Investigation of substitute jar materials for Laboratory grade ball milling machine to process electrode materials for energy storage devices

Sourabh Shinde1, Taukir Momin2, Vispi Karkaria3, Parshuram Karandikar4
1Dept. of Mechanical Engg., College of Engineering, Pune, India
2Dept. of Mechanical Engg., College of Engineering, Pune, India
3Dept. of Mechanical Engg., Northwestern University, IL, USA
4Dept. of Electronics and Telecommunication Engg. Army Institute of Technology, Pune, India

E-mail: shindesr19.mech@coep.ac.in

Abstract
Copious forms of energy are available in nature, but electrical energy is the convenient form of energy. As a result of this, it is expected that the need for electrical energy will increase considerably by the end of this decade. Thus, the storage of electrical energy is now becoming of paramount importance. Nevertheless, ultra-capacitors are currently a central area of research for energy storage devices due to their high-power density rating, short charging time and long cycling time. The capacitance of an ultra-capacitor is majorly a result of the processing of its electrode materials. Ball milling is one of the most profitable and cost-effective processes of electrode material processing. However, in most of the ball milling research, the focal point is on materials used for balls in ball milling. It is also observed that the material used to produce ball mill jars is of equal momentousness. So, this research aims to examine various materials as jars for a ball milling machine.

Keywords. Ultra-Capacitors, Capacitance, Ball Milling, Power density, Energy, Jars.

1. Introduction
To improve the performance of electric vehicles, it is critical to investigate the fundamental gaps in understanding the atomic and molecular level processes that govern their performance limits, operation, and failure [01-03].

There are two types of energy storage devices: Primary energy storage devices and Secondary energy storage devices: The chemical reaction in primary energy storage devices is irretrievable, and hence the entire device is required to be disposed of when the energy is discharged. Alternately, secondary energy storage devices are those which can be charged again and again as and when needed. Ultra-Capacitors is a new technology for secondary energy storage devices. Ultra-Capacitors can be an excellent option for tomorrow’s energy storage devices. Ultra-Capacitor is an energy storage technology that offers high power density, high reliability, almost instant charging and discharging and very long lifetimes. Ultracapacitors have been in evolution for decades, but the technology has developed swiftly in recent years. This development has been driven by advances in nanomaterials [01-06]. Ultra-Capacitors are dealing with increased concerns around fuel efficiency and emissions in the automotive and transportation segments. Ultracapacitors are now delivering note-worthy economic benefits across a wide range of markets, including automotive, transportation, grid and renewables, and industrial applications. Three key components of an ultra-capacitor are electrodes, a dielectric separator, and electrolyte. The electrodes are commonly of three types: Metal oxides, polymers, and carbon. For obtaining high power and power densities, the ions between the cathode and anode of ultra-capacitors should commute rapidly. To have high performance characteristics, the ultra-capacitor electrodes should meet the following standards [01]:

![Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/)

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Published under licence by IOP Publishing Ltd
Mechanically sturdy and chemically balanced electrode microstructure.

- Electron-ion transport path that is effective.
- Effective Electrochemical-active association between the electrode and the electrolyte.

Proper processing of ultra-capacitor electrode materials is very important. The finer the electrode material, the higher its capacitance rating. The increase in charge carrying capacity of the ultra-capacitor can only be observed when the surface area of the material is less than 3500 m²/g, pore volumes of 3 cm³/g and the pore sizes in the range of 1-2 nm [01]. There are various processes to grind electrode materials effectively. Ball milling is one of the most effective yet cheap manufacturing processes for the production of very fine electrode materials [07-12]. Most of the research revolves around the fact that only the balls of the ball milling machine play a vital role in the effectiveness of the ball milling process. However, it has been discovered that not only the ball mill ball material, but also the material used to make ball mill jars, has a significant impact on the effectiveness of the ball milling process. The common materials used for ball milling jars are stainless steel or high-grade steel. But, for small-scale applications, aluminium is also preferred as a material for ball milling jars. The problem with these materials is that the mass of these materials is excessively high, which results in an increased load on the motor of the ball milling jar. Moreover, the excess vibrations and noise are unavoidable during the operation. So, there is a need for substitute materials for manufacturing ball milling jars which can overcome all these drawbacks. As a result, three materials, viz., Polypropylene, Nylon, and Aluminum, are examined in this research as ball milling jar materials for small-scale applications. Special ball mill jars with steel layering are also suggested for extreme large-scale applications in this research.

