DESIGN AND MANUFACTURING OF THE PROTOTYPE FOR METAL-AIR BATTERY TESTING

By

Muhammad Adil

Tooba Tariq Khan

Muhammad Haseem Ayub

School of Chemical and Materials Engineering

National University of Sciences and Technology

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By

(Leader – 00000297360 Muhammad Adil)

(Member 1 - 00000321915 Tooba Tariq Khan)

(Member 2-00000288579 Muhammad Haseem Ayub)

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Supervisor Name: Dr. M. Talha Masood

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CERTIFICATE OF ACCEPTANCE

Certified that final copy of FYP thesis written by **Muhammad Adil** (000297360), **Tooba Tariq Khan** (000321915) and **Muhammad Haseem Ayub** (000288579) of School of Chemical and Materials Engineering (SCME), has been vetted by undersigned, found complete in all respects as per NUST statues/ Regulations, is free of plagiarism, errors and mistakes and is accepted as partial fulfilment for award of BS degree. It is further certified that necessary amendments as pointed out by GEC members of scholars have also been incorporated in the said thesis.

Signature: ____________________

Name of supervisor: **Dr. Muhammad Talha Masood**

Date: 12/06/2023

Dr M Talha Masood
Assistant Professor
SCME, NUST, H-12, Islamabad

Signature (HOD): ____________________

Date: 12-06-23

Signature (Dean/Principal): ____________________

Date: 16.6.2023

DEDICATION

"We dedicate this thesis to our beloved parents for their kind support throughout our academic career. We also dedicate our work to the faculty members and staff at SCME who supported us in this work."

ACKNOWLEDGMENT

In the blessed name of Allah Talla, the most compassionate, the most forgiving, we extend our utmost admiration and gratitude to the Almighty, the creator and sustainer of the universe. It is He who has blessed us with the faculty of thought and action and bestowed upon humanity the potential to positively transform the world. In the humblest manner, we express our profound appreciation for the bestowed potential to the supreme architect of the universe. All our accomplishments are solely a result of His blessings and guidance throughout our journey. Alhamdulillah.

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ABSTRACT

Metal air batteries have significantly grown over the years due to their superior energy density followed by their cost-effectiveness and eco-friendliness. To develop this technology further, it is necessary to investigate a variety of materials for effective electrochemical reactions on the anode and as catalysts on the cathode sides. The optimization of these two electrode materials is necessary for the MABs to be stable and effective. Due to the intricacy of the cathode side design and the presence of air, testing MABs can be difficult. A MAB prototype will be created, built, and tested to address these issues. This prototype should work with other anode/cathode materials for electrochemical testing and be reusable for other metal-air batteries. The prototype's design must have strong mechanical and chemical qualities that make it the best option for any battery system. The prototype also must be capable of enhancing the electrochemical processes taking place on both the anode and cathode sides. In conclusion, creating a MAB prototype is an essential step in developing this technology resulting in more affordable, energy-efficient, and environmentally friendly energy storage systems.

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CHAPTER 1

INTRODUCTION

The ever-increasing global concerns over environmental and energy issues have triggered substantial development and for that reason, there tends to be fuel depletion, climate change, air pollution, etc. Therefore, energy sources have become a major challenge and to avoid that batteries are a viable option due to their mobility and adaptability of batteries along with their superior energy characteristics. They can be used for a variety of tasks, including delivering electricity to far-off places or serving as a backup in case of an outage. Batteries are also essential for the switch to renewable energy sources because they allow energy storage to maintain a balance between grid supply and demand.

A battery, in general, is an energy-storing device that simply uses electrical energy to convert it to chemical energy by the incorporation of the redox reaction within the electrochemical cells, hence it is significant to provide a power supply for the transfer of the electrons within the external circuit to initiate charging or discharging. Therefore, oxidation and reduction occur simultaneously as long as the electric supply is delivered [1]

Moreover, amongst batteries, metal-air batteries have significantly grown due to their high energy densities which make them reliable to store huge amounts of energy. The first ever non-rechargeable Zinc-air battery was established in the early 19th century, and the company started marketing its goods in 1932. Since then, a significant amount of research and advancement has been made in the field of MABs. In comparison, Li-ion batteries perform greatly in the electronic engineering industry, but when compared with metal-air batteries, they have a much lower energy density (between three and thirty times lower).[2]

1.1. Metal-Air Battery

Metal-air batteries are a type of energy-storing device that employs a metal anode and an air cathode, which utilizes atmospheric oxygen. Since the anode can be manufactured from cheap metals and the air-cathode (natural oxygen) is readily available, therefore, these batteries are affordable. Since they have a larger heat capacity and power density compared to conventional batteries, they appear to be one of the practical and cutting-edge alternatives for the foreseeable requirements. It consists of three basic components of the battery including a metal anode made of different metals. An air cathode is made of porous materials and lightweight to consume oxygen from the atmosphere and an electrolyte that is as significant as the others which assists in ion conduction between the anode and the air cathode.[3]

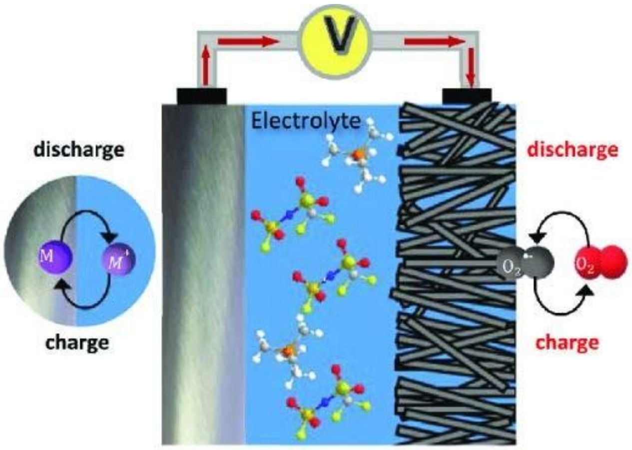

Figure 1: An illustration of the battery's discharging and charging reactions within the cell [4]

1.2. Discharging And Charging Reactions:

$M^{+}+\ xOH^{-}\ \text{-}\!\!\rightarrow\ M(OH)_{X}\ +xe^{-}$ (anode) **(1.1)**

$O_2+H_2O+4e^{-}\text{-}\!\!\rightarrow 4OH^{-}$ (cathode) **(1.2)**

Overall Reaction:

$M+\frac{1}{2}O_2\rightarrow MO$ (cell) **(1.3)**

During discharge, the metal anode oxidizes, thus losing electrons that flow from the external circuit to the air cathode to react with oxygen where it is reduced and consumes electrons from the electrolyte forming a metal oxide or hydroxide, and the discharging reactions are continued until all the metal anode has been consumed or the supply of air has been depleted. During charging, all the reverse reactions take place where the metal oxide or hydroxide converts back to the metal at the cathode anode, and the oxygen is evolved at the anode. The charging and discharge processes of the battery produce a theoretical voltage of 1.65 V, which may be computed as Eeq = E0 (cathode) - E0 (anode). However, in practice, the working potential of a zinc-air cell is often lower than 1.65 V, fluctuating between 1.35 and 1.4 V. This difference from the predicted value is ascribed to concentration losses, ohmic resistance, and internal variables.[5]

1.3. Zinc-Air Battery

Among non-air-cathode primary batteries or even metal-air batteries, zinc-air batteries (ZABs) have the maximum specific energy density of about 50 Wh kg1 which is also considered the highest among the other metal-air battery systems. Its size and energy density characteristics have changed over the past century to suit the applications and demands of the consumer market, leading to its current commercial form. Amongst other battery systems, they have the maximum volumetric and specific energy densities of about 500 Wh kg1 and 1000 Wh L1, respectively With a voltage of approximately 1.3 V, the discharge curve is basically flat which justifies its superior discharging property. [2]

They possess a high energy density which enables them to store a large amount of energy relative to their weight and can even be used for electrical vehicles. They are cost-effective which makes them a desirable alternative for use in large-scale energy storage systems or backup power applications since they are reasonably easy to produce. They have an extended shelf life which makes them highly efficient during emergency situations or in outlying areas where routine maintenance is impractical. Moreover, they can also be made rechargeable and can be used repeatedly, rather than single-use batteries. They are extremely environmentally friendly since they do not contain any heavy metals which are hazardous, not to mention their raw materials are abundant and widely available which makes them a more sustainable option than other materials.

1.4. Zinc-Air Battery Components

1.4.1. Zinc Anode

In zinc-air batteries, the anode functional part is entirely made of zinc metal, which becomes oxidized during discharge. As a consequence, the majority of research has been centered on ways to enhance the airborne cathode instead of the zinc anode. Given that HER (hydrogen evolution reaction) isn't anticipated to take place through the discharge process, the most significant field of study has been identified: it is believed that it will ultimately be possible to utilize all of the metal zinc during the discharge process, thus the battery has an improved storing capacity. The effectiveness of the zinc anode can be improved by increasing the surface area of the morphology used for the zinc anode so that the anode can have a more enhanced reaction electrolyte.[6]

1.4.2. Air-Cathode

The notion of making use of atmosphere air in zinc-air batteries demands the air electrode to have enough oxygen reduction reaction (ORR) catalysts as well as a heavily porous structure. Both of these considerations must be brought into account concurrently while designing an air electrode. Because catalysts are necessary to lower the extremely high binding energy of the oxygen reduction reaction (ORR), the layout of the air electrode influences the performance of the zinc-air cell. The air cathode solely functions as a substratum for ORR and since oxygen can be acquired from the atmosphere, an air electrode could be used. [6]

1.4.3. Electrolyte

Sodium hydroxide, Potassium hydroxide, and lithium hydroxide are alkaline electrolytes that are generally employed in these batteries. Due to the greater ionic conductivity of potassium ions of about 73.50 1 cm2/equiv in comparison with Sodium ions of about 50.11 1 cm2/equiv, which ultimately proves that potassium hydroxide is commonly used due to its ionic conductivity Furthermore, 30% KOH is commonly utilized since it has the highest ionic conductivity at this concentration, therefore, improving the concentration of potassium hydroxide is an effective solution to lower electrolyte resistance, however, too much KOH can cause increased viscosity in the electrolyte.[6]

1.5. Problem Statement

Metal-air batteries are, however, difficult to commercialize due to their complexity in design which makes them difficult and expensive to manufacture and thus have reduced the ability to compete with other batteries. Nevertheless, because of how heavily the battery's design affects its performance and cost which further increases due to the battery components; therefore, they should be reliable enough to increase the efficiency of the battery. It has become difficult to measure their performance on a lab scale due to their mechanical instability. Therefore, it will be necessary to create novel and straightforward design strategies for metal-air batteries that can balance the trade-offs between various performance indicators and enable effective and economical manufacturers to address these problems further. Other than this, an innovative design will enable an increase in the efficiency of the electrochemical reactions taking place thus improving the performance of the battery further.

1.6. Hypothesis

A solution is proposed for the development of metal-air batteries where transparent acrylic sheets can be incorporated for the design which are extremely cost-effective and environmentally friendly. The use of transparent acrylic sheets makes it simple to visualize the battery components and can easily be helpful to assess any problems that can compromise the battery’s performance. Moreover, they are lightweight which makes them easier to handle and install. They exhibit good mechanical stability and impact resistance, hence a reliable option for designing a battery tester that not only can be used for metal-air batteries but for any battery systems as well. This will also increase the electrochemical performance of the battery due to the rarity in the design which will assist in the development of a stable casing for lab-scale metal-air battery testing.

However, to initiate the testing on a lab scale, zinc air batteries can be studied amongst the other metal air batteries due to their extraordinary energy density, cost effectiveness and eco-friendliness to have more reasonable results which in turn would be a comparison with other metal air battery systems as well.

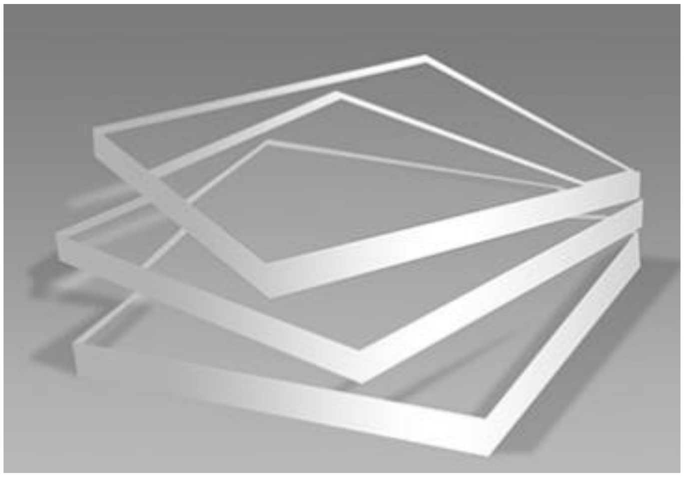

Figure 2: Acrylic sheets that can be used for prototype designing of metal-air batteries.[7]

1.7. Literature Review

Several research articles were looked at to use the most efficient and cost-effective battery components that could be incorporated into the battery design prototype. It had been very helpful in finding the efficiency of the material through the electrochemical tests that were carried out. The literature read was quite useful to determine the fabrication and characterization techniques that can be used for the battery components. Moreover, the literature has assisted in finding a unique metal-air battery design that could increase the reliability of the prototype and produce satisfactory electrochemical results. These are the following articles that were reviewed:

1.7.1. Zinc Nickel Indium (ZNI) Alloys:

The research article revolves around the preparation of three alloys that were used as anodes in order to enhance the overall performances of the Zinc anode anodes for Zinc-air batteries. The alloys were calcined at two different temperatures and had varying weight percentages of zinc, nickel, and indium. The alloy that consisted of the following components and composition include 90wt% zinc, 7.5wt%% nickel, and 2.5wt%% indium and was burned at 500°C was found to be the best out of the six alloys. This alloy's potential was altered to a more negative potential in the hydrogen evolution reaction. When compared to other alloys, it was observed that the anodic and cathodic parts of the cyclic voltammogram had only produced a slight difference which was almost negligible. Surprisingly, the alloys managed to produce reversibility after 100 cycles. This is a blatant sign that dendritic development was significantly curtailed.[8]

1.7.2. Coating of Aluminum Oxide on Zinc Particles:

A significant shortcoming found in the flexible zinc air batteries is that they tend to self-discharge due to the hydrogen evolution reaction (HER) which ultimately causes corrosion within the zinc anode. This effort intends to prevent the self-discharge of flexible printed zinc-air batteries by covering the zinc particles' surfaces with a thin layer of aluminum oxide. Using the simple and affordable sol-gel process, the aluminum oxide coating layer was immediately synthesized and applied to the zinc particles. The HER and corrosion were considerably impeded due to the coating of the oxide layer on the zinc anode. Moreover, the influences of oxide layer thickness on the zinc anode were determined by placing it in a 9 M KOH electrolyte to see the corrosion behavior on the anode. It was thus observed that corrosion was prevented by an adequate layer of aluminum oxide coating.[9]

1.7.3. Nanoporous Carbon Fiber Film:

A simple technique for producing nanoporous carbon nanofiber filaments (NCNFs) on a large scale by simply pyrolyzing electrospun polyimide fiber filaments at high temperatures. It had therefore resulted in a substantially large surface of about 1249 m2g followed by a low tensile modulus of about 1.89Mpa. A high electrical conductivity of about 147 Sm1 was determined and a moderate tensile strength of 1.89 MPa was obtained, Other than this, it was observed that the nanoporous carbon films acting as the bifunctional catalysts had resulted in enhanced performance of both ORR and OER. A maximum power density of about 185 mWcm2 along with a specific capacity and energy density of about 626 mAhg1 and 776 Wh kg 1 was produced respectively that were obtained for liquid Zinc air batteries when nanoporous carbon fiber film was tested as the air cathode. Moreover, when carbon nanoporous film was tested on liquid rechargeable zinc batteries, they produced superior results which include a high reversibility of about 62% followed by stability of about 0.13V after 500 cycles.[10]

1.7.4. PVA- Gel:

A Polymer-based gel electrolyte alongside with a solution of 6MKOH was used for flexible zinc air batteries. It was observed that a rapid discharge rate was due to the water content being significantly high in the gel which was stated to be maintained using a straightforward method for making the gel electrolyte. The ideal flexible battery may undergo a significant drain. The ideal flexible battery has a usual power density of a maximum of 64 mW cm-2 followed by a specific capacity of 37 mAh cm-2. Therefore, an extreme current density of about 50mAcm-2 resulted in a drained battery Through the use of post-mortem XRD studies as well as the three-electrode chronopotentiometry, the cause of the deteriorated Discharging and charging behavior was observed to determine the failure of the cell. The primary cause of both zinc and air electrode degradation is thought to be ZnO precipitation. A continuous bending test also demonstrates good flexibility when cycling, highlighting its potential for use in real-world scenarios.[11]

1.7.5. MoN-C/MoS2:

Extremely competent platinum catalysts replaced with electrocatalysts offers enormous potential. Due to their extremely large surface area, flexible, hierarchical pore architectures along with extraordinary catalytic activity, metal dichalcogenides (MDs) and metal-organic frameworks (MOFs) can be used as efficiently as active electrocatalysts. In the research article, an enhanced electrocatalyst, a vertically aligned nanosheet of molybdenum sulfide was enclosed with a framework of Molybdenum doped with nitrogen and carbon which was further disclosed within the coupling centers of the interfacial Molybdenum doped with nitrogen (Mo-N). The strong multifunctional electrocatalytic activity was observed with respect to the OER, ORR, and HER and stability. Other than this, high voltaic efficiency at about 63% along with good maximum power density was achieved at 196.4 mW cm-2 which demonstrated that the electrocatalysts had performed well as cathode electrocatalysts.

