International Research Journal of Natural and Applied Sciences
ISSN: (2349-4077)
Impact Factor 8.176 Volume 11, Issue 09, September 2024
Website- www.aarf.asia, **Email** : editor@aarf.asia , editoraarf@gmail.com

SIGNIFICANCE OF CARBON BASED SUPERCAPACITORS FOR EFFICIENT ENERGY STORAGE

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ABSTRACT

The ever-increasing consumption of fossil fuels as well as the skyrocketing price of those fuels have given rise to serious concerns regarding the rapid depletion of existing reserves of fossil fuels as well as the associated alarming emissions of greenhouse gases and pollutions in the air and on the soil. As a result, it is necessary to research and create methods of energy generation and storage that are kind to the natural world. Recently, there has been a significant amount of focus placed on the development of energy-storage devices such as electrochemical supercapacitors and batteries. This emphasis has been particularly intense. Electrochemical supercapacitors (ESCs) are capable of generating power density that is between 100 and 1000 times higher than that of batteries, although having an energy density that is between 3 and 30 times lower. Because of this, ESCs are particularly helpful for high-power bursts, such as when accelerating or breaking in high-speed transit systems. In addition, due to the chemical-free nature of the electric double-layer charge storage utilised by ESCs, these devices are capable of withstanding up to millions of charge and discharge cycles. In contrast, during the charge and discharge cycles of a battery, excessive redox reactions cause the active materials in the electrodes to expand, leading to volumetric modulation. Batteries also suffer from this swelling. Therefore, in terms of dependability, supercapacitors are a far better alternative than batteries.

Keywords: *Significance, energy storage, Carbon*

INTRODUCTION

A separator sits in between two electrodes of an electrochemical supercapacitor so that the electrodes can remain physically distinct from one another. When it comes to a symmetric supercapacitor, these two electrodes will be the same, but when it comes to an asymmetric supercapacitor, they will be different. The separator is immersed in electrolytes, which makes it ion-permeable yet electrically insulating. This allows ionic charge to be transferred between the electrodes. Separators made of polymer or paper are often utilised when working with organic electrolytes, whereas ceramic or glass-fiber separators are more frequently utilised when working with aqueous electrolytes. ESCs can be classified as either electric double-layer capacitors (EDLCs), in which the process of charge storage takes place at the interfaces between the electrolyte and the electrodes (Fig. 1a), or pseudocapacitors (PCs), in which the process of charge storage involves reversible and fast Faradaic redox reactions for charge critical issues related to the material/electrode design and the elucidation of energy-storage mechanisms. Our knowledge of carbon-based electrode materials for the storage of energy will greatly expand as a result of such an in-depth research, and we will also get valuable insights for the subsequent stages of development.

It has been observed that a considerable amount of effort is being put into the research, development, and deployment of continuous progress in high-performance energy storage systems with the goal of minimising the amount of energy that is wasted. This is in response to the fact that there are shortages in petroleum reserves, concerns about the effects of greenhouse gas emissions, and a rapidly growing demand for energy. Particular focus is being placed on the research and development of electrochemical storage technologies such as rechargeable batteries and supercapacitors (SCs). Although they can store far more energy for a shorter period of time than traditional capacitors, modern capacitors can only hold it for a certain length of time. At the moment, the majority of research efforts are concentrated on the discovery of novel anode materials that are in a position to enhance the general performance of SCs. Even though a large number of materials have been investigated, it is difficult to point to a material that is capable of replacing commercially applied activated carbons (ACs) as an anode material for SCs due to its high surface area, high stability, and good thermal and electric conductivity. This is despite the fact that a large number of these materials have been investigated. AC SCs are distinguished by having a large surface area, and they also provide strong electrical conductivity in addition to high voltage stability, temperature stability, long-cycling stability, and, most significantly, a low cost. It is important to note that AC SCs can be manufactured using biomass as the primary raw material, which offers a number of advantages. The first of these advantages relates to the preservation of the natural environment, while the second relates to the fact that biomass primary raw material is both affordable and readily available.

Chemical activation seems to be the most plausible choice among the other approaches because of how straightforward it is and how inexpensive it is [8, 9]. There are a number of methods that may be used to achieve a layered porous structure. According to the findings of the most recent review papers, the majority of the research works are either concentrated on the search for new anode materials or on the development of methods that allow for an improvement in the overall performance of SCs, such as by modifying materials that are already in use.

