desired properties for various applications, such as batteries, super capacitors, and structural materials. Future research should focus on optimizing the synthesis techniques and exploring the scalability of these materials for commercial energy storage devices.

5.1 Future Work

Future research will aim to explore the scalability of graphene coating methods, investigate the long-term durability of these materials, and further optimize their performance in specific applications such as next-generation batteries, fuel cells, and environmental sensors. Additionally, studies into the environmental impact and cost-effectiveness of large-scale production will be essential to advancing the commercial viability of graphene-coated ceramic electrodes.

References

[1] Jakubczak, M., & Jastrzębska, A. M. (2021). A Review on Development of Ceramic-Graphene Based Nanohybrid Composite Systems in Biological Applications. Frontiers in chemistry, 9, 685014. https://doi.org/10.3389/fchem.2021.685014

[2] Cygan T., Wozniak J., Kostecki M., Petrus M., Jastrzębska A., Ziemkowska W., et al. (2017). Mechanical Properties of Graphene Oxide Reinforced Alumina Matrix Composites. Ceramics Int. 43, 6180–6186. 10.1016/j.ceramint.2017.02.015

[3] Alshammari A. S., Halim M. M., Yam F. K., Kaus N. H. M. (2020). Synthesis of Titanium Dioxide (TiO2)/Reduced Graphene Oxide (rGO) Thin Film Composite by Spray Pyrolysis Technique and its Physical Properties. Mater. Sci. Semiconductor Process. 116, 105140. 10.1016/j.mssp.2020.105140

[4] Albina Jetybayeva, Douglas S. Aaron , Ilias Belharouak, Matthew M. Mench Critical review on recently developed lithium and non-lithium anode-based solid-state lithium-ion batteries Journal of Power Sources,Volume 56, 15 May 2023, 232914

[5] K. Krishnamoorthy, P. Pazhamalai, V.K. Mariappan, S. Manoharan, D. Kesavan, S. Kim, Two-Dimensional Siloxene–Graphene Hetero structure-Based High-Performance Super capacitor for Capturing Regenerative Braking Energy in Electric Vehicles, Adv. Funct. Mater. 31, 2008422 (2021)

[6] Loudiki , M. Matrouf A. El Mhammedi, M. Azriouil Preparation of graphene samples via electro chemical exfoliation of pencil electrode: Physico-electro chemical Characterization, Applied Surface Science Advances 7 (2022) 100195

[7] Güler Ö Güler S Selen V Albayrak G Evin E. Production of graphene layer by liquid-phase exfoliation with low sonication power and sonication time from synthesized expanded graphite. Fullerenes Nanotube Carbon Nanostructures . 2016;24:123–127

[8] Sevilla M Ferrero G Fuertes A Aqueous Dispersions of Graphene from Electro chemically Exfoliated Graphite. Chemistry—A European Journal . 2016;22:17351–17358.

[9] Nelly Ma. Rosas-Laverde, Alina Iuliana Pruna (2020) Graphene Oxide- Polypyrrole Coating for Functional Ceramics, Nanomaterials 2020, 10, 1188; doi:10.3390/nano10061188.

[10]Ramírez, C.; Belmonte, M.; Miranzo, P.; Osendi, M.I. Applications of Ceramic/Graphene Composites and Hybrids. Materials 2021, 14, 2071. https://doi.org/10.3390/ma14082071

[11] Pisello, A.L.; D'Alessandro, A.; Sambuco, S.; Rallini, M.; Ubertini, F.; Asdrubali, F.; Materazzi, A.L.; Cotana, F. Multipurpose experimental characterization of smart nanocomposite cement-based materials for thermal-energy efficiency and strain-sensing capability. Sol. Energy Mater.

Sol. Cells 2017, 161, 77–88.
[12] Adaikalam, K.; Teli, A.M.; Marimuthu, K.P.; Ramesh, S.; Lee, H.; Kim, H.S.; Kim, H.-S. Energy Storage Application of CaO/Graphite Nanocomposite Powder Obtained from Waste Eggshells and Used Lithium-Ion Batteries as a Sustainable Development Approach. Nanomaterials 2024, 14, 1129. https://doi.org/10.3390/nano14131129.
[13] Matios, E., Wang, H., Wang, C., Hu, X., Lu, X., Luo, J., & Li, W. (2019). Graphene Regulated Ceramic Electrolyte for Solid-State Sodium Metal Battery with Superior Electrochemical Stability. ACS Applied Materials & Interfaces. doi:10.1021/acsami.8b19519
[14] Wang, Y.; Wei, H.; Lu, Y.; Wei, S.; Wujcik, E.K.; Guo, Z. Multifunctional Carbon Nanostructures for Advanced Energy Storage Applications. Nanomaterials 2015, 5, 755-777. https://doi.org/10.3390/nano5020755
[15] Ramírez, C.; Osendi, M.I.; Moyano, J.J.; Mosa, J.; Aparicio, M. Electrochemical Response of 3D-Printed Free-Standing Reduced Graphene Oxide Electrode for Sodium Ion Batteries Using a Three-Electrode Glass Cell. Materials 2023, 16, 5386. https://doi.org/10.3390/ma16155386.