Interestingly, it was observed that a voltaic efficiency of about 63% was attained along with the highest power density of 196.4 mW cm. Not to mention that it had managed to produce cycling stability at 25mAcm-2 yet after 48 hours, hence its remarkable performance as an electrocatalyst. The synergistic interaction between the discrete active sites alongside distinctive chemical composition followed by pore architecture and the immediate electron transfer had resulted in such exceptional electrocatalytic properties. Furthermore, the sophisticated performance of the design based on the MOF/MD hybrid-based electrocatalysts had been anticipated to be inspired by this work for greater use in electrochemical energy devices. [12]

1.7.6. Manganese, Nitrogen Co-doped with Cobalt Porous Carbon:

Mesoporous carbon that is doped with heteroatoms in one dimension (1D) is a potential replacement catalyst to enhance the catalytic activity of ORR. In the research article, an Oxygen reduction reaction (ORR) electrocatalyst made of carbon nanotubes and Mn-doped with Co nanoparticles covered with a mesoporous carbon layer had been described. The 1D mesoporous design of the hybrid, which has a lot of active sites, led to its enhanced Oxygen reduction reaction (ORR) activity along with long-lasting performance and excellent selectivity. Moreover, the hybrid demonstrated remarkable performance equivalent to platinum doped with carbon as the catalyst for the air-cathode to be used by the primary Zn-air battery. Therefore, it would be highly beneficial to have a prepared electrocatalyst that is free of any noble metal which could then be used for energy applications to increase the efficiency of the battery.[13]

1.7.7. Ag-modified Cu Foams:

It is already known that the zinc anode's dendritic development and self-corrosion clearly influence the battery performance. Here, we describe a brand-new Cu foam substrate that has been used for the first time as a 3D anode in zinc-air batteries. Ag placed on Cu foam is shown to lower the corrosion current density on the anode by tafel and linear scanning voltammetry experiments and thus suppress the hydrogen evolution reaction (HER). An Ag modifies 3D anode has been employed with an anode capacity of about 200 mAh. The modified battery then exhibited an energy density of about 786 Wh kgZn-1 alongside a high specific capacity of about 676 mAh gZn-1 with high zinc consumption at about 87% and managed to produce 80 cycles yet after a two-hour period. Moreover, as the Ag-based Copper foams were employed as an anode, it had caused an increase in the Columbic efficiency of about 94%a Additionally, the three-dimensional Ag-modified anode had also resulted in no dendrites at discharge depths ranging between 5% to 20%. The Zinc-air batteries then resulted in an excellent energy efficiency of 60%, hence, providing a steady cycling of more than 40 cycles. The silver nanoparticles on the surface of the substrate had managed to control the homogenous deposition of the zinc amid the copper skeleton which had considerably inhibited the development of dendrites by providing a uniform and incessant transmission of electrons resulting in a steady cycling.[14]

1.7.8. Starch Gel:

Zinc-air batteries have been acknowledged as a leading contender for the upcoming generation of portable smart-wearable battery technology. Unfortunately, the expensive flexible electrolytes and challenging production procedures prevent flexible Zn-air batteries from being used commercially. In the research article, an inexpensive starch gel was made via the starch gelation technique for these batteries. The produced starch electrolyte, which benefits from exceptional hydrophilicity and adhesion, has managed to produce an ionic conductivity of about 111.5 mS cm1 which was considered very high and had significantly influenced the contact between the electrolyte and the electrodes. A flexible Zn-air battery with a starch gel electrolyte also offers exceptional mechanical flexibility, tough reliability under challenging conditions, and longer cycling of more than 200 alongside a power density of about 84 mW cm2 which was substantially large.. This research provides a method for creating flexible Zn-air batteries' high-performance solid-state electrolytes.[15]

Nanoengineered polymer electrolyte: Zinc-air batteries are sensitive to environmental factors (such as humidity and CO2) which also involves substantial self-discharge difficulties, decreasing the shelf life of the battery. To address the issues, a nanoengineered polymer electrolyte can be employed which is based on a near-neutral quaternary ammonium (QA) functionalized polyvinyl alcohol electrolyte membrane (as opposed to traditional alkali-type membranes). By producing hydrophobic or hydrophilic separations at the nanoscale, QA functionalization can help in the development of linked nanochannels. These nanochannels can manage to transport hydroxide ions with a reduced passage barrier while also preventing the crossing of hexaaminezinc ions. The zinc-air battery then exhibited high flexibility of the membrane followed by the increased cycle life of the battery. Not to mention the high volumetric energy density produced due to the membrane's improved chemical stability and greater water retention capabilities. More significantly, the zinc-air batteries had resulted in a reduced self-discharge rate of about 7% per or even less in a month and the entirely dried-out ZAB could regain its rechargeability after being refilled with the NH4 Cl solution.[16]

1.7.9. Bismuth Oxide Additives:

During the charging process, the development of dendrites was controlled at the surface of the anode by consuming the oxide additive in the zinc-air battery's anode. To examine the electrode's electrochemical performance, CV was put to use at a potential limit of 2.0 to 0.5 V followed by a sampling frequency of 1 mV/s. Surprisingly, a zinc anode with 3 wt.% oxide additive had managed to sustain cathodic peaks yet after 20 cycles with no discernible degradation. Following controlled kinetics, a multifaceted spherical shape was created with the additive at a current density of about 0.05 A/cm2 when SEM characterization was performed. There is absolutely no question that this oxide additive effectively decreased the growth of dendrites on the anode's surface. As a result, researchers have gained a greater understanding of the essential part that bismuth oxide addition serves to generate a dendrite-free zinc anode having an uninterrupted cycle. As a result of this, this anode is a great choice for zinc-air secondary batteries.[17]

After reviewing every article in detail related to ZABs, starch gel as the electrolyte proved to be competent and cost-effective, in addition to the nickel foam used as the air cathode with carbon black used as the active material due to its high catalytic activity in enhancing the ORR and OER activities and Zinc foil as the anode.

CHAPTER 2

MATERIALS AND METHODS

2.1. Battery Components Used in Detail and Their Specifications:

2.1.1. Zinc Foil:

The cathode is an integral part of the electrochemical process in a metal-air battery. This experimental battery has a cathode made of 100% zinc metal. Zinc's favorable properties as a cathode material are its availability, cheap cost, and little environmental impact. Due to its abundance, zinc is a practical metal for mass-producing batteries. In addition, zinc is safe and recyclable, making it an ideal choice for meeting the growing need for eco-friendly energy storage methods.

Zinc foil is used because it is the most effective type of zinc for the cathode. Thin sheets or strips of pure zinc metal are known as "zinc foil." Zinc foil has various benefits when used in metal-air batteries. To begin, the foil's expansive surface area facilitates better electrochemical reactions, leading to more effective energy conversion. Since there is more room for ions and electrons to move about, battery performance is enhanced, and energy density is raised as a result. Second, zinc foil has high electrical conductivity, which is essential for quick charge transfer within the battery itself. The foil's conductivity allows electrons to flow freely, reducing resistance and improving the battery's efficiency.

In addition to these chemical and electrical benefits, zinc foil is mechanically flexible and easy to handle during battery construction. To facilitate easy packaging and integration into a wide range of devices and systems, the foil may be readily bent and manipulated to meet the required battery layout.

It's important to keep in mind that zinc foil may have durability and stability restrictions, particularly after repeated battery cycling or when subjected to certain operating circumstances. Battery performance and longevity may suffer due to the foil's vulnerability to corrosion and deterioration. Because of this, scientists and engineers are always trying to make zinc foil more durable and compatible with other battery parts.

2.1.2. Configuration of Foil:

The prototype battery's negative electrode is made from zinc foil that has been precisely measured and polished for maximum efficiency. This battery uses zinc foil that is 1 inch by 1 inch (in terms of both length and breadth) and 0.1 millimeters thick.

Zinc foil is custom cut to precise proportions that meet the needs of the battery. Surface area requirements for effective electrochemical reactions are met by the 1-inch-by-1-inch dimensions. Increases in performance and energy density may be achieved by increasing the battery's surface area, since this is where the electrochemical processes really take place.

The thickness of the zinc foil is also significant for the sake of mechanical stability and charge transmission. The thickness of 0.1 mm provides an optimal compromise between longevity and electrochemical performance. While thinner foils are more likely to sustain mechanical damage, bigger foils may obstruct the free movement of ions and electrons inside the battery.

The foil is polished to perfection before being used. To polish zinc foil, its surface must be gently smoothed until it reflects light exactly like a mirror. There are many uses for this polishing process.

First, the zinc foil's polished surface makes for better contact with the electrolyte, which is essential for effective ion exchange when the battery is in use. Because zinc ions can now diffuse more easily because to the improved contact, electrochemical processes and battery performance as a whole are boosted.

Second, corrosion-causing surface defects and impurities are eliminated during the polishing process. By polishing the battery's exterior, we may lessen the chance of corrosion and increase its reliability and service life. As time passes, a battery's performance and utility may decline due to corrosion and the pollutants it produces.

2.1.3. Reactions on Foil:

Zinc foil cathodes undergo a series of surface reactions during battery discharge that ultimately result in the liberation of electrons and the creation of zinc oxide. Let's look further into the responses:

Zinc atoms at the anode (the zinc foil) oxidize, releasing electrons into the electrolyte during the discharge process. Here is how this procedure is illustrated:

Zinc (Zn) Zinc (Zn2+) ions + 2 e- **(2.1)**

As the freed electrons go through the external circuit, they generate an electric current that may be used to run a variety of electrical appliances.

Hydroxide ions (OH-) are formed in the electrolyte when oxygen from the air mixes with water and the electrons from the zinc anode at the cathode, which is normally an air electrode. The term "oxygen reduction" describes the process here. Putting it all together, we get 4 hydroxide ions (4OH-) when we react oxygen (O2) with 2 water (H2O) and 4 electrons. It is the job of the electrolyte to transport the hydroxide ions produced at the cathode to the anode.

Zinc oxide (ZnO) and water (H2O) are formed when hydroxide ions react with zinc ions upon reaching the zinc foil anode.

The ionic formula for zinc oxide (ZnO) and water (H2O) is:

zinc (Zn2+) + 2 hydroxide (OH-) ions. **(2.2)**

During battery discharge, energy is released, and electric current is generated as a result of zinc interacting with oxygen at the cathode to make zinc oxide.

Recharge of a battery causes an about-face in chemical processes. Energy for the opposite reactions comes from an external power source that is wired into the battery.

While oxygen is generated at the air cathode during charging (reduction), zinc oxide (ZnO) is reduced back to zinc atoms on the surface of the zinc foil cathode. The energy for this reduction process must be supplied by an external source.

In its simplest form, this reaction may be written as follows:

zinc oxide (ZnO) + 2 e zinc ions (Zn2+) + oxygen (O2-) **(2.3)**

The zinc ions are deposited back onto the zinc foil cathode during the reduction process so that they may be oxidised during the following discharge cycle.

The metal-air battery is an attractive alternative for energy storage because its reactions are reversible, allowing it to be charged and discharged again.

2.1.4 Electrolyte:

To facilitate ion movement between the anode and cathode, metal-air batteries rely on solid-state electrolytes. Starch is used as the solid-state electrolyte in the prototype metal-air battery detailed here. Starch is inexpensive, non-toxic, and easy to recycle, all of which make it a good candidate for this use.

2.1.4.1 Cost-Effective:

Due to its accessibility and low price, starch is a viable alternative for mass-producing batteries. Its low price helps make metal-air batteries more widely available and competitive in the market.

2.1.4.2 Non-Toxic:

Starch is a non-toxic carbohydrate polymer that may be found in many different plant foods. It is safe for humans and the environment, posing no threat whatsoever. This quality is crucial for the battery's security throughout its lifetime, from production to usage to disposal.

2.1.4.3 Easily Recyclable:

Recycling is an essential part of developing long-term, sustainable energy storage systems. Starch is simple to recycle since it is biodegradable and renewable. The starch-based solid-state electrolyte in batteries may be recycled and reused once they have reached the end of their useful life.

2.1.4.4 Ionic Conductivity:

Starch also has strong ion conductivity, thermal stability, and mechanical flexibility, all of which are desirable qualities in solid-state electrolytes. For the battery to work properly, these qualities are essential.

In metal-air batteries, solid-state electrolytes made from starch provide a stable and effective channel for ion transport. They allow ions, such as zinc ions, to move between the zinc anode and air cathode, which is required for the electrochemical processes that store and release energy.

It's important to remember that researchers are always working to enhance the functionality and characteristics of starch-based solid-state electrolytes. To improve the performance and dependability of metal-air batteries, researchers are working to increase their ion conductivity, optimize their mechanical strength, and investigate the use of composite materials.

2.2. Procedure:

Extraction of starch from regular wheat flour is the first step in making the starch-based electrolyte for the metal-air battery. An in-depth description of the procedure is as follows:

1. Normal wheat flour has a high concentration of starch, which may be extracted. Starch is made by combining flour and water and firmly stirring the resulting paste. The starch granules in the flour may be more easily extracted by stirring them apart from the other ingredients like proteins and fibers. A starch-water suspension is produced as a consequence.
2. The starch-water suspension is heated while being agitated constantly, a process known as gel formation. When heated, starch molecules become active, allowing them to take up more water and expand. The outcome is that the substance becomes thick and gel-like. The starch is evenly distributed, and lumps are avoided thanks to constant stirring throughout the cooking phase.
3. After the gel has formed, the liquid is cooled to room temperature and a film is produced on its surface. As the gel cools, it hardens and takes on a more rigid

structure. The gel is sliced into thin films or sheets when it has cooled. The metal-air battery uses these films as solid-state electrolyte.