Nanomaterials made of carbon

Diamond, graphite, and amorphous carbon are the three forms into which conventional carbon materials may be classified. The configuration of their constituent carbon atoms determines which qualities they exhibit. Diamond, for instance, has a unique diamond cubic crystal structure that has sigma bonding between sp3 hybridised carbon molecules. This gives diamond its renowned hardness and rigidity. Graphite is malleable because of its layered structure, which has strong covalent bonding between sp2 hybridised carbon atoms in the plane of individual layers but weak van der Waals interactions between neighbouring layers. New graphitic carbon nanomaterials with multi-dimensions have been created as a result of recent developments in nanoscience and nanotechnology. These include dimension-less (0D) fullerene, one-dimensional (1D) carbon nanotubes (CNTs), and two-dimensional (2D) graphene. This has led to the opening of a new frontier in the field of research into carbon materials. The structure of fullerene C60 is reminiscent of a soccer ball, and it is composed of 20 carbon hexagons and 12 carbon pentagons arranged in a cage of truncated icosahedrons. Since fullerene C60 is an ideal electron acceptor, it has found widespread application in solar cells for the purpose of charge separation. In comparison to other carbon nanomaterials, fullerene has seen relatively little usage as a medium for the storage of energy due to its intransitive nature, poor electrical conductivity, and limited surface area. Because of their exceptional electrical conductivity, high specific surface area, outstanding electrochemical activity, and the ease with which they can be functionalized into multidimensional and multifunctional structures with excellent electrical and mechanical properties, carbon nanotubes (CNTs), graphene, and mesoporous carbon, as well as their hybrids, have all been the subject of extensive research as supercapacitor electrodes up until this point.

A super capacitor is a component of an energy storage system

The greatest performers in the field of charge storage are li-ion batteries, which have energy densities of roughly 180 watt h/ kilogramme (which is nearly three to thirty times lower than supercapacitors). The devices known as supercapacitors are those that are able to store anywhere from a hundred to a thousand times more power than batteries in the same amount of accessible space. As a result, supercapacitors are favoured more for use in situations in which the energy storage capacity is not required to the same degree but where power surges are necessary.

Electrolytic capacitors have a high power density, but batteries have a lower power density (less than 1 kilowatt per kilogramme), notwithstanding their effectiveness in storing large quantities of energy. Figure 3 displays the Ragone plot with many storage methods superimposed on it. The existence of internal dissipation and leakage losses is responsible for the decrease in energy that takes place when the power level is sufficiently high or low. On this graph, the axes that are horizontal represent the power densities, while the axes that are vertical represent the energy densities. The discharge times of the various storage devices are depicted by the diagonal lines ($E = Pt$). According to what can be gleaned from the narrative, supercapacitors are the ideal material for filling the space between batteries and electrolytic capacitors. It is evident from looking at the map that electrolytic capacitors have a larger power density than supercapacitors, which have a power density of about 10 kW/kg.

Electrode Materials

The primary criterion for categorising supercapacitors into their respective categories is the process through which they hold a charge. The broad categories that supercapacitors fall under are depicted in Figure 1. Both electric double-layer capacitors (EDLCs) and pseudo capacitors are types of electrostatic capacitors (PCs). In some contexts, EDLCs may also be referred to as electrostatic capacitors. Charge is stored in EDLCs at the electrode/electrolyte interface via an electrostatic charge absorption process. This takes occur when the electrode is in contact with the electrolyte. The most appealing materials for EDLCs have been those based on carbon, mostly due to the availability of these elements in nature and the high surface area they provide; nevertheless, the relatively low specific capacitance of these materials is a drawback.

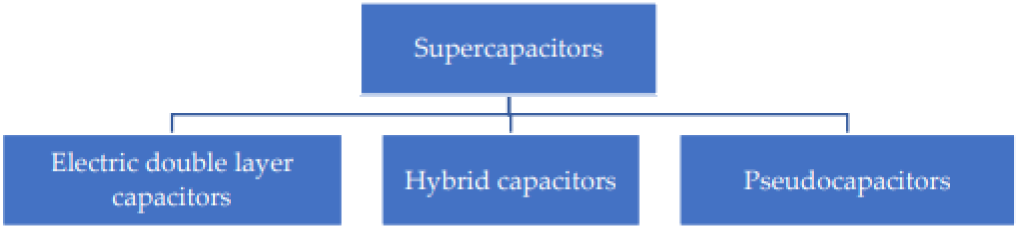

Figure 1 Classification of super capacitors

OBJECTIVE

1. To research and develop different recycling methods for all of the carbon materials that will be used in the proposed supercapacitors.