The flow of the research paper is organised as follows,
Section 2 deals with the properties of electrode materials for ultra-capacitors. Section 3 illustrates ball milling of electrode materials for ultra-capacitors, section 4 examines various materials used to make ball milling jars, and section 5 deals with experimentation procedures for the research, following with conclusions and acknowledgement in section 6 and section 7 respectively.

2. Properties of electrode materials for ultra-capacitors
Activated carbon, metal oxides, and polymers are among the various types of electrode materials used for ultra-capacitors [13]. Activated carbon is one of the most readily available materials used as an electrode. Activated carbon is one of the most acceptable materials for making electrodes because of its good conductivity, high porosity, ease of availability, and thermal stability [13]. Pseudo capacitors are mostly manufactured out of metal oxides. A pseudo capacitor is part of an electrochemical capacitor, and forms together with an electric double-layer capacitor (EDLC) to create an ultra-capacitor. Nickel, Manganese, Magnesium, and cobalt oxides are more commonly used in the ultra-capacitor industry as electrode materials. The conductivity of these metal oxides depends on the crystallinity of the metal oxide. The higher the crystallinity of the material, the greater its conductivity [13]. Conducting polymers are also excellent as an electrode material in ultra-capacitors. Polymers for battery electrodes are made with the appropriate monomers and connectivity to meet these requirements. Some other conducting polymers used as electrodes in ultra-capacitors are polyaniline, polythiophene, and polypyrrole [13].

A mixture of manganese dioxide and activated carbon is used as an electrode material for research purposes. The mixture is made in the ratio of 1:1 by weight. As manganese dioxide is cheap and has an appropriate crystallinity, If the crystallinity of manganese oxide is very high, positive ion exchange will be limited. But this will lead to a lower surface area, and an increase in conductivity [14]. If there is low crystallinity, conductivity will be reduced, so there should be an adjustment between electrical conductivity and the surface area of the material. Activated carbon, on the other hand, is the most acceptable material to make electrodes for ultra-capacitors because of its excellent conductivity, small pore size, and large surface area due to its carbon microstructure [13].

Ideally, there are two commonly used electrode fabricating processes: Powder technology and film technology. Powder technology refers to a process in which electrode material granules are crushed into nano-sized powder. This powder is then adhered over the conducting core. The powder technology process is very easy and is extensively used for laboratory experiments. This powder of electrode
materials can be produced through a variety of operations like crushing, ball milling, powder metallurgy, etc. But film technology is a complex process as compared to powder technology. Film technology involves chemical decomposition of the electrode material over the conducting core. A variety of chemical reactions happen to get electrode material over the conducting core. Powder technology is employed in the research to fabricate electrodes from manganese dioxide and activated carbon. Manganese dioxide is grinded in a special type of ball milling machine known as ‘Laboratory grade ball milling machine’. This type of ball milling machine provides magnificent advantages for laboratory experiments.

3. Ball milling of electrode materials

A ball mill is a type of grinder used to crush materials into fine powder for use in pyrotechnics, mineral dressing processes, paints, ceramics, selective laser sintering, and electrode manufacturing. The ball mill works on the principle of impact and enfeebled. The ball mill is one of the most effective yet ignored fields in the electrode manufacturing industry. A ball mill consists of a hollow jar where material to be crushed or ground is fed into the machine. This jar has several spherical balls made of various materials like steel, zirconia or even ceramics and rubber in some cases. These balls apply impact on the material to grind, and after a long period of time, very fine, nano-sized grinded materials are obtained. Ball milling machines are broadly classified into various types: Vertical Axis ball milling machines, Horizontal axis ball milling machines, Industrial ball milling machines, Planetary (Multi-jar) ball milling machines. The ball milling machine used in this research is a special type of ball milling machine which is designed as a combination of a horizontal axis and a planetary ball milling machine, termed as ‘Laboratory grade ball milling machine’.