4. Battery applications benefit from the starch-based electrolyte's thin films' adaptability. The films are simple to include into battery design and facilitate rapid ion transfer between the battery's anode and cathode.
5. Depending on the particular qualities and needs of the starch-based electrolyte, the manufacturing procedure may differ. The electrolyte's ion conductivity, mechanical strength, and stability may be optimised by experimenting with different modifications in the starch extraction, gel forming, and film cutting operations.

2.3. Significance of Solid-state Gel:

Starch gel as a solid-state electrolyte offers several advantages over liquid electrolytes, making it an excellent choice for metal-air batteries. Here's an expanded explanation of the benefits of using starch gel as a solid-state electrolyte.

Figure 3: Starch Gel

2.3.1. Leakage Prevention:

Unlike liquid electrolytes, which have a higher risk of seeping out of the battery, starch gel provides a more secure containment for the electrolyte material. The gel consistency helps to prevent electrolyte leakage, ensuring the integrity and safety of the battery system.

2.3.2. Reduced Evaporation:

Solid-state electrolytes, such as starch gel, have a lower tendency to evaporate compared to liquid electrolytes. This characteristic is particularly important in metal-air batteries, which can generate heat during operation. The use of a solid-state electrolyte minimizes the risk of electrolyte loss due to evaporation, ensuring stable and prolonged battery performance.

2.3.3. Enhanced Safety:

Metal-air batteries with solid-state electrolytes, like starch gel, offer improved safety compared to liquid electrolyte-based batteries. Solid-state electrolytes are less prone to leakage, reducing the risk of chemical spills and potential hazards. Additionally, the use of non-toxic and biodegradable starch further enhances the safety aspect of the battery, making it environmentally friendly and safe for handling and disposal.

2.3.4. Sustainability and Low Cost:

Starch is a renewable and readily available resource, making it a sustainable choice for solid-state electrolytes. It can be produced from various plant sources, such as wheat, corn, or potatoes, through a relatively simple extraction process. The abundance and low cost of starch contribute to the cost-effectiveness of metal-air batteries, making them an attractive option for large-scale energy storage applications.

2.3.5. Recyclability:

Starch, being biodegradable, can be broken down by natural processes and recycled. At the end of the battery's life cycle, the starch-based electrolyte can be processed and reused or safely disposed of without significant environmental impact. This recyclability aligns with the principles of circular economy and sustainable energy storage practices.

The utilization of starch gel as a solid-state electrolyte in the prototype metal-air battery represents an exciting development with the potential to revolutionize the energy storage industry. Its ease of manufacture, low cost, environmental friendliness, and recyclability make it a compelling contender for various large-scale energy storage applications, including renewable energy integration and grid stability.

2.4. Slurry Coated Nickel Foam Air Electrode:

The oxygen reduction process, necessary for the production of energy, is greatly aided by the air electrode in the prototype metal-air battery. The prototype uses a nickel foam air electrode, which is notable for its three-dimensional porous structure and several benefits for high-quality battery operation.

The nickel foam air electrode is porous in three dimensions, meaning it is made up of a system of linked pores and open channels. The area of the electrode that is in touch with the oxygen is greatly increased by this design. Because of the electrode's larger surface area, chemical energy may be efficiently converted into electrical energy via a process known as oxygen reduction.

Because of its porous nature, a slurry coating may be applied to a nickel foam air electrode. The electrode is covered with a slurry made of active ingredients, conductive additives, and a binder. By boosting the catalytic activity of the electrode and the electrochemical processes, the slurry coating maximises the oxygen reduction process.

The oxygen reduction process is made easier by the slurry's active elements, which often include catalysts like platinum. By improving electron transport inside the electrode, the conductive additives aid in encouraging efficient electron flow when the battery is in use. When applied to a nickel foam electrode, the binder keeps the slurry's constituents from separating.

By raising the oxygen-interacting surface area, boosting the catalytic activity, and allowing the efficient transfer of electrons, the slurry coating on the nickel foam air electrode improves the electrode's performance. As a result, the battery's overall efficiency and power output will improve.

The oxygen reduction process is enhanced by the nickel foam air electrode's three-dimensional porous structure and slurry coating, making the metal-air battery more powerful and efficient.

2.4.1 Slurry:

The metal-air battery prototype uses a slurry coating made from a carefully prepared combination of many components. Here's a more in-depth look at what each ingredient does for the sludge:

Commonly employed as a binder in battery electrode compositions, Nafion is a brand of perfluorinated sulfonic acid polymer. Nafion functions as a binder in the slurry to keep everything together and stick to the electrode. It aids in keeping the active components in excellent contact with the electrode and preserves the slurry coating during battery use.

Commonly utilised in battery slurry compositions is isopropanol, commonly known as isopropyl alcohol. It's multifunctional in the mud. To begin, it plays the role of a dispersing agent, aiding in the dissolution and distribution of the slurry's other solid components like carbon black. Second, the isopropanol helps the slurry thicken up to the right consistency, which makes coating the electrode surface more manageable.

Deionized water is water that has had all of its dissolved minerals and other contaminants ionised out of it. Deionized water is used in the slurry to act as both a solvent and a diluting agent. In addition to facilitating a more uniform blending of the other ingredients, its fluidity is essential for coating the electrode. Deionized water is used so that the electrochemical processes in the battery are not disrupted by impurities or pollutants found in tap water.

As a conductive addition, carbon black is often used into battery electrode compositions. Being a highly conductive type of carbon, it aids in increasing the electrode's electrical conductivity and the slurry coating's electron transport. The electrode's total conductivity is enhanced by adding carbon black to the slurry, which facilitates efficient electron flow when the battery is in use.

Depending on the needs and optimisation of the metal-air battery design, the exact amounts of each component indicated in the slurry formulation (50 l of Nafion, 800 l of isopropanol, 150 l of deionized water, and 10 mg of carbon black) may vary. The goal of the formulation is to create a slurry with the right consistency for excellent adhesion, viscosity, and electrochemical performance.

2.4.2 Nafion:

Nafion is a popular ion-exchange fluoropolymer-copolymer made from sulfonated tetrafluoroethylene. Nafion plays a critical function in boosting the air electrode's performance as part of the prototype metal-air battery's slurry coating. Here is a more in-depth description of Nafion's properties and how they affect the electrode:

Nafion's distinctive ion-exchange characteristics are the result of the presence of sulfonate groups in its molecular structure. Within the electrolyte, these sulfonate groups attract and exchange cations like protons (H+) and metal ions. This quality is especially useful for metal-air batteries because it improves the electrolyte's ionic conductivity, which speeds up the transfer of ions during the battery's electrochemical processes.

Nafion is first dissolved in isopropyl alcohol so that it may be more easily incorporated into the slurry. The Nafion may be dissolved in the isopropyl alcohol and the resulting mixture will be uniform. Incorporating the Nafion into the slurry in this way helps to achieve uniform performance over the electrode's face.

Nafion is added to deionized water after being dissolved in isopropyl alcohol. The slurry's consistency and fluidity may be adjusted by adding deionized water as a diluent. The air electrode may be efficiently coated with a slurry made from Nafion and deionized water. Nafion in the slurry coating increases the electrolyte's ionic conductivity, making it a more effective electrolyte. This facilitates the transport of ions across the electrode-electrolyte interface, including oxygen and metal ions. Rapid oxygen reduction at the air electrode is made possible by increased ionic conductivity. The improved energy conversion and power output of the battery are also due to the higher ionic conductivity.

The interaction between oxygen and the electrode is aided by the inclusion of Nafion to the slurry coating. Nafion's sulfonate groups serve to bring oxygen to the electrode's surface, where it may be used effectively in oxygen reduction processes.

This improves the battery's overall efficiency by increasing its capacity to convert chemical energy into electrical energy. It’s incorporation into the slurry coating has strengthened the metal-air battery prototype's ionic conductivity, reaction kinetics, and oxygen reduction capacity. All of these aspects contribute to the battery's overall performance and dependability, making it a potentially useful energy storage technology.

2.4.3 Iso-proponal:

An essential part of the slurry coating for the experimental metal-air battery is isopropanol, often known as isopropyl alcohol. It serves numerous critical purposes in the slurry formulation that improve the electrode's performance as a whole. Here's a more in-depth look at how isopropanol affects the slurry and its properties:

An effective solvent for Nafion, which is a sulfonated tetrafluoroethylene-based fluoropolymer-copolymer employed as a binder in the slurry, is isopropanol. Solubilizing Nafion in isopropanol creates a uniform solution that distributes the Nafion evenly throughout the slurry. To improve the slurry's stability and adherence to the electrode, Nafion is dispersed evenly throughout the coating slurry.

Isopropanol helps distribute the Nafion powder evenly throughout the slurry. Since it can dissolve Nafion, the binder will be evenly distributed throughout the electrode's surface, ensuring reliable performance. This uniform distribution is crucial for maximising the efficiency of the electrode's active components and creating desirable electrochemical reactions.

As an added bonus, isopropanol helps keep the slurry free of air bubbles. The performance of the electrode and the efficiency of the oxygen reduction process might be negatively impacted if bubbles are present during the coating and preparation steps. By reducing bubble formation, isopropanol helps the slurry cover the electrode uniformly and smoothly.

Nafion is easier to dissolve and more evenly distributed throughout the slurry thanks to the use of isopropanol as a solvent in the formulation. A continuous and homogeneous slurry coating on the electrode is promoted by the addition of isopropanol, which also helps avoid the production of bubbles. The prototype metal-air battery relies on these properties to work at its best, since they improve the efficiency of the electrochemical processes and the stability and stickiness of the slurry, respectively.

The slurry's diluent and ion source, on the other hand, is deionized water. It allows for the passage of ions during electrochemical processes by providing the electrolyte with the ionic conductivity it needs. To ensure the cleanliness and dependability of the slurry and the overall battery performance, deionized water is preferable over tap water to eliminate contaminants that might interfere with the electrochemical operations.

2.4.3 Carbon Black:

Carbon black is an important component added to the slurry mixture as a catalyst in the metal-air battery prototype. It plays a crucial role in accelerating the oxygen reduction process, which is a key electrochemical reaction that occurs at the air electrode. The presence of carbon black enhances the efficiency of the battery by facilitating the conversion of oxygen into hydroxide ions.

As a catalyst, carbon black acts as a surface for the oxygen molecules to adsorb and react with the hydroxide ions. This promotes the overall reaction rate and enables a faster oxygen reduction process. By speeding up this reaction, carbon black contributes to the high-power output and quick reaction time of the battery.

Furthermore, carbon black also serves as a protective agent for the electrodes in the metal-air battery. It acts as a barrier, preventing direct contact between the electrodes and potentially corrosive substances present in the electrolyte. Corrosion can lead to the degradation of the electrodes, reducing the battery's efficiency and lifespan. By shielding the electrodes, carbon black helps maintain their integrity and prolongs the battery's overall performance.

In summary, the addition of carbon black to the slurry mixture in the metal-air battery prototype serves two important functions: as a catalyst, it accelerates the oxygen reduction process, resulting in improved battery performance, and as a protective agent, it guards the electrodes against corrosion, ensuring long-term efficiency and reliability.

2.5 Nickel Foam:

Together with its slurry covering, the nickel foam air electrode performs a critical function in the prototype metal-air battery, helping to maximise the oxygen reduction process and enable the production of energy. In this article, we will examine the features and importance of the nickel foam electrode in further depth:

The nickel foam electrode has a three-dimensional structure, which is beneficial in many ways. The enormous surface area created by the network of metallic strands increases the electrode's exposure to air and the interaction between the electrode and ambient oxygen. The enhanced battery life is a direct result of the increased surface area, which allows for better oxygen diffusion and speeds up the oxygen reduction process.

The porosity of a nickel foam electrode is another distinguishing feature. The foam's porous nature allows air to reach the electrode's surface without difficulty. The oxygen reduction process relies on a steady supply of oxygen, which is ensured by the electrode's porosity. As a result of the porosity, mass transport constraints are reduced, and large current densities are made possible inside the electrode itself.

As we've already established, a slurry mixture is used to coat the nickel foam electrode. Carbon black, starch, Nafion, isopropanol, and deionized water are some of the ingredients in the slurry. There are a few uses for this coating. First, it creates a catalyst-rich environment, which improves the efficiency of the oxygen reduction process. As a conductor, carbon black speeds up electron transport in the chemical process. In addition to facilitating their utilisation and limiting their loss during battery operation, the slurry coating also aids in immobilizing and distributing the active components on the electrode surface.

The nickel foam electrode's synergistic improvement of the metal-air battery prototype is due to its three-dimensional structure, porosity, and slurry coating. The nickel foam electrode allows the metal-air battery to produce electricity with high energy efficiency and power density by enabling efficient oxygen diffusion, supporting optimal catalyst utilisation, and guaranteeing excellent contact between the electrode and the air cathode.

CHAPTER 3

BATTERY EVALUATION

In the process of developing and manufacturing batteries of any sort, one of the most important steps is to conduct an analysis of the battery's performance. We did an examination of the metal-air battery prototype that was created and built as part of the scope of this progress report.

3.1. Instrumentation for Examination of Batteries:

3.1.1. Neware Battery Tester:

The Neware Battery Tester is an advanced and flexible tool for testing and characterising batteries, such as the ancestor of the metal-air battery. Because of its capabilities and characteristics, battery performance can be thoroughly tested and analysed. Let's go further into the capabilities of the Neware Battery Tester:

The Neware Battery Tester's extensive set of testing features makes it an excellent choice for a wide variety of battery assessment applications. The battery's capacity, energy efficiency, and cycle stability may be evaluated by subjecting it to charge/discharge cycling. The pulse cycling feature of the tester allows for high-current pulses to be applied intermittently to mimic real-world use scenarios. This permits a more precise assessment of the battery's efficiency under varying loads. Capacity fading, the slow decline in battery capacity over numerous charge/discharge cycles, may also be measured with the Neware Battery Tester.

The Neware Battery Tester is designed to precisely measure the vital parameters that shed light on a battery's performance. Important indications of the battery's performance and behaviour, such as voltage, current, capacity, and resistance, may be measured precisely. Taking readings of the battery's voltage and current allows one to monitor its electrical activity during the charging and discharging processes.

Resistance tests reveal the battery's internal resistance, which influences its power output and efficiency, while capacity measurements reveal the battery's entire charge storage capacity.

The Neware Battery Tester is capable of doing numerous tests concurrently. Since numerous batteries or test circumstances may be compared at once, evaluating battery life can be done more quickly and with less wasted effort. The performance changes and features of the batteries under study may be better understood via the use of simultaneous testing, which also allows for comparison examination across various battery samples or experimental circumstances.

Researchers and producers of batteries may benefit greatly from the Neware Battery Tester due to its extensive testing capabilities and precise parameter monitoring. With this specialised equipment, we can study the cycle stability, capacity, energy efficiency, and other performance indicators of the prototype metal-air battery. This data is essential for determining the metal-air battery's potential and practicality, as well as for directing future research and development.

