Recent Advancements in Rechargeable Batteries Using Recycled Mattress Materials

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The recent advancement in science and technology demands high-performance and efficient rechargeable batteries for many applications. The electrification of automobiles and the increasing use of consumer electronics devices require high-performance batteries and supercapacitors. The objective of this research was to "***develop materials and technology for safer, high-performance, and environment-friendly batteries and supercapacitors using recycled mattresses.***" Dr. Gupta's team at the National Institute for Materials Advancement (NIMA) has developed rechargeable supercapacitors and batteries using recycled mattresses. Figure 1 shows a general schematic of such devices. The process creates high-performance carbon from various recycled mattress parts such as shoddy, coconut fiber, cotton, and polyurethane foams. A rechargeable battery is composed of at least four components: anode, cathode, separator, and electrolyte. For the dual carbon batteries, both the anode and cathode were made of recycled mattresses. The performance of the fabricated devices was tested. Different electrolytes such as aqueous and organic were used to boost their performance. It was observed that these devices were electrochemically stable up to 10,000 charge-discharge cycles (Figure 2a). The Coulombic efficiency was almost 100% suggesting no loss of energy during the charge and discharge process. The organic electrolytes can provide higher working potential and thus increase the energy and power density. The energy and power density plots of the shoddy-based device are shown in Figure 2b.

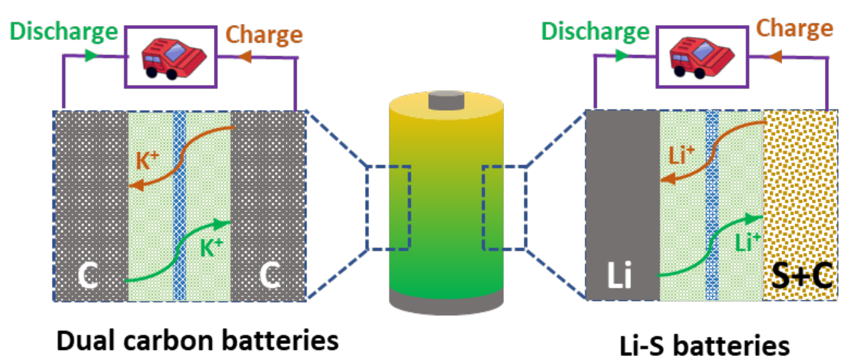

Figure 1: Schematics of rechargeable batteries.

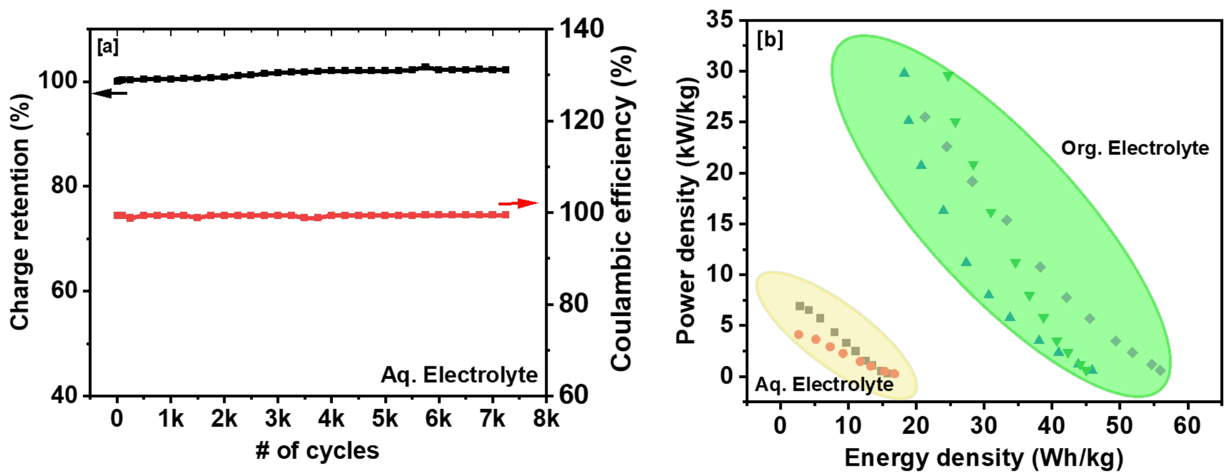

Figure 2: (a) Charge retention and Coulombic efficiency of shoddy-based rechargeable device and (b) comparison of energy and power density of the device in aqueous and organic electrolytes.

There is a great necessity to enhance the performance of energy storage systems due to the ever-growing demand of society. The development of novel technologies led to lithium-sulfur (Li-S) batteries. They have attracted great attention because a Li-S battery has a theoretical specific energy of around 2600 Wh/kg, which is five times higher than that of Li-ion batteries, composed of a $LiCoO_2$/graphite system. On top of that, elemental S is plentiful and friendlier to the environment in comparison to currently used materials in other batteries, which makes it aligned with a more sustainable future. However, several issues arise in practical terms that have been hindering the commercial use of Li-S batteries. The first issue is that the highly electrically insulating S and Li_2S can prevent the flow of electrons during the process which decreases the practical energy density. The second issue is that during the discharging process, which consists of the removal of Li ions from the S cathode, there is the formation of Li polysulfide species which are soluble in organic electrolytes. That leads to the removal of active S from the cathode causing loss of capacitance, referred to as the shuttling effect. The third issue is related to the large volume expansion of S upon the incorporation of Li atoms into its chemical structure which can lead to variations up to 80% of its initial volume. Based on that, there has been a massive effort from the scientific community to overcome such drawbacks which are low electrochemical stability and capacitance loss in Li-S batteries.