![Figure 1. Laboratory grade ball milling machine](image)

Fig 1. shows a diagrammatic representation of a laboratory grade ball milling machine which is designed and manufactured by us. Four jars are accompanied in this case. The motor used is a 300 rpm, 100-Watt planetary DC gear motor. The controller enables the operator to control the speed of the motor and allows the operator to set a specific time for ball milling. Some of the many advantages of this type of ball milling machine are: It can crush materials in small and large quantities, which means that it is possible to build a ball mill machine of any capacity as needed. Moreover, the cost of installation is less as compared to other robust ball milling machines. Furthermore, it is suitable for grinding materials in small as well as large quantities, implying that a ball mill machine of any capacity can be manufactured as required. Also, the machine produces minimum noise during operation. Applications of this type of ball milling machine are:
As a result of all these factors, the ‘Laboratory grade ball milling machine’ is used to crush manganese dioxide for ultra-capacitors. The jars of the ball milling machine are rotated at approximately 80 rpm and the cycle time is kept at 20 hrs [03]. The appropriate speed of ball milling is very important as more speed will cause high centrifugal forces and hence, material will adhere to the inner walls of the jar during ball milling, and hence the effectiveness of the process will be lost. But on the other hand, if the speed of ball milling is very low, very few centrifugal forces will be generated, so the material in the ball mill will experience less impact and enfeeble. A lot of research has already been done on various electrode materials for ultra-capacitors. But the processing of this electrode material is also an important aspect. Even though ball milling is a type of electrode processing technique, it is a neglected field of research. Hence, this research mainly focuses on the ball milling process for electrode material processing.

4. Materials for Ball milling jars
A wide range of materials are used to manufacture the jars of a ball milling machine. Austenitic stainless steel is the most used jar material for ball milling machines. Austenitic stainless steel has a face centred cubic structure. This structure is achieved by adding austenite stabilising elements like manganese, nickel, and nitrogen. Austenitic stainless steel has a superior ultimate tensile strength of 510 MPa. Aluminium is another metal used as a jar material for small-scale ball milling machines. Aluminium has a good ultimate tensile strength rating of 180-280 MPa. But aluminium is much lighter as compared to steel. Austenitic stainless steel has a mass density of 7800 kg/m³ and, on the other hand, aluminium has a mass density of 2720 kg/m³. Aluminium is approximately 30% lighter than austenitic stainless steel. But still, aluminium can not be used for many small-scale applications because it cannot absorb vibrations and noise. The leakage through ball milling jars made of aluminium is uncontrollable. Even more, 2720 kg/m³ of mass density is even though it is less than aluminium, it is not tolerable for many applications of laboratory use. So, there is a need for lighter materials which can also absorb vibrations and noise. Composites can be used as a substitute for jar materials in ball milling machines to overcome all these problems. Composites, also known as Fibre-Reinforced Polymer (FRP) composites, are generated from a polymer matrix that is reinforced with a man-made or natural fibre (like glass, aramid, or carbon) or other reinforcing material. Nylon and Polypropylene are used to make ball milling jars in this research for small scale applications. Nylon is the most widely used synthetic substance; its applications are spread across a wide range of activities, from daily household activities to various industrial applications. Nylon is a silk-like thermoplastic, usually made from petroleum, that can be melt-processed into fibres, shapes, or films. Nylon polymers can be mixed with a huge variety of additives to achieve many different variations in their properties. Nylon has an ultimate tensile strength of 70 MPa and has a mass density of 1140 kg/m³. Alternately, polypropylene is a thermoplastic polymer used in a wide variety of applications. It is generated through chain-growth polymerization from the monomer propylene. Polypropylene belongs to the group of polyolefins and is partly crystalline and non-polar. Its properties are like polyethylene, but it is somewhat harder and more heat resistant. Polypropylene has the lowest mass density of 855 kg/m³ and a good ultimate tensile strength of 40 MPa. Table 1. shows the properties of the materials linked with the material cost for each selected material. These properties and the cost of material are taken by performing a market survey while purchasing material for jars. These jars made of Nylon and Polypropylene are compatible with only small to medium scale applications as the strength of these jars is not enough to sustain extreme large forces during the grinding or crushing at a considerably larger scale in a ball milling machine.
Table 1. Material properties and material cost

| Material               | Ultimate Tensile Strength | Density | Material Cost |
|------------------------|---------------------------|---------|---------------|
| Austenitic Stainless-Steel | 510 MPa                   | 7800 kg/m³ | 2.04 $/kg    |
| Aluminum               | 280 MPa                   | 2730 kg/m³ | 1.98 $/kg    |
| Nylon                  | 70 MPa                    | 1140 kg/m³ | 2.20 $/kg    |
| Polypropylene          | 40 MPa                    | 855 kg/m³  | 2.60 $/kg    |