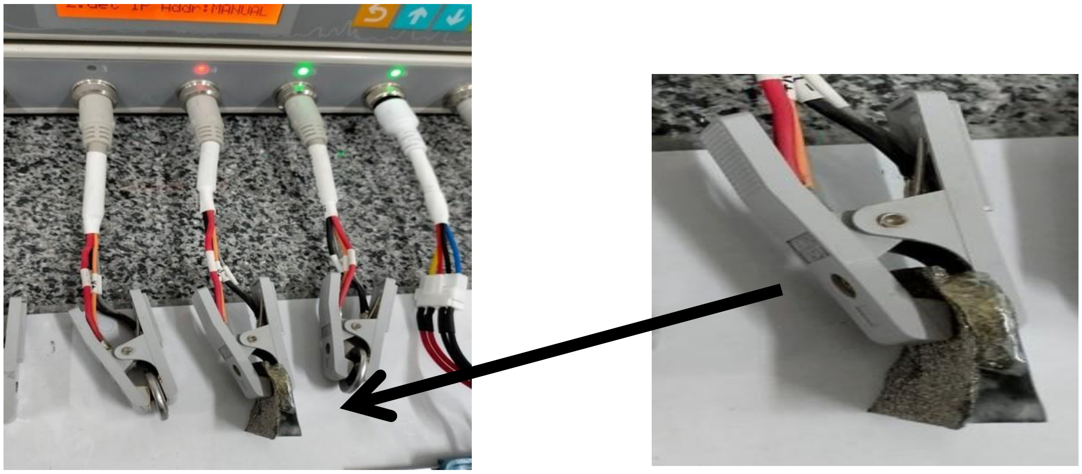

Figure 4: Battery evaluation without casing

3.1.2. The First Discharge of the Battery:

Discharging a battery for the first time is an essential part of learning about its behavior and performance. Acquiring the measurement of the first battery discharge offered crucial information into the early behavior and performance of the metal-air battery prototype. Let's get into more detail about the procedure and its importance:

The prototype metal-air battery was attached to the Neware Battery Tester so that the first discharge could be measured. By connecting the two, the discharge process may be carefully monitored and controlled by exact measurements of voltage and current.

Discharging the battery at a constant current until the voltage reached an established cut-off point is known as a constant current discharge. 0.8 V was selected as the cut-off voltage since it is a typical number for a metal-air battery's discharged state. The Neware Battery Tester enabled accurate voltage measurement by maintaining a consistent discharge rate throughout the operation. This was achieved by supplying a steady current throughout the discharge cycle.

Discharge Voltage Measurement: The Neware Battery Tester measured the battery's voltage as it discharged. The voltage was recorded until it hit 0.8 V, which was the set limit. The Neware Battery tests showed that the prototype battery had an initial discharge value of 1.2 volts.

The measurement of the first discharge of a battery is important for a number of reasons. The first thing it does is give you an idea of how well the battery performs under ideal circumstances in terms of both capacity and voltage. This metric serves as a starting point from which other assessments of performance may be compared and evaluated. Second, it provides information about the battery's health and performance by revealing details about the battery's internal resistance and voltage characteristics. Finally, the measurement taken at the selected cut-off voltage gives an idea of the battery's useable energy at the end of its life, which helps establish its overall performance and usefulness.

A first discharge value of 1.2 volts was recorded for the metal-air battery prototype during Neware Battery testing, which is promising. It's an encouraging sign that the battery managed to keep its voltage quite high during its first discharge, suggesting that its method of converting and storing energy is effective. This indicates that the prototype has potential, and it is worth investigating and testing further in following discharge cycles.

3.1.3 Evaluation of Battery:

Based on the evaluation of the metal-air battery prototype using the Neware Battery Tester, several positive findings were observed, indicating its potential as an energy storage solution. Let's expand on the evaluation results and their implications:

Working Condition: The prototype of the metal-air battery was found to be in a working condition during the evaluation. This indicates that the battery was functional and able to undergo the necessary discharge and measurement processes. A working condition is a fundamental requirement for further testing and analysis.

Initial Discharge Voltage: The battery exhibited an encouraging initial discharge voltage of 1.2 volts. This voltage level suggests that the battery retained a relatively high voltage during its initial discharge, indicating efficient energy conversion and storage processes. A higher initial discharge voltage is indicative of the battery's ability to deliver usable energy and maintain stable performance.

High-Power Output: The metal-air battery prototype demonstrated a high-power output during testing. This refers to the battery's capability to deliver a significant amount of power, typically measured in watts, which is essential for applications requiring a burst of energy or high energy demand. The ability to produce a high-power output suggests that the battery has the potential to meet the energy requirements of various devices or systems.

Quick Reaction Time: The battery showed a quick reaction time, indicating its ability to respond rapidly to power demands. This characteristic is important in applications where immediate power delivery is crucial, such as in high-performance devices or systems that require instant power availability. A quick reaction time ensures a seamless and efficient energy supply.

High Capacity and Low Cost: Based on the evaluation results, metal-air batteries, including the prototype, exhibit high capacity and low cost compared to other energy storage options. High capacity refers to the battery's ability to store a significant amount of energy, which is essential for prolonged usage and applications with high energy demands. Additionally, the low cost of metal-air batteries makes them an attractive option for large-scale energy storage solutions, offering a more economical alternative to other energy storage technologies.

The positive evaluation results suggest that metal-air batteries, including the prototype, hold promise as a source of energy storage. Their encouraging initial discharge voltage, high-power output, and quick reaction time indicate potential advantages in terms of energy capacity, performance, and cost-effectiveness. These findings highlight the feasibility of utilizing metal-air batteries in various applications where reliable and efficient energy storage is required.

3.2. AUTOCAD Used to Design Battery Casing Prototype:

For visualising the battery’s design prototype, we made a 3D model on AutoCAD Fusion

360. The idea was to create a battery that could accommodate any metal-air battery. A moldabledesign is suggested that has two main parts.

3.2.1 Material:

The material for out battery design prototype would be Acrylic. The several reasons why we used acrylic material are below

3.2.2 Transparency:

Acrylic may be seen through since it is a transparent substance. This comes in handy when testing the batteries and need to see how it acts. Any colour shifts or bubbles will be immediately apparent.

3.2.3 Strength and Durability:

Because of its strength and resilience, acrylic can survive a certain amount of abuse while testing. This is crucial since any malfunctions or damage to the prototype during testing would invalidate the data.

3.2.4 Easy to Work With:

Since it is so malleable, acrylic may be shaped, drilled, and cut to fit your exact specifications for testing. This is crucial if you plan on making any changes to your prototype as testing progresses.

3.2.5 Chemical Resistance:

Acrylic is impervious to a broad variety of chemicals, including acids and bases, making it suitable for use in several testing settings without fear of degradation from battery chemicals.

3.3 Anode Holder:

3.3.1 Prototype Layout and Setup:

The anode holder in the prototype metal-air battery is a perfect square, measuring 50 mm on each side. It's 5 mm thick, so it'll provide your battery components some much-needed stability as you put them together.

3.3.2 Hollow Compartment:

The anode holder's hollow central compartment measures 1 inch by 1 inch. The battery's anode, zinc foil, goes in here, where it has its own special chamber. The opening to the hollow area measures 1 inch in length and is located at the top. To avoid any accidents from occurring when inserting the zinc foil, the slit has been made to suit its thickness of 1 mm, which is slightly bigger than the foil's thickness.

3.3.3 Loading Space:

Below the hollow compartment is a loading space that stretches from one end of the anode holder to the other. The nickel foam is loaded onto the gel electrolyte, and this loading region serves as a route for doing so. Battery components are efficiently brought into electrical contact with the anode and air electrode thanks to the loading area's careful attention to their alignment and placement. Fastening assemblies may be employed to keep the battery parts in place thanks to the holes in each of the loading area's four corners.

3.3.4 Top Lid:

The anode holder and top lid of the metal-air battery prototype are each 50 mm in height and breadth. The anode holder's hollow chamber is 1 inch by 1 inch, and so is the anode's expanded central portion. The battery's components may be pressed together and made to make solid connections by inserting the protruding piece of the top lid into the hollow compartment of the anode holder.

The top cover has ventilation holes or pores to improve airflow. These pores are essential to the air electrode's functionality, since they let atmospheric oxygen into the battery, where it may take part in the oxygen reduction process and contribute to the production of energy. The anode holder and the top lid each have four holes that may be used for attaching assemblies to keep the battery components in place and secure.

The anode holder and top lid of the prototype metal-air battery provide a well-designed and organised framework for the battery's components. It facilitates the anode's insertion and alignment, creates passageways for the electrolyte and air movement, and guarantees good connections among the battery's parts.

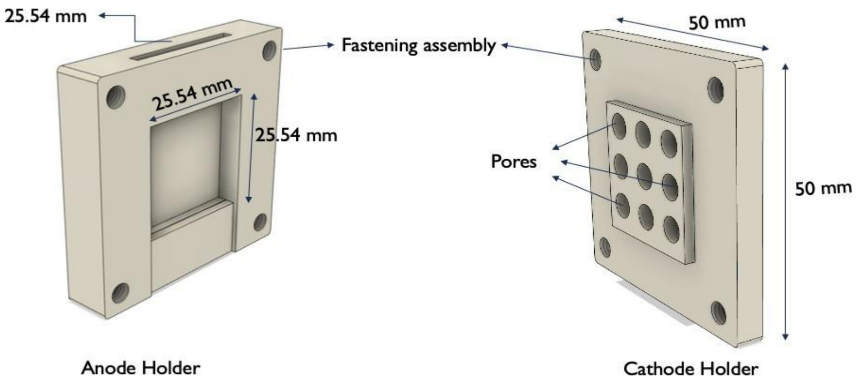

Figure 5: Battery Design Specifications.

3.3.5 Construction:

The components of the metal-air battery must be placed and connected in a certain order during construction. An outline of the construction procedure follows.

Anode insertion involves gently inserting zinc foil into the anode holder's hollow chamber. When the foil falls into place, it will provide a secure platform for the battery in the compartment.

The electrolyte is administered by spreading the solid gel electrolyte over the zinc foil. For optimal ionic conduction and reactivity with the zinc anode, it is crucial that every nook and cranny of the hollow compartment be filled with the electrolyte.

Over the gel electrolyte, apply the nickel foam that will act as the air electrode. If you want good air-to-electrode contact, it's important that the foam cover the whole gel electrolyte.

3.3.6 Electrode External Connections:

The assembly design takes into account the need for external connections in order to facilitate testing. Connections to a wide range of testing and measuring tools are made possible by the zinc foil and nickel foam. Copper connections, for example, can't be placed on the outside of a battery since doing so would raise resistance and decrease the battery's efficiency. In order to get trustworthy findings, it is essential to keep the testing environment as clean and stable as possible from the outset.

3.3.7 The Finished Product Once It's Secured:

After everything is lined up and, in its place, the anode holder's top lid is set in place. To provide secure connections between the battery parts, a hollow compartment of the same size as the enlarged central piece of the top lid is a perfect fit. The top lid is then securely fastened in place by tightening the screws.

Following these procedures and making sure all the connections are secure will provide the best possible functioning, performance, and testing of your metal-air battery prototype.

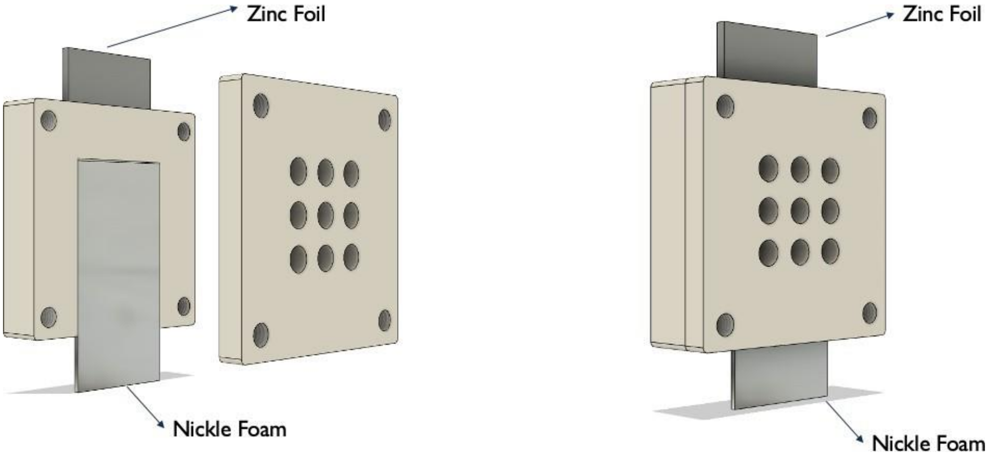

Figure 6: Battery assembly in casing.

3.4 Design Constraints and Adaptations:

The team had difficulties with the milling of the acrylic sheet throughout the process of realising the design for the battery tester on AutoCAD. Acrylic presented challenges in machining since the CNC machines at NUST were mainly built for dealing with wood or metal. Cutting acrylic sheet at such high speeds on CNC machines generated enough heat to possibly melt the material. In order to protect the acrylic sheet from damage, it was necessary to investigate other milling possibilities.

CNC mechanical machining, which uses cutting tools to form the material, was considered. However, complications emerged from this strategy as a result of the high temperatures produced. Normal CNC machine speeds were greater than was safe for use with heat-sensitive, pliable materials like acrylic. Mechanical machining may be utilised for assembly design, however there are limitations dependent on the assembly's material and complexity.

Laser cutting was also considered; this involves using a highly concentrated beam of light to precisely cut through material. Acrylic sheets are ideal for laser cutting because clean cuts may be made without the need for additional heat. This strategy, however, may be costly and calls for specialised equipment that the team may not have had at their disposal.

Another option that was thought of was using a water jet cutter. In this technique, a stream of water at high pressure is used to make clean cuts. Cutting acrylic sheets using a water jet requires specialised equipment and might be more time-consuming than other methods.

Acrylic sheets are fragile and need specific thought and machinery before being machined to prevent breakage. It's important to remember that there are constraints associated with CNC mechanical machining even if it's a viable choice. Depending on the material, the assembly's design, and the availability of specialised equipment, laser cutting and water jet cutting are potentially possible choices.

The final machining choice chosen will rely on a number of criteria, such as the nature of the project's needs and the team's resources.

3.4.1 Machining Constraints:

It was discovered that the typical machine speeds of CNCs were too high for milling the 5mm acrylic sheets utilised in the design, due to the sheets' sensitivity to severe heat. During the machining process, the acrylic might melt or distort due to the intense heat produced by the high speeds. Because of this, mechanical machining for the assembly design presented a substantial issue.

Mechanical machining has a wide range of applications, and acrylic is no exception. However, there are challenges when dealing with acrylic sheets thinner than 5mm or with materials that are sensitive to heat. The design process itself may generate new complications that have an impact on the manufacturing process. The combination of these elements made it impossible to machine the acrylic sheets to the required effect without damaging them.

Laser cutting and water jet cutting are two procedures that might be investigated as alternatives to conventional milling in order to meet this problem. In particular, laser cutting enables a regulated and accurate cutting technique, which generates less heat and has no threat of destroying the acrylic sheets. Although more time-consuming, water jet cutting provides a cool cutting procedure that sidesteps problems caused by high temperatures.

Laser or water jet cutting may be used instead of mechanical machining to reduce the dangers connected with the high heat produced by the process. These other strategies may protect the 5mm acrylic sheets from damage while yet allowing for accurate cutting and shape of the assembly parts.

3.4.2 Assembling of the Pieces of Casing:

Laser cutting has a thickness constraint of around 5mm per sheet, thus the assembling of the case components required careful planning and execution. There were difficulties in molding and shaping any component of the assembly that was thicker than this.

Sheet thickness was restricted due to the laser cutting method's limitations. However, as material thickness grows, it becomes more challenging to attain the needed degree of accuracy and retain the ideal form without substantial variations when using laser cutting.