2. To locate potential sources of supercapacitor materials and technologies for use in the foreseeable future

METHOD

In recent times, there has been a growing interest in the utilization of pseudo-capacitive and battery-type materials as electrodes in supercapacitors. This rise in interest can be attributed to the high energy storage capacity of these materials. However, the majority of the supercapacitor devices that are employed in commercial applications continue to make use of carbon-based materials, particularly activated carbon, as electrodes. This is due to the fact that pseudo-capacitive and battery-type materials have lower power densities and rate capacities. In the next subsections, a variety of carbon-based materials, whether they are in their natural state, functionalized, or in the form of composites, will be addressed in further detail. These materials will be employed as electrodes in SCs.

Two-dimensional graphene, also known as 2D graphene, is a nanomaterial composed of carbon that possesses remarkable physiochemical properties. These properties include a large surface area distribution (SSA), outstanding electrical conductivity, mechanical strength, and a very rich surface chemistry. The utilization of graphene as an active material in SC applications has expanded as a result of the outstanding features that it possesses. Geim and Novoselov were the first people to successfully extract graphene from graphite in 2004. They did this by employing the micromechanical exfoliation process, sometimes known as the Scotch tape method. As a result of the successful separation of the graphene layers from graphite, scientists have devised and utilized a variety of additional synthesis procedures throughout the course of the past twenty years in order to generate graphene. Depending on the synthesis approach that is chosen, these strategies for synthesis can be categorized as either top-down or bottom-up. Graphene layers are separated from bulk material such as graphite through the use of mechanical means in the top-down method, which includes exfoliation (chemical mechanical or liquid). On the other hand, graphene is produced through the decomposition of carbon-containing precursors in the bottom-up techniques, which include chemical vapor deposition and epitaxial growth.

RESULT

The usage of graphene as an active material in SCs has increased at a rapid pace; thus, graphene is presently undergoing a transitional phase by entering the commercialization stage. On the other hand, it is still not as advanced as the electrode materials that are based on activated carbon, which are highly utilized due to the fact that activated carbon is both cost-effective and scalable. As a result, it is anticipated that graphene will soon be utilized in a more widespread manner in electrochemical energy storage and conversion devices in general, and supercapacitor cells in particular. Nevertheless, in order to make these processes more cost-effective, environmentally friendly, and scalable, it is necessary to develop new synthesis methodologies and make adjustments to the manufacturing processes that are now being utilized. Below, in Table 1, you will find an illustration of the electrochemical performance of electrodes based on graphene.

Table 1. The electrochemical performance characteristics of graphene-based carbon electrodes.

Sample	Capacitanc (Fri)	Energy (Wh kg-I)	Power (kW kg-1)	Retention/Cycl (%)	Ref:
VGNS	230			99/1500	[83]
rGO	585.44	81.31	62.64	97.14/5000	[86]
4NG	405	68.1	558.5	87.7/5000	[84]
NB-GO	835	23.23	872	80/10,000	[87]
NiSe	1280	50.1	816	98/2500	[88]
NiCo2S4/	704.34	20.9	800.2	80.3/1500	[89]
SGP	928.56	25.6	4098	77.68/11,000	[90]
MP-rGO	1942	39.1	700	78.6/3000	[91]
ZnS/RGO	772	349.7	18,000	76.1	[92]
Cu-BPA/G0	611,6	54.37	200	86/2000	[93]

AC is the electrode active material that is used in supercapacitors the most frequently because it possesses great conductivity, inertness, a very high surface area, a tuneable pore size, and the ability to be made in huge numbers at a cost-effective rate. Carbon is created by subjecting synthetic materials, such as polymers, or naturally occurring materials, such as rice husk-based precursors or coconut shells, to a thermal treatment at a high temperature. This process takes place in an inert atmosphere. Through the utilization of a variety of activation agents, waste resources such as biomass waste and fruit leftovers may be utilized as precursors in order to produce carbon compounds. This is an additional approach that is both beneficial and efficient. These materials are not only readily available in large quantities, but they also contribute to the reduction of waste and the enhancement of the environment as a whole. There are many different applications that may make use of carbon that is created by the usage of these materials. One of these uses is the storage of electrochemical energy, notably in supercapacitors. The porous structure of carbon that has been synthesised can be enhanced even further by activation by making use of the various activation agents that have been mentioned in detail above. In order to improve the electrochemical performance of supercapacitors, it is necessary to have certain desired qualities. These characteristics include a high specific surface area and a pore size that is optimized according to the electrolyte solution that is being used. The insertion of functional groups or the preparation of composites with pseudo-capacitive materials such as transition metal oxides or conducting polymers as dopants are two methods that may be utilized to further enhance the capacitive performance of the material. In light of the fact that the total capacitance is the sum of the electric double layer capacitance that originates from the surface charge storage of highly porous activated carbon and the pseudo-capacitive contribution that is made by dopants or functional groups through fast and highly reversible Faradic charge storage, this results in higher specific capacities. Due to the fact that the porous features described above have the potential to have a significant impact on the performance of supercapacitors, the carbons that are formed from templates are of tremendous popularity among scientists. The electrochemical properties of several AC-based electrodes are presented in Table 2, which may be found to the right.