So, for large scale applications, there is a need for some strong materials which can not only withstand extremely high forces but also be cost-effective. Some of the carbon reinforced polymers are very strong, having an ultimate tensile strength in the range of 1000-1200 MPa. But the cost of these materials is exceedingly high, in the range of $25-30/kg. Moreover, these materials are very difficult to machine and only a few machining processes can be carried out on them, like forming, etc. This research also examines the use of a thin mild-steel layer at the inner periphery of the jars, with the rest of the jar being made of nylon or polypropylene. Through trial and error, the thickness of this mild-steel layer was found to be ideally more than 1.8 mm. For research purposes, the jars are specially designed to be compatible with laboratory grade ball milling machines. Jars are manufactured on the CNC lathe machine. Special care is taken to machine these materials as the temperature withstanding ability of these materials is not as high as steel and aluminium. So, the jars are turned at not more than 200-400 rpm.

Figure 2. Ball milling jars for Laboratory grade ball milling machine

Fig 2. shows the design and labelled diagram of the ball milling jars used in research which is designed and manufactured by us. A lid is also manufactured to prevent the fall of the electrode materials from the jars during manufacturing. For special types of jars, the mild steel layer is press fitted into the previously turned Nylon and Polypropylene jars. The overall manufacturing cost of all these jars is shown in Table-2.

Table 2. Overall manufacturing cost for selected jars

| Type of Jar     | Overall manufacturing cost |
|-----------------|-----------------------------|
| Aluminum Jars   | 20.22 $                     |


Nylon Jars 28.78 $
Polypropylene Jars 29.63 $
Nylon jars with mild-steel inner layer 39.91 $
Polypropylene jars with mild-steel inner layer 40.76 $

So, the cost of the jars will be increased by 15-20% for small-scale applications, but this will lead to the use of a considerably smaller motor and save electricity.

5. Experimentation

Ultra-capacitors are made from a mixture of crushed manganese dioxide and carbon in the ratio of 1:1 by weight. Fig. 3 shown here is the ultra-capacitor is made by us and the same is used to carry out the experimentation. First, manganese dioxide is crushed in a laboratory grade ball milling machine into a nano-sized powder. 50% of the wastage factor was also considered. Five samples of crushed manganese dioxide each from different types of jars, viz. Aluminium jars, Nylon jars, Polypropylene jars, Nylon jars with a mild-steel inner layer, and Polypropylene jars with a mild-steel inner layer. A slurry is formed from the mixture of crushed manganese dioxide and activated carbon with the use of an IPA solution. Slurry is then loaded over a steel mesh and then is allowed to dry in the proportion of 20 mg/cm². Polyethylene is used as a dielectric separator between the two electrodes. Following this process, five stacked type ultra-capacitors are made from the manganese dioxide crushed in each of five jars. The adhering agent used to paste the polyethylene sheets together is cyanoacrylate. These ultra-capacitors are now pressed tightly to ensure proper adhesion of the dielectric to prevent leakage. Potassium sulphate of molarity 0.65 is used as an electrolyte [15-20].

Figure 3. Stacked typed ultra-capacitor

The performance analysis of the electrodes of ultra-capacitors manufactured from each of the five jars can also be done using an electron beam microscope. The magnifying capacity of an electron beam microscope can be as large as 400-1900 times. These microscopes can be used to measure the size of ball milled product particles. But these microscopes are very delicate and expensive to work with. Nevertheless, an indirect approach is used to evaluate the performance ratings of all the ultra-capacitors manufactured from electrodes crushed in five different jars. In this indirect approach, ultra-capacitors are evaluated to determine the effectiveness of these ball milling jars made of five different materials. The capacitance rating of these ultra-capacitors is calculated using charge discharge tests. In this research, indirect approach turns out to be more beneficial than direct approach as indirect approach directly affiliates the application-based investigation of proposed ball mill machine jars and furthermore,
indirect approach is cost effective and easy to apply. The performance of these ultra-capacitors manufactured from electrodes processed in Aluminium jars, Nylon jars, Polypropylene jars, Nylon jars with mild-steel inner layer, and Polypropylene jars with mild-steel inner layer was evaluated and noted. From fig. 5, and fig. 6, it can be observed that the specific capacitance values of ultra-capacitors made from electrodes crushed in jars made of Nylon and Propylene show better ratings as compared to ultra-capacitors made from the electrodes crushed in aluminium jars. Jars with a mild-steel inner layer show less capacitance rating because they are meant for large-scale ball milling. The equivalent resistances of Aluminium and Polypropylene jars are almost similar, with a difference of just 1.9 Ohms. Ideally, the equivalent series resistance of an ultra-capacitor should be as low as possible [21-23].