This constraint necessitated careful planning throughout the casing's design phase to guarantee that its constituent parts could be laser cut efficiently within the allowable thickness range. This required measuring and checking the thickness and dimensions of each part to make sure they were suitable for laser cutting.

It's possible that additional machining steps or production strategies would have been explored had any section of the casing been thicker than 5mm. This may include trying out new techniques, such computer numerical control (CNC) machining, or trying out new materials that work better with the specified thickness.

In order to properly construct the casing components while retaining the desired design and minimising deviations from the planned standards, it was necessary to have a thorough awareness of the constraints of laser cutting and to consider the thickness requirements throughout the assembly process.

3.4.3 Media Used for the Binding of Assembly:

The next stage was to choose an acceptable glue for binding the parts together after they had been divided and sliced into several pieces and the assembly arrangement had been finalised. When deciding on an adhesive for the assembly of acrylic sheets, ethyl alcohol emerged as the clear winner. For the following reasons, ethyl alcohol is often used in this manner:

Ethyl alcohol's solvent qualities enable it to dissolve the top layer of acrylic sheets. When the solvent evaporates, a sticky coating is left behind to aid adherence. Ethyl alcohol's surface-dissolving properties provide a strong adhesion between the acrylic sheets.

Fast evaporation: ethyl alcohol has a low boiling point, hence it evaporates fast. Because the solvent may evaporate quickly, the dissolved acrylic can establish a connection between the sheets, making this characteristic essential for adhesive applications. Rapid evaporation shortens the time required to form a strong, long-lasting connection.

When it comes to acrylic sheets, ethyl alcohol is suitable and won't significantly degrade or harm the material. To ensure that the adhesive capabilities of the acrylic are not diminished during bonding, it does not undergo any chemical reaction with acrylics.

Ethyl alcohol is readily accessible and cheap in comparison to other adhesives, making it a cost-effective choice. It serves as both a solvent and an adhesive, making it useful in many different fields. Because of its availability, low cost, and manageability, it is a practical option for adhering acrylic sheets together.

Various variables, including the acrylic sheets' quality and thickness, the cleanliness of the surfaces being bonded, and the project's needs, might affect ethyl alcohol's adhesive strength. To guarantee appropriate adhesion depending on the particular application and circumstances, it is advised to follow the manufacturer's specifications and perform testing.

3.4.4 Selection of Fasteners:

Mechanical fasteners were used to secure the glued components during assembly of the design. During the digital design process, the fastener sizes were selected to guarantee th the right ones were utilized for the assembly. This method simplified the process of sourcing the required fasteners from retailers.

Fasteners are chosen based on assembly specifications such as material thickness, load capacity, and desired security. Screws, bolts, nuts, and washers are all examples of common mechanical fasteners. These fasteners may be found at most home improvement shops and come in a broad range of sizes, materials, and styles.

Figure 7: Fasteners used in casing.

Mechanical fasteners allow the completed parts to be held together firmly, improving the assembly's structural integrity. Fasteners are selected based on a number of criteria, including the kind of material being secured, the expected forces or loads, and the overall design requirements.

Photos of the chosen fasteners might be provided in the assembly instructions as a visual aid and to avoid any confusion. You may use these images as a reference for finding the right fasteners and learning their intended functions during construction.

3.5 Incorporation of Battery in Design Casing:

Once all the battery's constituent elements had been designed and built, they had to be assembled into the battery's housing before it could be put through its paces for testing and assessment. The integration method was meticulously prepared to guarantee correct assembly and mechanical stability, both of which are essential to the battery's electrochemical performance.

The following order was established for the installation of the battery's various components:

I. To begin, the prepared zinc foil was inserted into the allotted compartment of the casing. The battery's anode was constructed from this.

II. The gel was solidified and used as electrolyte, which was poured onto the zinc foil. The anode and electrolyte were properly installed, completing the battery's lower half.

III. The next stage was to place the nickel foam into its assigned space in the housing, which required cutting the foam to size. The battery's air electrode is nickel foam.

IV. Carefully inserting the anode (Zn foil) and air electrode (Nickel foam) into their respective compartments, both sides of the battery were then pressed together in the case. The pieces were pressed together until there was no space between them; this allowed for optimal contact and electrochemical reactions.

V. Apply fasteners: Screws or bolts were used to connect the two sections of the casing. This helped keep the battery's components in place during testing and inspection by adding an extra degree of mechanical stability.

VI. Connect battery to external circuit: An external circuit was connected so that current could flow, and battery performance could be gauged. This required making a connection between the battery's positive and negative terminals and those of the external circuit.

Figure 8: Battery Assembled in Casing.

Once the battery was completely installed inside the housing, it could be put through its paces for analysis. The battery's effectiveness was evaluated using a battery of electrochemical experiments. The battery's performance was evaluated both with and without the protective case by measuring its voltage, current, capacity, and resistance.

The design's efficacy and influence on battery performance may be evaluated by measuring the battery's electrochemical output after it has been installed in the housing.

3.6 Electrochemical Testing of Battery with Casing:

Following integration into the housing, an electrochemical assessment was performed on the battery to evaluate the integrity of the interfaces and the efficiency with which the assembly's compactness was put to use. The purpose of these tests was to evaluate the cased batteries against those that had not been housed in a case. Some typical electrochemical studies for judging a battery's performance are as follows, while others may be done as well depending on the factors and goals in question:

Analysis of voltage was performed by monitoring the battery's voltage output across a variety of uses, including charging and discharging cycles. The reliability of the battery's voltage output may be estimated using this method.

The current that was passing through the battery as it was being charged and discharged was analyzed. The battery's capacity to provide and store electrical energy is revealed through this investigation.

Capacity testing: a predetermined number of charge-discharge cycles were used to calculate the battery's capacity, or the maximum amount of energy it can store. The study aids in judging the battery's ability to store energy.

The battery's internal resistance, which has an effect on its efficiency and power delivery, was measured as part of the resistance study. Better efficiency and power generation may be expected from engines with lower internal resistance.

The battery's cycling performance was measured by repeatedly charging and discharging it. The battery's consistency and longevity through numerous cycles are evaluated here.

To examine the battery's impedance behavior over a wide range of frequencies, electrochemical impedance spectroscopy (EIS) was carried out. The integrity of the battery's interfaces and the procedures by which charges are transferred inside it may be better understood thanks to this examination.

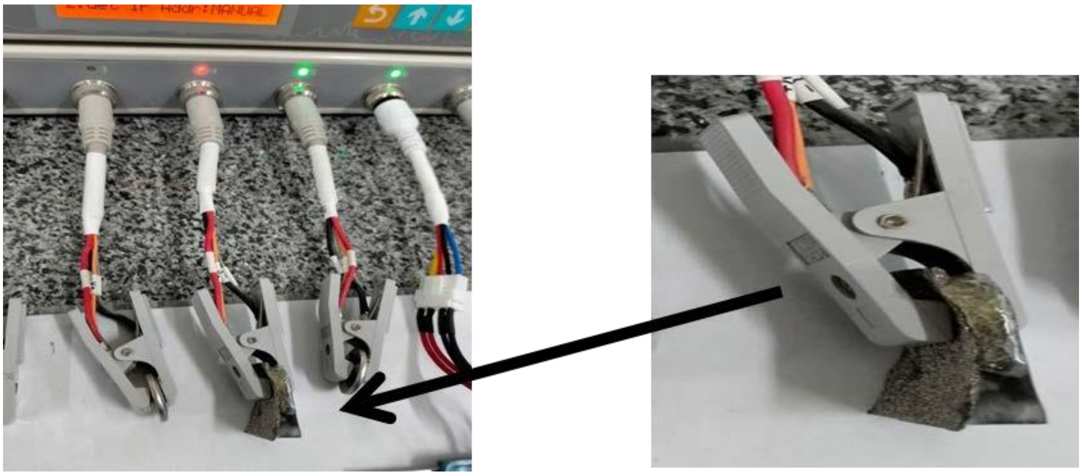

Figure 9: Battery Testing in Progress.

The results of these electrochemical tests provide light on the battery's overall efficiency. It was feasible to assess the assembly's effect on the reliability of the battery interfaces and the efficiency with which the compactness afforded by the housing was put to use by comparing the findings to those obtained from tests conducted without the housing. The results of these analyses contributed to a better understanding of the design's impact on the battery's electrochemical efficiency as a whole.

CHAPTER 4

RESULTS AND DISCUSSIONS

Different characterization techniques were utilized to analyze and optimize the battery components individually and the performance of the battery once it was assembled. The following are the techniques along with the results obtained and the conclusions drawn from the results.

4.1 EDAX & SEM:

Energy dispersive x-ray analysis (EDAX) is a spectroscopic method for determining a material's make-up, as explained in the text. By using EDAX to testing of metal-air battery components, scientists may learn more about the anode, cathode, and electrolyte's chemical composition.

Researchers may use EDAX to go deep into these materials' elemental make-up. Using this method, any contaminants or impurities in the battery components may be isolated. Researchers may get a deeper understanding of the potential negative impacts of these contaminants on battery performance if they are able to identify and localize them.

Battery materials may be assessed for their overall chemical stability with the use of EDAX analysis. It details the elements found in the battery and how they are dispersed among the various parts. This information is useful for predicting the likelihood of chemical reactions or deterioration over time and establishing the compatibility of various components within the battery system.

EDAX analysis provides vital information for advancing the state of the art in metal-air battery technology. Scientists may use the information about the battery's chemical make-up to figure out where it might be improved and how to make it last longer and perform better. Researchers can improve metal-air battery reliability and performance by first characterizing the chemical characteristics of the battery's components and then using that knowledge to the development of new materials and designs.

4.1.2 EDAX for Nickel Foam:

4.1.2.1 Elemental Mapping:

In this passage, we learn about EDAX (Energy Dispersive X-ray Analysis), a very effective analytical method for determining the elemental make-up of various substances. An EDAX study of nickel foam would provide information on the quantity of individual elements in the material.

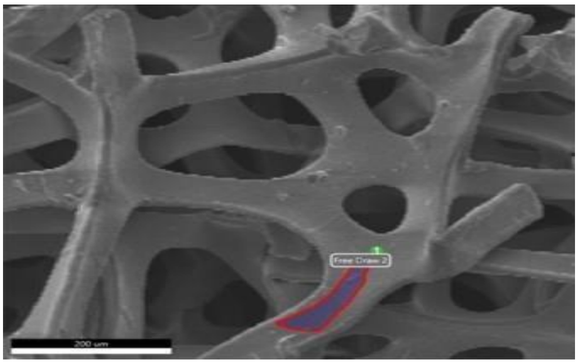

Figure 10: EDAX sampling of Nickle Foam.

Researchers may learn more about the nickel foam sample's make-up by doing an EDAX study on it. The study showed that nickel was the most abundant element in nickel foam, suggesting that it was mostly made of nickel. Carbon, oxygen, and copper were also found, but in lower concentrations.

Since there is a lot of nickel in the foam, it might be used in batteries and fuel cells, which employ electrochemistry. Nickel's great electrical conductivity and exceptional corrosion resistance are only two of its impressive electrochemical features. Because of its unique properties, nickel foam is well-suited for improving electrochemical efficiency and device functionality.

The nickel foam sample's EDAX analysis reveals interesting details about its elemental makeup, revealing both the predominance of nickel and the presence of other elements. With this information, scientists can make more educated decisions and advance the state of the art in energy storage and conversion systems as they investigate the material's potential uses in a wide range of electrochemical devices.

The nickel foam sample's pore size range is introduced in this paragraph with its elemental makeup, since the latter may have a significant effect on the former's characteristics and prospective uses. The pore size, which is the dimension of the voids and air pockets inside the foam, is commonly expressed in micrometers.

The nickel foam has a wide pore size distribution, with sizes ranging from 50 to 250 micrometers. Because of its potential impact on the foam's permeability and surface area, this quality is important for electrochemical applications. The capacity of a material to transport gases, liquids, or ions through its structure is vital in a number of electrochemical processes, and this ability is influenced by the pore size of the material. Additionally, the contact area between the foam and the electrolyte may be improved by the higher surface area supplied by the smaller holes, resulting in more effective electrochemical reactions.

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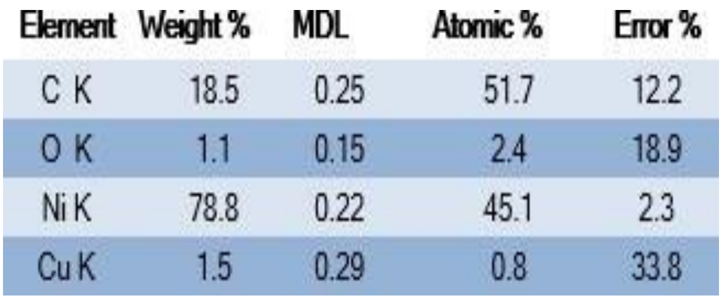

Element	Weight %	MDL	Atomic %	Error %
C K	18.5	0.25	51.7	12.2
O K	1.1	0.15	2.4	18.9
Ni K	78.8	0.22	45.1	2.3
Cu K	1.5	0.29	0.8	33.8

Figure 11: Elemental Percentages in Nickle Foam.

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Carbon and oxygen were detected in the nickel foam sample, suggesting the existence of organic residue from the manufacturing process. Organic chemicals may have been utilised as binders or coatings during production, perhaps leaving behind carbon and oxygen residues. While they aren't the main ingredients, they don't have to be absent for the material to have good electrochemical performance.

The production process may have included copper impurities or additives, which might explain the presence of trace amounts of copper in the nickel foam. Copper might have been present in the raw components or accidentally incorporated during the foam manufacturing processes. Such impurities should be taken into account because of their possible impact on the material's qualities and performance. EDAX examination of the nickel foam sample reveals interesting information about its composition, such as the presence of trace contaminants and residual organic debris. These results help round out our knowledge of the material's characteristics and provide direction for further study. Researchers can optimise production by analysing the nickel foam's elemental composition, pore size distribution, and possible contaminants, opening up exciting opportunities for specialised uses in electrochemical devices and other areas.

4.1.2.2 Pore Size Determination:

Particularly pertinent to its use as an air electrode in metal-air batteries, the paragraph emphasises the importance of pore size and strand thickness in nickel foam. The benefits and significance of these traits are further upon below:

High Surface Area: Nickel foam's enormous surface area is the consequence of its well-defined pore structure and optimal strand thickness. This larger surface area is beneficial for catalytic activity because it offers more locations for oxygen reduction events to take place. More oxygen may diffuse into the electrode material more quickly, leading to enhanced electrochemical performance.

Second, nickel foam's pore size greatly contributes to improved reactant transport, especially oxygen diffusion. The oxygen may travel via the network of pores in the electrode to the reaction sites, where electrochemistry takes occur. Assuring an adequate supply of oxygen for reactions and reducing diffusional limits are two ways in which efficient transport of reactants improves battery efficiency.

Third, nickel foam's strand thickness improves its mechanical strength and durability, making it a more desirable material. During usage, metal-air batteries might experience mechanical stresses such expansion and contraction due to charge-discharge cycles. The mechanical resilience provided by the foam's larger strand size allows it to sustain these forces without compromising its structural integrity.

The stability of nickel foam as an air electrode is enhanced by the interaction between the pore size and the strand thickness. By fine-tuning these features, the foam may delay electrode deterioration and keep up its electrochemical performance for longer. This steadiness is critical for ensuring the battery's long-term dependability and continuous functioning.

The flexibility to adjust the pore size and strand thickness of nickel foam is a major benefit. The structure of the foam may be altered by the manufacturer to better suit various uses. They may fine-tune the material's performance in metal-air batteries and other electrochemical applications by manipulating these factors.