Table 2. The electrochemical performance characteristics of carbon electrodes.

Sample	**SSA (m^2g^{-1})**	**APS (nm)**	**Capacitance (Fg^{-1})**	**Energy Density ($Wh\ kg^{-1}$)**	**Power Density ($kW\ kg^{-1}$)**	**Ref:**
KOH-CX-4:1	2334	------	222	10	400	[**101**]
hCNC-5.0	2737		266	153	1000	[**102**]
RFCA100-800-800	1775	2.19	197	------	-------	[**103**]
RPC	2797	1.9	56	44	564	[**104**]
CSAC7	1343	------	338	-------	------	[**105**]
HAC-WS	652	2.65	225	72.2	1547.6	[**106**]
TiC-CDC	------	------	163	--------	--------	[**107**]

Carbon may be found in a variety of shapes and forms, including activated carbon, graphite, and lonsdaleite, to name a few examples. In spite of this, graphene, carbon onions, nano-diamonds, carbon nano-horns, fullerene (C60, C240, C540, and C20), and carbon nanotubes (CNTs) are some of the innovative and exotic carbon nanostructures that have been found and explored over the course of the last several decades. In comparison to the other allotropes of carbon, carbon nanotubes (CNT) have been the subject of the most research because of their straightforward chemical composition, atomic bonding, and varied structural features. It was Sumio Iijima at the NEC Corporation in 1991 who was the first person to successfully synthesize carbon nanotubes (CNTs) using the arc discharge method. This technology has revolutionized a wide range of scientific subjects, including physics, chemistry, and material science.

CONCLUSION

In response to the ever-increasing levels of pollution and a number of other environmental issues that have been brought about by the automotive industry, there has been an increase in the demand for hybrid electric vehicles and electric vehicles that are powered by electricity. Despite the fact that it has seen tremendous advancements over the course of the past few years, the electrochemical energy storage system is still years behind traditional fuel-based cars even though it has witnessed major advances. When compared to traditional cars that are powered by fuel, this is the most major drawback that hybrid electric vehicles and electric vehicles face. What makes this specific feature of the design noteworthy is the incorporation of supercapacitors into the battery system that is already in place. Due to the fact that it has shown promising results, this combination system, which is more popularly known as hybrid capacitors, has recently attracted a lot of attention in the field of energy storage technologies. The supercapacitors are able to provide the required amount of energy in an instant for a short length of time when the battery is unable to do so. This design works in conjunction with the battery. It is possible for the battery to once again provide the necessary energy in the event that there is a requirement for a continuous flow of energy. In the mechanical, chemical, and physical worlds, respectively, electrode materials that are based on graphene and feature a variety of architectural layouts were shown to display positive performance. Therefore, as a consequence of this, the electrochemical performance of the energy storage devices has the potential to benefit from an improvement. There is a possibility that the power capacity of ultracapacitors can be enhanced by the incorporation of mesopores onto the surfaces of micropores in extremely minute amounts.

REFERENCES

1. Chen, Xuli & Paul, R. & Dai, Liming. (2017). Carbon-based supercapacitors for efficient energy storage. National Science Review. 4. 1-37. 10.1093/nsr/nwx009.

2. Dubey, Richa & Guruviah, Velmathi. (2019). Review of carbon-based electrode materials for supercapacitor energy storage. Ionics. 25. 10.1007/s11581-019-02874-0.

3. Pandolfo, A.G. & Hollenkamp, A.F.. (2016). Carbon Properties and Their Role in Supercapacitors. Journal of Power Sources. 157. 11-27. 10.1016/j.jpowsour.2006.02.065.