**Figure 4.** Specific Capacitance of ultra-capacitors with selected jar materials (Farad/gm)

| Material                  | Specific Capacitance |
|---------------------------|----------------------|
| Aluminium                 | 1.6                  |
| Nylon                     | 1.7                  |
| Polypropylene             | 1.8                  |
| Nylon jars with mild-steel inner layer | 1.1 |
| Polypropylene jars with mild-steel inner layer | 1.2 |

**Figure 5.** Equivalent series resistance of ultra-capacitors with selected jar materials (Ohms)

| Material                  | Equivalent Series Resistance |
|---------------------------|------------------------------|
| Aluminium                 | 19.9                         |
| Nylon                     | 14.9                         |
| Polypropylene             | 21.8                         |
| Nylon jars with mild-steel inner layer | 17.5 |
| Polypropylene jars with mild-steel inner layer | 16.2 |
Figure 6. Energy density of ultra-capacitors with selected jar materials (Joule/gm)

Figure 7. Power density of ultra-capacitors with selected jar materials (Watt/gm)

Figure 8. Correlation between the density of surface material at inner surface of ball milling jars (g/cm³) and specific capacitance of ultra-capacitors (Farads) manufactured from electrodes in this jar.
From fig. 7 and fig. 8, it is evident that polypropylene is an excellent substitute for jar material for small-scale laboratory grade ball milling machines. But if the applications extend to a larger scale, i.e., for industrial applications, polypropylene will no longer be strong enough to withstand extremely high impact forces. Even aluminium will fail to withstand these forces for industrial scale applications. The only option in that case would be the use of steel. But steel has a very high density of 7.8 gm/cm³. Therefore, the load on the motor will be increased. Due to this, an innovative idea of using a mild-steel inner layer for Nylon and Polypropylene is proposed in this research. The effectiveness of this jar material is very much equal to the jars made entirely of steel. Fig. 8 shows a curve depicting the correlation between the materials used for jars and the performance rating of the ultra-capacitors manufactured from the electrodes processed in these jars. An equation is derived to predict the specific capacitance of the ultra-capacitors based on the density of the jar material in which the electrodes of the ultra-capacitors were crushed. The equation derived is:

\[ \rho = 0.5375C^3 - 4.6232C^2 + 9.3393C + 2.7 \]  

(1)

Where, \( \rho \) – Density of material at the inner surface of ball milling jar (gm/cm³).  
\( C \) – Specific Capacitance of the ultra-capacitors manufactured from the electrodes crushed in these jars (Farad/gm).

The equation was derived by us using a small regression model for the purpose of curve fitting using (Fig. 8), considering all the jar materials taken into consideration. The efficiency of the equation for a given set of data was closely equal to 96.6%. Special care must be taken that specific capacitance values are always positive and hence, negative values after solving the equation must be neglected.

6. Conclusion
The research examines the performance of the ultra-capacitors based on the jar inner surface materials in which the electrode materials of ultra-capacitors are crushed. An indirect approach is portrayed in the research paper, where ball milled material is used to make electrodes for ultra-capacitors, and then the performance of these ultra-capacitors is compared and results are evaluated for five different types of jar materials: Aluminium, Nylon, Polypropylene, Nylon with mild-steel inner layer, and Polypropylene with a mild-steel inner layer. A laboratory-grade ball milling machine is used for experimental purposes. The ball milling was done at 80 rpm and with 20 hours of cycle time [03]. After the experiments, it was observed that the ultra-capacitors made from manganese dioxide and activated carbon grind in polypropylene jars using stainless steel ball mill balls showed a better capacitance rating for small scale applications. But, for large-scale applications, Polypropylene jars with a mild-steel inner layer are recommended. These jars show performance ratings very similar to steel jars. Using the recommended jars, a few more advantages are observed:

- The overall weight of the ball milling jars is reduced by 69% with the use of Polypropylene and by 41.5% with the use of Nylon as jar materials for small scale applications as a substitute for Aluminium jars.
- Polypropylene and Nylon jars meant for low scale applications produce 25% less noise and vibrations.
- The power required for ball milling is reduced by 18%, so the load on the motor is also minimized.
- Cleaning of the jars can be easier. As the jar colour can be used in contrast with the colour of the material to be grind. This is because Polypropylene and Nylon are available in various colors.
- Aluminium jars are more prone to leakage. But Polypropylene and Nylon are composite materials. So, jars made from composite materials get compressed when the bolts on the lid are applied, minimising the leakage by 70%.
• Research also proposes composite jars with a mild-steel inner layer for large scale industrial applications.

The correlation curve between the ‘density of surface material at the inner surface of ball milling jars and the specific capacitance of ultra-capacitors manufactured from electrodes in this jar’ can be used as a tool to predict the effectiveness of a particular type of jar material. This can be an effective equation to decide excellent jar materials and thereby also evaluate the capacitance rating for ultra-capacitors whose electrodes are processed in this jar of material under consideration.

7. Acknowledgement

The authors of this paper highly acknowledge the support of the management of the Army Institute of Technology, Pune, and the College of Engineering, Pune for providing laboratory facilities during the experimentation. Last but not least, the authors also express their gratitude towards the workshop staff of the Army Institute of Technology for helping and guiding them wherever needed.

8. References

1. L S Godse, Vispi Karkaria, Dr P.B Karandikar, Dr N.R Kulkarni: Innovative Methods of Ball Milling to Grind Activated Carbon as an Electrode Material for Enhancing the Performance of Ultracapacitor. International Conference on Energy, Communication, Data Analytics and Soft Computing, pp. 2034-2041. IEEE, (2017).

2. He Liu, Xining Cheng, Yan Chong, Hong Yuan, Jia-Qi Huang, Qiang Zhang: Advanced electrode processing of lithium-ion batteries: A review of powder technology in battery fabrication. Particuology, 57, pp. 56-71 (2021).

3. L.S. Godse, Dr. P.B. Karandikar, Dr. M.Y. Khaladkar: Study of Carbon Materials and Effect of Its Ball Milling, on Capacitance of Supercapacitor. 4th International Conference on Advances in Energy Research, Energy Procedia, 54, pp. 302 – 309, (2014).

4. Adnan Alamili, Yiqin Xue, Faith Anayi: An experimental and analytical study of the ultra-capacitor storage unit used in regenerative braking systems. Applied Energy Symposium and Forum, Renewable Energy Integration with Mini/Microgrids, Energy Procedia 159, pp. 376-381, (2019).

5. Dan Li, Ziye Kang, Hao Sun, Ying Wang, Haiming Xie, Jia Liu, Jiefang Zhu: A bifunctional \( \text{MnxCo}_3\text{-xO}_4 \)-decorated separator for efficient Li-LiI-O2 batteries: A novel strategy to promote redox coupling and inhibit redox shuttling. Chemical Engineering Journal, 428, January (2022).

6. R Nandhini, P.A. Mini, B. Avinash, S.V. Nair, K.R.V. Subramanian: Supercapacitor electrodes using nanoscale activated carbon from graphite by ball milling. Materials Letters, 87, pp. 165-168, (2012).

7. Gelines Moreno-Fernandez, Nicolas Boulanger, Andreas Nordenstrom, Artem Iakunkov, Alexandr Talzyin, Daniel Carriazo, Roman Mysyk: Ball-milling-enhanced capacitive charge storage of activated graphene in aqueous, organic, and ionic liquid electrolytes. Electrochimica Acta, 370, (2021).

8. Karine R. R., Claire Mayer-Laigle, Bruno Piriou, Xavier Rouau: Comparative comminution efficiencies of rotary, stirred and vibrating ball-mills for the production of ultrafine biomass powders. Energy, 227, (2021).

9. Sara I. Ahmad, Hicham Hamoudi, Janarthanan Ponraj, Khaled M. Youssef: In-situ growth of single-crystal plasmonic aluminum lithium-graphene nanosheets with a hexagonal platelet-like morphology using ball-milling. Carbon, 178, pp. 657-665, (2021).