Given these benefits, the design and optimisation of nickel foam for air electrode applications in metal-air batteries hinges on pore size and strand thickness. By studying and optimising these features, scientists and engineers may improve the foam's electrochemical performance, stability, and mechanical qualities, resulting in longer-lasting, more powerful batteries.

4.1.2.3 Crystal Size:

Especially in metal-air batteries, the grain size of nickel foam is a critical factor in defining its characteristics and prospective uses. For more on why grain size matters, consider the following:

The increased number of grain boundaries in nickel foam with a tiny grain size results in a bigger surface area. This larger surface area increases the catalytic efficiency of the electrode by providing more locations for electrochemical reactions. Battery life and efficiency may both benefit from the increased oxygen diffusion and reaction kinetics made possible by the bigger surface area.

Second, the mechanical characteristics of nickel foam are enhanced because of its reduced grain size. Because of the greater number of tiny grains, the foam is more robust and can better withstand mechanical loads without deforming. The battery's functioning presents structural problems, such as volume variations and mechanical loads, which are better able to be absorbed by the foam because to its enhanced mechanical resilience.

Third, nickel foam has better electrical conductivity than other materials because its granules are smaller. When grain boundaries are packed closely together, electrons have more places to go. Because of the decreased resistance, increased battery performance is possible because to the enhanced electrical conductivity of the electrode.

Longevity and resistance to deterioration are enhanced in nickel foam with smaller grain size. Since the structure is more homogeneous and compact due to the smaller grains, flaws and voids are less likely to occur. The foam's characteristics are better preserved over time because to the foam's increased structural integrity, which also contributes to the metal-air battery's greater operating stability and durability.

Strengthened Resistance to Corrosion The corrosion resistance of nickel foam may be enhanced by making the grain sizes smaller. Because there are fewer grain boundaries, the foam is more protected from electrochemical reactions that might break it down. Since electrode deterioration due to corrosion may severely affect performance, this increased corrosion resistance is especially useful in the harsh conditions of metal-air batteries.

The above details highlight the potential of nickel foam with a tiny grain size as an air electrode material in metal-air batteries. In order to facilitate effective electrochemical reactions and guarantee the lifespan of batteries, it is preferable that the material have a high surface area, good mechanical qualities, high electrical conductivity, high durability, and high resistance to corrosion. To maximise its potential in metal-air battery applications, further research and development may concentrate on optimising the grain size of nickel foam.

When used as an air electrode in metal-air batteries, nickel foam shows promising features. The strand thickness, grain size, and pore size all play important roles in determining its usefulness in different contexts.

Nickel foam's vast surface area, because to its porous nature and thin strands, aids in catalytic activity and allows for rapid oxygen transport. The enhanced battery efficiency is due in part to the larger surface area, which affords many more active sites for electrochemical processes and hence more efficiently reduces oxygen. The linked pore structure also facilitates efficient oxygen transport, which guarantees an adequate supply of oxygen to the electrode's active areas.

Nickel foam's tiny grain size improves its characteristics and possible applications beyond only surface area concerns. The increased surface area and greater number of active sites for electrochemical reactions are both results of the lower grain size. This property improves the material's oxygen transport and hence its catalytic activity. The mechanical characteristics, electrical conductivity, durability, and corrosion resistance of the foam are all improved by its tiny particle size. It increases the foam's mechanical strength, so it can better endure mechanical pressures and keep its shape while the battery is in use. As a result of the higher electrical conductivity, resistive losses are minimised and battery performance is enhanced. In addition, the air electrode's longevity, stability, and performance reliability are all enhanced by the reduced particle size.

Researchers can tailor nickel foam for use in metal-air batteries by adjusting features including pore size, strand thickness, and grain size. The benefits of nickel foam may be greatly increased via careful manipulation of its features, such as its catalytic activity, oxygen transport, mechanical strength, durability, and resistance to corrosion. Nickel foam is an attractive option for the development of metal-air batteries and the acceleration of improvements in energy storage systems due to these advantages.

4.1.3 EDAX of Carbon Black Powder:

The abundance of individual elements in the carbon black powder sample may be determined with great precision using EDAX analysis. The method identifies and measures the distinctive X-ray emissions from each element by exposing the sample to X-rays; this provides invaluable information on the elemental makeup of the sample.

Carbon, hydrogen, oxygen, nitrogen, and maybe additional impurities or trace elements are among the elements whose abundances are revealed by the study. Carbon black powder's quality and purity, as well as its applicability, may be gauged from these facts.

Since the carbon black powder's physical, chemical, and electrical characteristics are affected by the relative abundance of elements, EDAX analysis is a crucial technique for quality control and characterization. Researchers and producers benefit from knowing the material's elemental makeup so they can determine whether or not it will work in a certain situation.

Carbon black powder's elemental makeup may be gleaned via an EDAX analysis, laying the groundwork for future study, optimization, and quality evaluation.

4.1.3.1 Elemental Mapping

The carbon black powder was analyzed, and its properties were supplied, which shed light on its make-up. Here's some more detail on why each trait is so crucial:

First, the carbon black powder is said to have a particle size between 8 and 15 micrometers. The qualities and uses of a material depend critically on the particle size. Because of its large surface area and other desired features, carbon black powder has a specific particle size, which in this instance implies that it is composed of tiny particles.

The EDAX examination of carbon black powder revealed that it contains around 89.6 wt.% carbon, making it the second most carbon-dense substance known to man. The name of the substance itself suggests that it will have a high carbon content. Carbon is the main ingredient of carbon black, giving it its distinctive black color and providing it with other unique features including strong electrical conductivity and great reinforcing capabilities.

Third, the study shows that the carbon black powder includes around 7.8 weight percent oxygen. There may have been surface oxidation or oxygenated functional groups in the carbon black sample, both of which are indicated by the presence of oxygen. The surface chemistry, reactivity, and compatibility of a material may be affected by these oxygen-containing species.

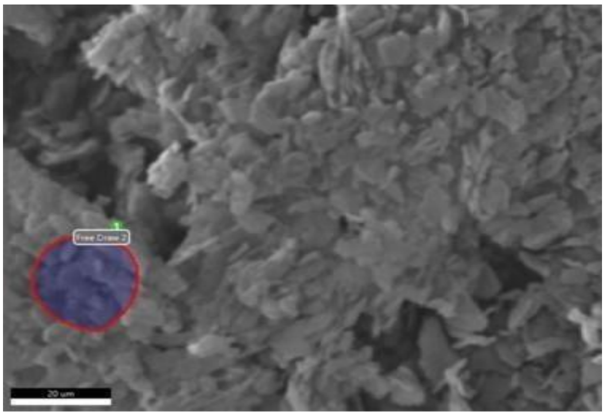


Figure 12: EDAX sampling of Carbon Black Powder.

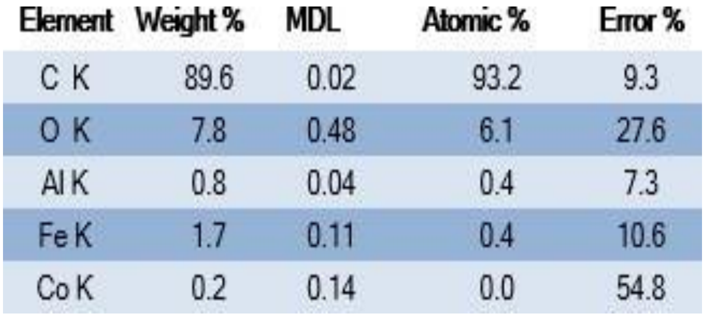
EDAX testing revealed trace levels of numerous additional elements inside the carbon black powder, bringing up point #4. The analysis reveals that there is around 0.8% aluminum, 1.7% iron, and 0.2% cobalt in the powder. These substances are very certainly industrial byproducts or trace elements found in the original raw materials.

While carbon is the main component of carbon black powder, additional elements present in trace quantities show that the substance is not completely pure. The material's characteristics and usefulness may be compromised by the presence of impurities or trace elements. Thus, depending on the application or needs, more analysis and purification may be required.

The EDAX analysis of the carbon black powder, while highlighting the predominance of carbon and recognising the existence of other elements, gives vital insights on its elemental makeup as a whole. If you want to use carbon black powder for anything special, such reinforcing materials, conductive additives, or pigment formulas, you'll need to know exactly what goes into making the powder.

Indeed, it is probable that the presence of functional groups on the surface of the particles accounts for the existence of oxygen in the carbon black powder. The presence of these functional groups on a material's surface may alter its characteristics and reactivity, and may result naturally from production or be added on purpose. Carbon black's surface chemistry may be modified by the addition of functional groups to make it more reactive or compatible with other chemicals.

It is plausible that the trace levels of aluminium, iron, and cobalt found in the study came from either the production process or outside contamination. The characteristics and reactivity of a material may be affected by trace elements even when they are present in minute levels. To lessen their effect, it may be required to use stringent purification and quality control procedures, particularly in contexts where they might be harmful.



Element	Weight %	MDL	Atomic %	Error %
C K	89.6	0.02	93.2	9.3
O K	7.8	0.48	6.1	27.6
Al K	0.8	0.04	0.4	7.3
Fe K	1.7	0.11	0.4	10.6
Co K	0.2	0.14	0.0	54.8

Figure 13: Elemental Percentages of Carbon Black Powder.

Another important consideration is the carbon black powder's particle size. Surface area, reactivity, and dispersibility are all enhanced when particles are smaller. Due to its large surface area and low density, carbon black with smaller particle sizes is useful as a conductive additive, pigment, or catalyst. However, bigger particle sizes are sometimes preferable for applications that call for superior packing and mechanical qualities, such as in rubber compounds or plastic masterbatches, because of their greater bulk density and increased flowability.

Researchers and producers may benefit greatly from the data provided by the EDAX examination of the carbon black powder, which considers the powder's composition and particle size. It's helpful for learning about the material's characteristics and reactions as well as its possible applications. Using this data, researchers may focus on perfecting the carbon black powder for specialized uses, raising performance standards, and creating industry-specific solutions.

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4.1.3.2 Particle Size and Shape:

Carbon black powder has great promise as a catalyst in metal air batteries, particularly for the oxygen evolution reaction (OER) and the oxygen reduction reaction (ORR) due to its sheet-like structure and tiny particle size. The benefits are elaborated about below:

Carbon black powder's enormous surface area is essential for its catalytic activity because of its tiny particle size and sheet-like structure. The enhanced surface area promotes effective OER and ORR processes by providing more active areas for the interaction between the catalyst and reactants. Increased exposure of the catalyst to the electrolyte, and therefore a greater number of reaction sites, and enhanced catalytic efficacy, results from the increased surface area.

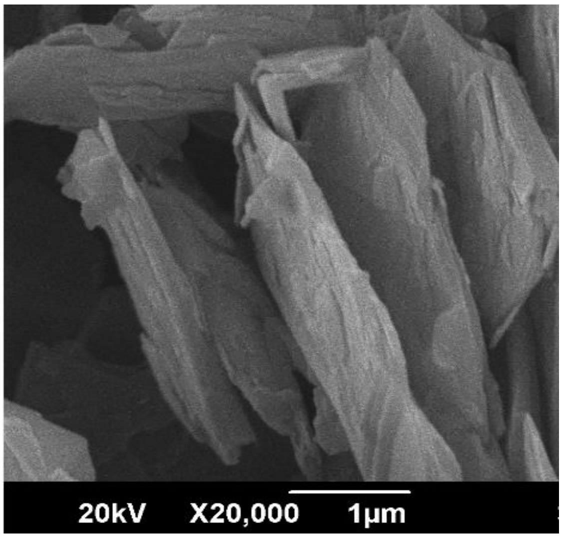

Figure 14: SEM image of particles of Carbon Black Powder.

Because of its tiny particle size and sheet-like shape, more reactants may contact the catalyst, leading to increased reactivity. The catalyst's reactivity is improved because more active sites may be packed into a smaller volume because to the larger surface area. Increased OER and ORR efficiency in metal air batteries is a direct result of increased accessibility of reactants to the catalyst surface, which in turn leads to quicker reaction kinetics.

The sheet-like shape of carbon black particles increases their electrical conductivity, which leads to benefit number three. These sheets work together to create a network that speeds up charge transfer in electrochemical processes by facilitating efficient electron transport. Enhanced conductivity promotes efficient catalytic activity and overall battery efficiency, making it especially crucial for metal air batteries.

Carbon black powder's tiny particle size and sheet-like shape make it particularly well-suited for use in metal air batteries. The tiny particles are more resilient to mechanical and electrochemical stresses that occur during battery operation and are thus less likely to be damaged. The structural stability provided by the sheet-like structure also helps to avoid particle aggregation and keeps the catalyst's shape unchanged even after repeated cycles.

Carbon black powder has advantageous qualities for catalyzing the OER and ORR in metal air batteries due to its sheet-like structure and tiny particle size. Effective electrochemical processes, higher reactivity, better conductivity, and longer durability are all made possible by these characteristics. Carbon black powder has potential as a catalyst material for developing metal air battery technology, which would lead to the creation of more efficient and long-lasting energy storage systems due to its many benefits.

In addition to its catalytic activity, conductivity, durability, and reactivity, carbon black powder's sheet-like structure and microscopic particle size may also be relevant factors. Large surface area for catalytic processes is provided by the sheet-like shape, and the tiny particle size improves the catalyst's efficiency. In metal-air batteries, this combination improves the catalytic efficacy of carbon black powder for OER and ORR processes. Because of its sheet-like shape and tiny particle size, this catalyst is well suited for maximizing electrochemical processes.

4.2 Battery Evaluation:

Multiple experiments measuring charging and discharging capacities were run to evaluate the metal air battery's performance and the efficacy of the suggested design for its housing. The findings from these tests provide important information about the battery performance and may help enhance its capability

Figure 15: Evaluation of Battery in NEWARE testing unit.

The quantity of energy a battery can hold throughout a charging cycle is evaluated by the charging capacity test. The battery's energy storage capacity and charging efficiency may be evaluated using this test. Charging capacity is a measure of a battery's potential to keep a charge and power an electronic device for an extended period of time.

However, the battery's ability to supply a charge when discharged is evaluated by the discharging capacity test. The battery's ability to provide energy over a certain time frame is measured here. A larger discharge capacity means that the battery can maintain its power output for a longer period of time.

The total performance of the battery can only be determined by correctly interpreting the results of these tests. Researchers may determine the efficacy of the suggested design for the housing of the metal air battery by comparing the acquired charging and discharging capacities with the specified specifications or benchmark values. The success of the battery's design depends on whether or not the actual capacities obtained are consistent with the predicted ones. If the capacities are too low, though, it may be necessary to make some adjustments to the battery's design to bring it up to snuff.

The columbic efficiency of a battery is measured alongside its charging and discharging capacity. Columbic efficiency measures how close the amount of charge provided during discharge is to the amount that could be delivered if the charging capacity had been fully used. It aids in the detection of possible energy losses and inefficiencies by providing insights into the efficacy of charge transfer inside the battery.

Researchers may analyse the battery's overall efficiency and performance in terms of charge retention and transfer by calculating and visualising the columbic efficiency. Since greater columbic efficiency means that more of the charge accumulated while charging is properly supplied during discharge, it is indicative of a more efficient battery.

Researchers may learn more about the metal air battery's performance by analysing and evaluating the findings of charging and discharging capacities and the columbic efficiency. To increase the battery housing's efficiency, stability, and overall performance, they can now pinpoint design flaws and figure out how to fix them.