4. Hussain, Sajjad & Rohit, Rohit & Rana, Dolly & Jamwal, Deepika & Park, Jae & Katoch, Akash. (2021). Carbon Based Supercapacitors. 10.1016/B978-0-12-819723-3.00112-8.

5. Frackowiak, Elzbieta & Abbas, Qamar & Beguin, Francois. (2013). Carbon/carbon supercapacitors. Journal of Energy Chemistry. 22. 226–240. 10.1016/S2095-4956(13)60028-5.

6. Miao, Ling & Song, Ziyang & Zhu, Dazhang & Gan, Lihua & Liu, Mingxian. (2020). Recent advances in carbon-based supercapacitors. Materials Advances. 1. 10.1039/D0MA00384K.

7. Dou, Qingyun & Park, Ho. (2020). Perspective on High-Energy Carbon-Based Supercapacitors. Energy & Environmental Materials. 3. 10.1002/eem2.12102.

8. Zhang, Y.; Mei, H.X.; Cao, Y.; Yan, X.H.; Yan, J.; Gao, H.L.; Luo, H.W.; Wang, S.W.; Jia, X.D.; Kachalova, L.; et al. Recent advances and challenges of electrode materials for flexible supercapacitors. Coord. Chem. Rev. 2021, 438, 213910

9. Sharma, K.; Arora, A.; Tripathi, S.K. Review of supercapacitors: Materials and devices. J. Energy Storage 2019, 21, 801–825.

10. Kouchachvili, L.; Yaïci, W.; Entchev, E. Hybrid battery/supercapacitor energy storage system for the electric vehicles. J. Power Sources 2018, 374, 237–248.

11. Wang, C.; Song, Z.; Shi, P.; Lv, L.; Wan, H.; Tao, L.; Zhang, J.; Wang, H.; Wang, H. High-rate transition metal-based cathode materials for battery-supercapacitor hybrid devices. Nanoscale Adv. 2021, 3, 5222–5239

12. Afif, A.; Rahman, S.M.; Tasfiah Azad, A.; Zaini, J.; Islam, M.A.; Azad, A.K. Advanced materials and technologies for hybrid supercapacitors for energy storage—A review. J. Energy Storage 2019, 25, 100852

13. Miller, E.E.; Hua, Y.; Tezel, F.H. Materials for energy storage: Review of electrode materials and methods of increasing capacitance for supercapacitors. J. Energy Storage 2018, 20, 30–40.

14. Raj, B.; Padhy, A.K.; Basu, S.; Mohapatra, M. Review—Futuristic Direction for R&D Challenges to Develop 2D Advanced Materials Based Supercapacitors. J. Electrochem. Soc. 2020, 167, 136501.

15. Balasubramaniam, S.; Mohanty, A.; Balasingam, S.K.; Kim, S.J.; Ramadoss, A. Comprehensive Insight into the Mechanism, Material Selection and Performance Evaluation of Supercapatteries. Nano-Micro Lett. 2020, 12, 85

16. Xie, L.; Sun, G.; Su, F.; Guo, X.; Kong, Q.; Li, X.; Huang, X.; Wan, L.; Song, W.; Li, K.; et al. Hierarchical porous carbon microtubes derived from willow catkins for supercapacitor applications. J. Mater. Chem. A 2016, 4, 1637–1646.

17. Liao, Q.; Li, N.; Jin, S.; Yang, G.; Wang, C. All-Solid-State Symmetric Supercapacitor Based on Co3O4 Nanoparticles on Vertically Aligned Graphene. ACS Nano 2015, 9, 5310–5317.

18. Chen, S.; Wang, L.; Huang, M.; Kang, L.; Lei, Z.; Xu, H.; Shi, F.; Liu, Z.-H. Reduced graphene oxide/Mn3O4 nanocrystals hybrid fiber for flexible all-solid-state supercapacitor with excellent volumetric energy density. Electrochim. Acta 2017, 242, 10–18.

19. Zhou, R.; Han, C.; Wang, X. Hierarchical MoS2 -coated three-dimensional graphene network for enhanced supercapacitor performances. J. Power Sources 2017, 352, 99–110.

Qin, K.; Wang, L.; Wen, S.; Diao, L.; Liu, P.; Li, J.; Ma, L.; Shi, C.; Zhong, C.; Hu, W.; et al. Designed synthesis of NiCo-LDH and derived sulfide on heteroatom-doped edge-enriched 3D rivet graphene films for high-performance asymmetric supercapacitor and efficient OER. J. Mater. Chem. A 20