10. Yiru Zou, Chao Wang, Hanxiang Chen, Haiyan Ji, Qian Zhu, Wenshu Yang, Linlin Chen, Zhigang Chen, Wenshuai Zhu: Scalable and facile synthesis of V2O5 nanoparticles via ball milling for improved aerobic oxidative desulfurization. ScienceDirect, 6, issue 2, pp. 169-175, (2021).
11. Trimurti L. Lambat, Sami H. Mahmood, Deeb Taher, Subhash Banerjee: Sulfamic acid catalyzed oxonium-ene reactions under ball milling conditions: Straightforward access to highly functionalized Oxabicyclo [3.2.1] octenes. *Current Research in Green and Sustainable Chemistry*, 4, (2021).

12. Gaoce Han, Jize Yan, Zhen Guo, David Greenwood, James Marco, Yifei Yu: A review on various optical fibre sensing methods for batteries. *Renewable and Sustainable Energy Reviews*, 150, (2021).

13. Priyanka Sharma, Vinod Kumar: Study of electrode and electrolyte material of supercapacitor. *Materials Today: Proceedings*, 33, pp. 1573-1578, (2020).

14. Zhaowang Dong, Yang Xia, Xueyi Guo, Jinlong Zhao, Linfong Jiang, Qinghua Tian, Yong Liu: Direct reduction of upgraded titania slag by magnesium for making low oxygen containing titanium alloy hydride powder. *Powder Technology*, 368, pp. 160-169, (2020).

15. Shreyas Thombare: Dual Battery Fast Charging System for Electric Vehicles. *Global Transitions Proceedings*, August (2021).

16. Xiaolin Xu, Jinrui Nana, Ju Wang, Zepeng Gao: Estimate of super capacitor's dynamic capacity. *Energy Procedia*, 105, pp. 2194 – 2200, (2017).

17. Haoxiang Zhang, Wenbin Niu, Shufen Zhang: Extremely stretchable, sticky and conductive double-network ionic hydrogel for ultra-stretchable and compressible supercapacitors. *Chemical Engineering Journal*, 387, (2020).

18. Dacheng Zhang, Xiong Zhang, Xianzhong Sun, Haitao Zhang, Changhui Wang, Yanwei Ma: High performance supercapacitor electrodes based on deoxygenated graphite oxide by ball milling. *Electrochimica Acta*, 109, pp. 874-880, (2013).

19. Zhiwei Lv, Yuqiang Yan, Chenchen Yuan, Bo Huang, Can Yang, Jiang Ma, Junqiang Wang, Lishan Huo, Zhiqiang Cui, Xunli Wang, Weihua Wang, Baolong Shen: Making Fe-Si-B amorphous powders as an effective catalyst for dye degradation by high-energy ultrasonic vibration. *Materials and Design*, 194, (2020).

20. Ping Wang, Geng Zhang, Meng-Yu Li, Ya-Xia Yin, Jin-Yi Li, Ge Li, Wen-Peng Wang, Wen Peng, Fei-Fei Cao, Yu-Guo Guo: Porous carbon for high-energy density symmetrical supercapacitor and lithium-ion hybrid electrochemical capacitors. *Chemical Engineering Journal*, 375, (2019).

21. Henry Kahimbi, Seok Bok Hong, MinHo Yang, Bong Gill Choi: Simultaneous synthesis of NiO/reduced graphite oxide composites by ball milling using bulk Ni and graphite oxide for supercapacitor applications. *Journal of Electroanalytical Chemistry*, 786, pp. 14-19, (2017).

22. Jing Zhao, Botao Zhu, Guijin Yang, Yujun Fu, Yanna Lin, Jinyun Li: Vacuum annealed MnO2 ultra-thin nanosheets with oxygen defects for high performance supercapacitors. *Journal of Physics and Chemistry of Solids*, 150, (2021).

23. Aranizadeh, A. Zaboli, O. Asgari Gashteroodkhani, B. Vahidi: Wind turbine and ultra-capacitor harvested energy increasing in microgrid using wind speed forecasting. *Engineering SciSsence and Technology, an International Journal*, 22, Issue 5, pp. 1161-1167, (2019).