4.2.1 Charging and Discharging Capacity:

The zinc anode and atmospheric oxygen undergo a reversible electrochemical process that powers the battery. During discharge, the zinc anode oxidises, reacting with atmospheric oxygen to produce zinc oxide. When an external circuit is connected to this reaction, the released electrons may power an appliance or carry out electrical work.

The procedure is inverted during the charging phase. When the battery is subjected to an external electrical current, the electrons begin to travel in the opposite direction. Because of this, zinc oxide disintegrates at the cathode, and zinc ions are converted back into metal at the anode. Simultaneously, the oxygen that has been liberated is returned to the atmosphere.

A zinc-air battery's charging capacity is the highest amount of energy it can store while being recharged. It's the maximum amount of chemical potential energy that may be stored electrically. The charging capacity is a measure of the battery's ability to store energy and is often expressed in ampere-hours (Ah).

When evaluating the effectiveness and practicality of a zinc-air battery, the charging capacity is crucial. It controls how much energy may be stored electrically and then released during discharge. Batteries with larger storage capacity may be used for longer periods of time before they run out of juice.

Maximising the charging capacity of zinc-air batteries requires efficient charging procedures. The total capacity and efficiency of the battery is affected by factors such as charging current, voltage limitations, and charging time. Researchers and engineers that take the time to learn about and optimise these factors may increase the performance and lifespan of zinc-air batteries, making them more suited for use in a wide range of applications from portable devices to electric cars.

Several variables affect the zinc-air battery's charging capacity and, by extension, the battery's efficiency and performance. When it comes to charging, one crucial aspect is the quantity of zinc oxide that must be converted back into metallic zinc. It takes more power to reverse the oxidation cycle and recharge a battery that has produced a significant quantity of zinc oxide during discharge.

The ability to charge is also affected by the quantity of oxygen that must be released back into the air. The greater the oxygen loss during discharge, the greater the oxygen demand during charging. The battery's ability to charge is enhanced by the influx of fresh air.

The charging capacity of a zinc-air battery is also affected by how well charge is transferred between the battery and the charger. The charging process requires a steady and efficient return of electrons to the zinc anode. If there are any obstacles in the way of the charge being transferred, the battery will not be able to be charged to its full potential.

Because of the high energy density of zinc and the availability of infinite amounts of air as the cathode material, zinc-air batteries offer a high theoretical charging capacity. The oxygen in the air can't get to the cathode fast enough to take part in the electrochemical process, since oxygen has a sluggish diffusion rate. Because of this restriction, the battery may not be able to charge as quickly as it might otherwise.

Zinc-air battery charging capabilities have been the subject of ongoing research and development. To improve oxygen diffusion and charge transfer rates, scientists investigate several approaches, such as optimising battery architecture, electrolyte composition, and catalysts. In order to make zinc-air batteries more feasible for applications that demand large amounts of stored energy and long periods of operation, it is necessary to overcome these obstacles.

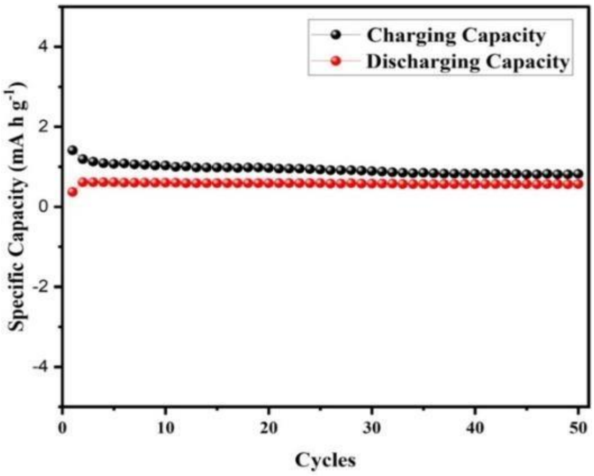

Figure 16: Charging and Discharging capacity of battery.

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The procedure is inverted during the charging phase. When the battery is subjected to an external electrical current, the electrons begin to travel in the opposite direction. Because of this, zinc oxide disintegrates at the cathode, and zinc ions are converted back into metal at the anode. Simultaneously, the oxygen that has been liberated is returned to the atmosphere.

A zinc-air battery's charging capacity is the highest amount of energy it can store while being recharged. It's the maximum amount of chemical potential energy that may be stored electrically. The charging capacity is a measure of the battery's ability to store energy and is often expressed in ampere-hours (Ah).

When evaluating the effectiveness and practicality of a zinc-air battery, the charging capacity is crucial. It controls how much energy may be stored electrically and then released during discharge. Batteries with larger storage capacity may be used for longer periods of time before they run out of juice.

Maximizing the charging capacity of zinc-air batteries requires efficient charging procedures. The total capacity and efficiency of the battery is affected by factors such as charging current, voltage limitations, and charging time. Researchers and engineers that take the time to learn about and optimize these factors may increase the performance and lifespan of zinc-air batteries, making them more suited for use in a wide range of applications from portable devices to electric cars.

Several variables affect the zinc-air battery's charging capacity and, by extension, the battery's efficiency and performance. When it comes to charging, one crucial aspect is the quantity of zinc oxide that must be converted back into metallic zinc. It takes more power to reverse the oxidation cycle and recharge a battery that has produced a significant quantity of zinc oxide during discharge.

The ability to charge is also affected by the quantity of oxygen that must be released back into the air. The greater the oxygen loss during discharge, the greater the oxygen demand during charging. The battery's ability to charge is enhanced by the influx of fresh air.

The charging capacity of a zinc-air battery is also affected by how well charge is transferred between the battery and the charger. The charging process requires a steady and efficient return of electrons to the zinc anode. If there are any obstacles in the way of the charge being transferred, the battery will not be able to be charged to its full potential.

Because of the high energy density of zinc and the availability of infinite amounts of air as the cathode material, zinc-air batteries offer a high theoretical charging capacity. The oxygen in the air can't get to the cathode fast enough to take part in the electrochemical process, since oxygen has a sluggish diffusion rate. Because of this restriction, the battery may not be able to charge as quickly as it might otherwise.

Zinc-air battery charging capabilities have been the subject of ongoing research and development. To improve oxygen diffusion and charge transfer rates, scientists investigate several approaches, such as optimising battery architecture, electrolyte composition, and catalysts. In order to make zinc-air batteries more feasible for applications that demand large amounts of stored energy and long periods of operation, it is necessary to overcome these obstacles.

Several reasons have been found after analysing the test data that might contribute to the battery's poor charging capacity. Battery electrodes with low conductivity may be to blame, since this prevents electricity from flowing freely when charging. Optimising the electrode design or researching ways to increase the conductivity of the electrode materials are two potential solutions to this problem.

The chemical stability or contamination of the battery electrolyte is another possible cause of the charging capacity decline. When a battery is being charged or discharged, electrochemical processes take place, and the electrolyte plays a critical role in promoting these reactions. These processes may be slowed or prevented altogether if the electrolyte is polluted or chemically unstable. To fix this problem and guarantee the electrolyte's stability and purity, further research and study into its composition and quality is required.

A poor charging capacity may also be caused by a battery's internal resistance being excessive. The term "internal resistance" describes the opposition presented by the battery's own components, such as the electrodes, electrolyte, and connections. As a result of this resistance, charging voltage reduces and efficiency decreases. Assessing the battery's design, materials, and assembly methods to pinpoint and resolve the root causes of the high internal resistance is essential for finding a solution to this issue.

In order to address these issues and enhance the battery's charging capacity, further testing and analysis are in the works. The purpose of this in-depth analysis is to learn what is causing the low charging capacity so that appropriate measures may be taken to remedy the situation. We will investigate methods to increase electrode conductivity, stabilise the electrolyte, and lower internal resistance. By fixing these problems, the battery's charging capacity should increase, resulting to better performance and energy use.

Results from the tests performed provide useful information on the challenges of creating high-performance batteries. The results of this study highlight the value of careful planning, extensive testing, and thorough analysis in achieving the required performance characteristics.

The problems that were discovered during testing may be used as learning opportunities to improve the battery's design. When we recognise the problems and think through their consequences, we can better target our efforts to find solutions that will boost the battery's charging capacity and overall performance.

Moving ahead, we will dedicate ourselves to never-ending R&D to better our battery construction. To overcome the obstacles found during testing, we will investigate unproven strategies, cutting-edge technology, and cutting-edge materials. We want to significantly improve the charging capacity and overall performance of our battery by taking a proactive approach and using the information gathered from the testing results.

Our commitment to developing cutting-edge battery technology has not wavered. We recognise the significance of creating high-performance batteries that may be used in a wide range of contexts. We are convinced that we can overcome the obstacles we have faced and pave the way for the development of batteries with enhanced performance, efficiency, and dependability via our commitment to continuous research, refinement, and innovation.

4.2.2 Columbic-Efficiency:

The coulombic efficiency of an electrochemical cell, such as a battery, is a critical performance indicator. It measures how well the charging process converts the electrical energy given while charging into the electrical energy produced during discharge. The coulombic efficiency, expressed as a percentage, is determined by contrasting the actual charge stored during discharge with the potential charge stored based on the charge supplied during charging.

The performance and efficiency of a battery may be better understood by the computation of coulombic efficiency. If the coulombic efficiency is 100%, then all the charge input during charging has been stored and is eventually discharged. However, if the coulombic efficiency is less than 100%, it indicates that part of the provided charge is wasted.

There are a number of causes that contribute to a decrease in coulombic efficiency. As the battery is being charged or discharged, unwanted chemical reactions or the production of irreversible compounds might occur. Low coulombic efficiency may also be caused by things like electrode deterioration, unstable electrolytes, and inefficient charge transfer mechanisms.

Researchers and engineers may learn about the effectiveness and efficiency of a battery system by measuring and tracking its coulombic efficiency. This data is crucial for developing more effective battery designs, enhancing charging and discharging procedures, and figuring out what, if anything, is reducing the battery's overall efficiency.

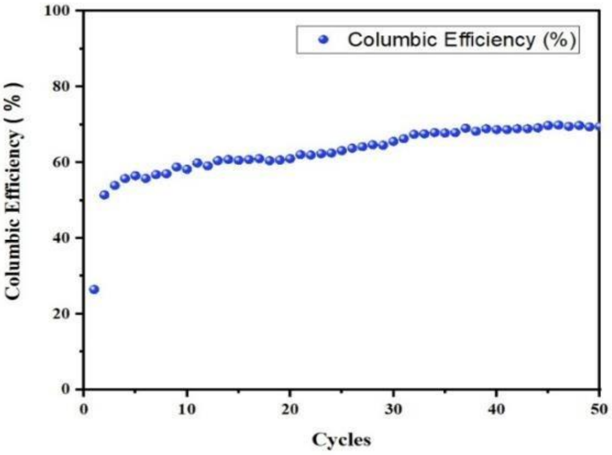

Figure 17: Columbic Efficiency curve.

To sum up, coulombic efficiency is a quantitative measure of the efficiency with which an electrochemical cell, such as a battery, converts electrical energy during charging into electrical energy during discharge. This is an essential parameter for evaluating the effectiveness and performance of batteries, which in turn facilitates the creation of methods to further improve their overall effectiveness and functionality.

The performance and lifespan of a zinc-air battery are closely related to its coulombic efficiency. If the battery can store and discharge charge efficiently, it will last longer and perform better. This metric is measured in coulombs per charge. However, if the battery has a low coulombic efficiency, it may lose charge or energy and may not perform as well or last as long.

Due to its unique chemistry and functioning, a zinc-air battery requires constant attention paid to its coulombic efficiency. Since atmospheric oxygen is used as cathode material, the amount of oxygen available may change depending on the circumstances. The rate at which electrochemical reactions occur while charging and discharging may be affected by environmental factors like humidity, temperature, and pressure.

Researchers have been exploring several approaches to increase the coulombic efficiency of a zinc-air battery. Using catalysts to increase zinc oxide reduction during charging has been shown to improve charge transfer efficiency and hence overall performance. To improve the battery's performance, porous electrodes are used to enable oxygen to move more freely throughout the battery.

In addition, the coulombic efficiency may be enhanced by optimizing the design of the electrolyte and electrodes to decrease internal resistance. To maximize the storage and subsequent release of the electrical charge given during charging, resistance must be minimized.

Further, the zinc-air battery's working environment must be monitored and managed for optimal performance. Consistent conditions for the electrochemical processes to occur may be maintained by keeping the humidity, temperature, and air pressure at optimal levels.

An all-encompassing strategy that considers catalyst utilization, electrode porosity, internal resistance reduction, and environmental management is necessary to maximize the colombic efficiency of a zinc-air battery. The goal of these studies is to improve zinc-air battery performance and efficiency so that they may be used in more situations.

In conclusion, the coulombic efficiency of batteries, especially zinc-air batteries, is a crucial measure for assessing and optimizing performance. Better performing and longer lasting batteries may be developed with the aid of study into the elements that impact coulombic efficiency and tactics for increasing it.

4.3 Electrochemical Testing of Battery with Casing:

Electrochemical analyses were carried out to gauge the battery's efficiency and get insights into its durability and use. In the case of metal air batteries in particular, these assessments looked at how well the battery assembly made use of the battery's tiny size. These tests were performed so that results could be compared to those obtained when the battery was not encased.

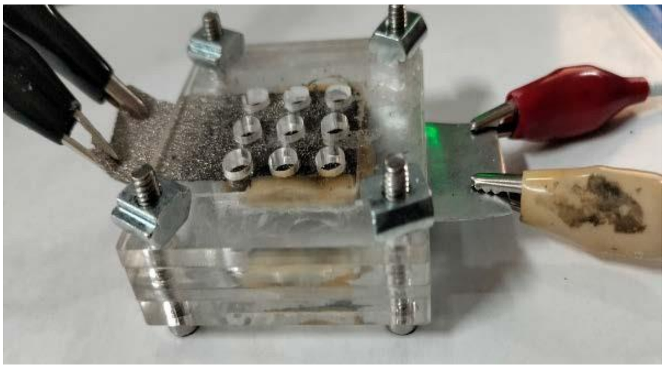

Figure 18: Successful Battery Testing in Progress.

Many important factors went into the electrochemical evaluation. The evaluation of the stability of the created contact inside the battery was a significant factor. An effective battery relies on a strong connection between the various parts of the battery, including the anode, cathode, and electrolyte. Researchers may learn more about what could be hindering the battery's performance and lifespan by analyzing the stability of this interface.

The electrochemical study also included an evaluation of how well the battery pack's small size was put to use. To function at their best, metal air batteries often use a space-saving and sturdy construction. Researchers may learn how well the battery assembly makes use of its small size for energy storage and discharge by analyzing its utilisation of the area available.

To better comprehend the effect of the case on the battery's performance, these data will be compared with those obtained in prior electrochemical tests without the casing. By comparing the two, we can see whether the battery's electrochemical behavior has changed for the better after the case was added.

The electrochemical analysis of the battery, in its whole, reveals instructive details about the interface established inside the battery and the efficient use of its compactness. These findings may inform future investigations into improving the design and functionality of metal air batteries, leading to more effective and trustworthy methods of energy storage.

4.3.1 Cyclic Voltammetry Analysis:

Before the creation of the housing, there were a number of obstacles to conducting a cyclic voltammetry (CV) investigation on the battery. The mechanical unreliability of the batteries was a significant challenge. During testing, the battery's components may have shifted and caused a short circuit if they hadn't been contained properly. Due to the potential for direct contact between the anode and cathode should the semisolid electrolyte shift, the desired electrochemical processes may be disrupted, making precise analysis challenging.

The lack of a protective shell also made it difficult to make solid electrical contact with the battery during testing. In order to accurately regulate and monitor the electrochemical reactions taking place within the battery, proper electrical connections are required for CV analysis. It was difficult to make firm connections to the battery for reliable testing without the housing.

Before the housing was created, doing a CV study on the battery was not possible due to mechanical instability difficulties and a lack of solid electrical connections. These issues were resolved via the invention of the housing, which provides mechanical stability to the battery, prevents short circuits, and allows for reliable electrical connections to the testing apparatus.

The addition of the housing made CV analysis of the battery feasible, giving scientists a new window into the battery's electrochemical behaviour and efficiency. By subjecting the battery to different voltages and then measuring the current response, CV analysis may provide details about the battery's redox processes and charge storage capacities.

Successful implementation of CV analysis was made possible by the housing, which overcame mechanical instability issues and established reliable electrical contacts, all of which contributed to a deeper understanding of the battery's electrochemical characteristics and bolstered future research and development efforts.

It was difficult to examine the battery using cyclic voltammetry (CV) before the housing was made. The batteries' inherent mechanical unreliability posed a serious problem. Without sufficient containment, the battery's components might have moved around during testing, resulting in a short circuit. If the semisolid electrolyte moves, the anode and cathode might come into touch with one another, disrupting the intended electrochemical processes and making exact analysis difficult.

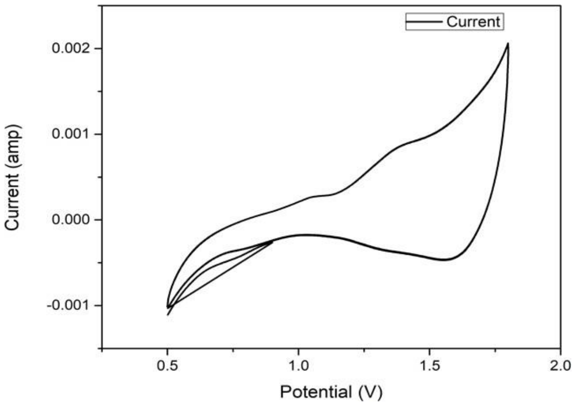

Figure 19: CV at 100mV for 8 segments

Due to the battery's exposed interior, reliable electrical contact was challenging during testing. Correct electrical connections are necessary for CV analysis in order to appropriately control and monitor the electrochemical processes occurring inside the battery. Without the housing, it was difficult to create secure connections to the battery for trustworthy testing.

There was no way to conduct a CV analysis of the battery prior to the development of the housing because to mechanical instability issues and a lack of reliable electrical connections. The battery's mechanical stability, the prevention of short circuits, and the availability of trustworthy electrical connections to the testing equipment were all addressed by the development of the housing.

Because of the housing, scientists now have a new way to examine the battery's electrochemical behavior and efficiency using CV analysis. Battery redox processes and charge storage capabilities may be elucidated by CV analysis by exposing the battery to varying voltages and then monitoring the current response.

The battery's electrochemical characteristics were better understood, and future research and development efforts were bolstered thanks to the housing, which overcame mechanical instability issues and established reliable electrical contacts.

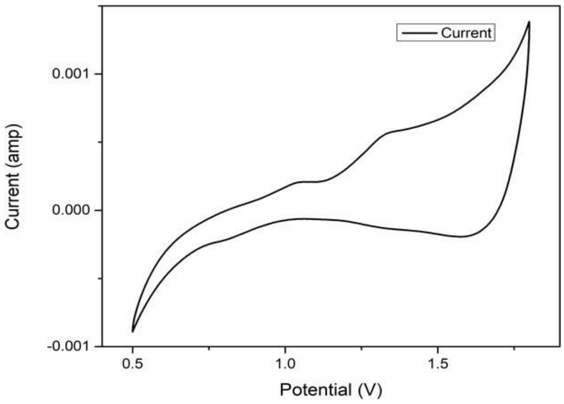

Figure 2020: CV at 50 mV.

Using cyclic voltammetry (CV) to inspect the battery before the housing was manufactured was a time-consuming and tedious process. There was a major issue brought on by the batteries' intrinsic mechanical unreliability. The battery's components may have shifted around during testing if they weren't properly contained. Electrochemical processes are disrupted, and precise analysis is more challenging if the semisolid electrolyte shifts and brings the anode and cathode into contact with one another.

The battery's open construction made it difficult to ensure good electrical contact during testing. For CV analysis to work, the battery's electrical connections must be made correctly so that the battery's electrochemical activities can be controlled and monitored. Safe connections to the battery for reliable testing were difficult to establish in the absence of the casing.

Due to mechanical instability and unreliable electrical connections, a CV study of the battery could not be performed before the building of the housing. The design of the enclosure took into account the mechanical integrity of the battery, the avoidance of short circuits, and the availability of reliable electrical connections to the testing apparatus.

The housing allows researchers to do CV study of the battery's electrochemical activity and efficiency in previously unattainable ways. Analyzing the current response of a battery while subjecting it to varied voltages might provide light on the battery's redox processes and charge storage capacities.

Thanks to the housing, which addressed mechanical instability difficulties and provided stable electrical connections, the battery's electrochemical properties were better understood, and future research and development efforts were boosted.

The designed battery case has passed cyclic voltammetry (CV) examination, which is a major step in determining the battery's electrochemical performance. The ideal functioning of the battery is confirmed by the test's CV findings, which give vital insight into the device's behavior.

The mechanical and electrochemical reliability of the battery is essential to its effectiveness. By analyzing the CV, scientists may determine how well the electrochemical interface holds together between the electrolyte, anode, and cathode while the battery is charged and discharged. Findings confirming the battery's stability suggest the electrochemical processes taking place inside it are managed and constant, resulting in predictable and dependable operation.

The good CV study also implies that the battery is mechanically stable. Since the CV test was carried out without incident, this may indicate that the created battery shell is physically sound and can endure the stresses and motions experienced during operation. This mechanical steadiness is crucial for ensuring the battery's durability and dependability in practical settings.

Because of its superior performance as measured by the CV data, it can be concluded that the battery's new housing effectively stores and retrieves charges. The analysis's CV curves provide information on the redox processes taking place at the anode and cathode, revealing the battery's capacity to store and release electrical energy. This high level of efficiency is encouraging since it shows that the time and work put into developing the battery, including the housing, was worthwhile.

In conclusion, the positive outcomes of the CV study and the acquired findings verifying the battery's excellent performance and stability (both electrochemically and mechanically) are encouraging signs for its future applications. These results not only validate the battery's potential for real-world applications, but also open the door to additional research into improving its design and functionality.

4.3.2 Electrochemical Impedance Spectroscopy:

Battery durability and performance may be gauged by electrochemical impedance spectroscopy (EIS), a sophisticated method for evaluating the electrochemical behavior of batteries. Battery internal resistance, charge transfer kinetics, and interfacial characteristics may all be learned by EIS measurements of the battery's impedance response throughout a wide frequency range.

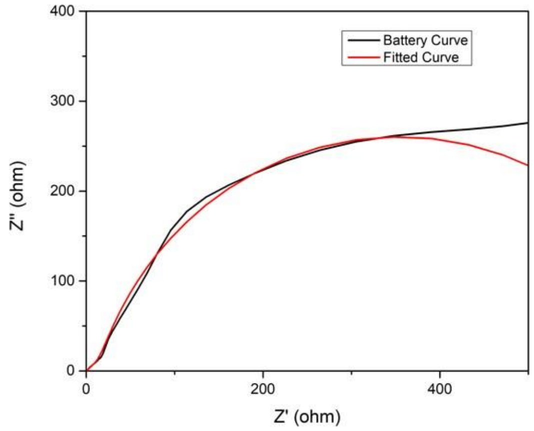

Figure 211: EIS fitted curve at 1000-10000 Hz.

The mechanical and electrochemical reliability of a battery may be determined by analysing the EIS findings. Insights regarding the battery's behavior may be gleaned from the impedance spectra acquired during the EIS test thanks to its many characteristics and factors.

The Nyquist plot, which plots the imaginary component of the impedance versus the real component, is a useful metric derived from EIS. Information regarding the battery's charge transfer resistance and diffusion processes may be gleaned from the shape and properties of the Nyquist plot.

The EIS data may reveal whether or not the battery is suffering mechanical instability due to short circuits. The existence of internal short circuits or mechanical defects inside the battery structure may be indicated by sudden shifts or anomalies in the impedance spectra. However, reliable and consistent impedance behavior is indicative of mechanical robustness.

EIS also allows for the assessment of electrochemical stability. The battery's capacity to sustain electrochemical reactions across charge and discharge cycles may be inferred from the impedance spectra. Smooth and consistent electrochemical processes, such ion transport and charge transfer kinetics, are reflected in a battery with a stable and well-defined impedance response.

The mechanical and electrochemical stability of the battery may be evaluated with the use of the EIS data. They are able to detect any discrepancies or outliers that may point to structural or electrochemical instability in the battery. Knowing the battery's performance limits is essential for improving its design and optimising its performance.

In conclusion, the EIS results are critical in gauging the battery's mechanical and electrochemical stability. They provide important information about the battery's internal workings, impedance, and overall efficiency. Researchers can improve the battery system's reliability and performance with the use of this data after careful analysis and interpretation.

The battery's superb capacitive behavior is evident from the fact that the EIS curve is almost a perfect semicircle. Capacitance is the ability of two metal plates, or electrodes, to store electrical charge. In the absence of physical contact between the electrodes, capacitive behaviour cannot occur. It follows that the enclosure prevents any possibility of a short circuit during electrochemical testing of our battery.

Capacitive behavior, as shown in the EIS data as a nearly perfect semicircular curve, is indicative of a battery with steady electrochemical performance. The storage of charge between two electrodes is known as capacitive behavior, and it requires that the electrodes not be in physical touch with one another.

The half-circle shape of the EIS curve indicates good electrode separation, which is necessary for a battery to store and discharge its charge without considerable leakage or short circuits. This proves that the problem of electrode mobility and direct contact, which previously produced short circuits, has been solved by the housing.

A battery's stability and performance might be jeopardized if the EIS curve isn't a perfect semicircle or shows other anomalies, such as electrode contact problems or electrolyte leaking. A well-defined semicircular curve, on the other hand, indicates that the enclosure has supplied the mechanical stability required to avoid short circuits and preserve electrode separation.

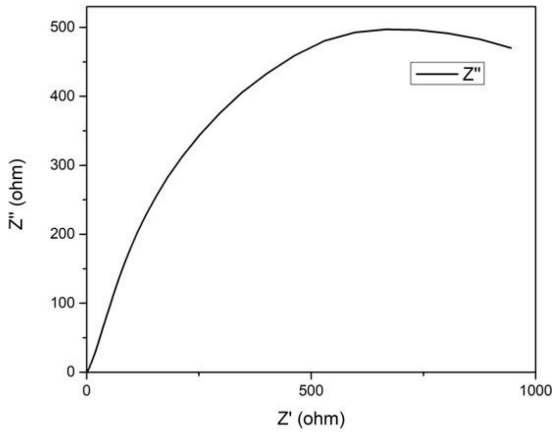

Figure22: EIS at 0-10000 Hz.

The EIS findings also show that the battery's electrodes are working properly because of their capacitive behavior, which allows for the effective storage and release of charge. This is promising news for the battery's electrochemical performance and provides further evidence that the casing has helped to maintain the battery's structural integrity.

Overall, the EIS findings showed a nearly perfect semicircular curve, indicating that the battery exhibited acceptable capacitive behavior and was devoid of short circuits while the shell was in place. The battery's mechanical and electrochemical stability may thus be tested with confidence, leading to more accurate results when subjected to electrochemical testing.

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The mechanical and electrochemical stability of the battery may be evaluated with the use of the EIS data. They are able to detect any discrepancies or outliers that may point to structural or electrochemical instability in the battery. Knowing the battery's performance limits is essential for improving its design and optimising its performance.

In conclusion, the EIS results are critical in gauging the battery's mechanical and electrochemical stability. They provide important information about the battery's internal workings, impedance, and overall efficiency. Researchers can improve the battery system's reliability and performance with the use of this data after careful analysis and interpretation.

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CONCLUSIONS

In recent years, the development of alternative energy storage technologies has gained significant attention due to increasing concerns over environmental and energy issues such as fuel depletion, climate change, and air pollution. Zinc-air batteries (ZABs) have emerged as a promising option due to their high energy density, cost-effectiveness, and environmental friendliness. However, their complexity in design and the need for optimization of anode and cathode materials present significant challenges to their commercialization. Therefore, the creation of a ZAB prototype is an essential step towards improving the efficiency and reliability of these batteries. The optimization of the anode and cathode materials is crucial for ZABs to be stable and effective. The cathode side design and the presence of air make testing ZABs challenging. However, creating a ZAB prototype can help address these issues. The prototype should work with other anode/cathode materials for electrochemical testing and be reusable for other metal-air batteries. Its design must have strong mechanical and chemical qualities that make it the best option for any battery system. The prototype also must enhance the electrochemical processes taking place on both the anode and cathode sides. ZABs can store a large amount of energy relative to their weight and can even be used for electrical vehicles. They are cost-effective, making them a desirable alternative for use in large-scale energy storage systems or backup power applications. Moreover, they have an extended shelf life, making them highly efficient during emergency situations or in outlying areas where routine maintenance is impractical. They can also be made rechargeable and used repeatedly, rather than single-use batteries. Additionally, they are extremely environmentally friendly since they do not contain any heavy metals which are hazardous, not to mention their raw materials are abundant and widely available which makes them a more sustainable option than other materials.

However, ZABs are difficult to commercialize due to their complexity in design, which makes them difficult and expensive to manufacture. The battery's design heavily affects its performance and cost, and the battery components increase the cost further. Therefore, novel and straightforward design strategies are necessary to balance the trade-offs between various performance indicators and enable effective and economical manufacturing to address these problems. The proposed solution for the commercialization of ZABs is the incorporation of transparent acrylic sheets in their design. This approach is cost-effective and environmentally friendly, as the use of transparent acrylic sheets makes it simple to visualize the battery components, enabling easy assessment of any problems that can compromise the battery's performance. Moreover, the sheets are lightweight, making them easier to handle and install, and exhibit good mechanical stability and impact resistance, making them a reliable option for designing a battery tester that can be used not only for ZABs but for other metal-air batteries or battery systems as well. Metal air batteries, including ZABs, are poised to play a crucial role in the energy sector, particularly as the demand for energy continues to rise. Energy storage is equally important as sustainable energy production, and metal air batteries have the potential to revolutionize the field of energy storage. These batteries offer long-life, sustainable, and efficient charge storage devices that can revolutionize electric vehicles, space applications, and general household energy requirements. Through this research, we were able to manufacture and implement a design for testing these metal air battery platforms. The availability of a research platform for metal air batteries is instrumental in fully capitalizing on their potential. The tests conducted on different configurations have shown promising results, providing a foundation for focusing on the electrochemical performance of the batteries without the concerns of mechanical stability and other related issues, thereby expediting progress in the field.

Conclusively, the development of ZABs holds significant promise for addressing the global energy and environmental challenges we face today. The creation of a ZAB prototype is an essential step towards improving their efficiency and reliability, and the proposed solution of incorporating transparent acrylic sheets in their design is a cost-effective and environmentally friendly approach that could enable effective and economical manufacturing. With continued research and development, ZABs hold great potential for the future of energy storage, contributing to a more sustainable and environmentally friendly future. Furthermore, the availability of a research platform for metal air batteries enhances our ability to explore their potential and paves the way for advancements in electric vehicles, space applications, and household energy requirements.

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