Despite these issues, one of the most promising approaches lies in using carbon-based materials as a host for the S cathode. They can greatly optimize the properties of Li-S batteries by improving the electric conductivity along with preventing the dissolution of polysulfides from the cathode to the electrolyte. This effect takes place due to the high conductivity and surface area of carbon-based materials allowing them to function as a conducting substrate whereas confining the polysulfide derivatives into their pores. Alongside that, obtaining the optimal pore size allows the carbonaceous structure to effectively withstand the volume expansion upon discharge of the battery. The type of pores present in the carbon structure can play a major role in efficiently buffering the volume of the S cathode. Their pores can be micro-, meso-, or macro-sized. Micropores smaller than 2 nm have been the most satisfactory in preventing polysulfide dissolution due to their size. Also, mesopores that are between 2 to 50 nm can host S atoms along with providing channels for the transport of Li^+, which translates to a better electrode/electrolyte interface. Lastly, macropores which are pores larger than 50 nm are seldom employed since they are too large to properly arrange S atoms. Hence, balancing the number of micro and mesoporous carbon-based materials is one of the aspects to considerably improve the electrochemical performance and stability of Li-S batteries. Another aspect is that even though carbon is widely available, obtaining the optimal structure that is suitable for Li-S can be a costly process. For example, fullerene, graphene, and carbon nanotubes are materials suitable for such applications, however, they require demanding techniques and equipment to be properly synthesized and isolated. To counter these drawbacks, this report discusses a facile approach to obtain carbon matrices derived from renewable sources that functioned as effective materials to fabricate cathodes for Li-S batteries. From that, an efficient way to tackle the inherent issues of Li-S batteries is proposed while using readily available and renewable sources. Through that, the combination of a Li-S system that is highly desired for energy storage due to its great potential along with the use of low-cost and eco-friendly carbon-based materials to assemble it and revert its drawbacks is presented. Based on that, our team developed three different Li-S batteries using recycled parts of a mattress such as coconut (Coco), shoddy (Sh), and cotton (Cot) as an anode.

Several tests were performed to elucidate a battery's performance. One of them is the electrochemical impedance spectroscopy (EIS) presented in Figure 3a. Among other things, this technique provides the value of the charge transfer resistance of the cell. In this sense, the electrode that displayed the lowest resistance is the one that presented the smallest semi-circle which, in this case, was the MRC-Cot electrode. Such improvement was quite considerable as MRC-Cot presented a resistance that was nearly seven times lower than the MRC-Coco electrode which culminated in a higher capacitance for this material. Based on that, the lowest internal resistance of MRC-Cot served as a good indication that it would present a better performance when compared to the other electrodes. Hence, further tests were displayed for the MRC-Cot. Another important electrochemical characterization is the cyclic voltammetry (CV) presented in Figure 3b, which provides some information regarding the type of mechanism a battery is going through. It could also be observed that there was a shift in the peak position after the 1^{st} cycle to slightly higher potentials. Two cathodic peaks and the two overlapped anodic peaks are typical of Li–S cells with carbon-based cathodes.

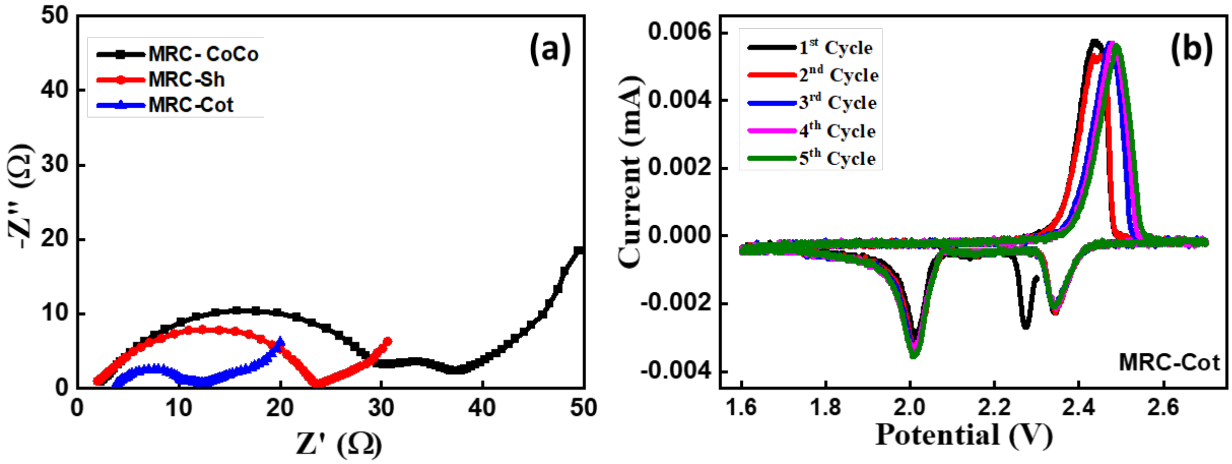

Figure 3: (a) EIS plots and (b) CV curves for Li-S batteries fabricated using a recycled mattress.

Also, the specific capacity of the Li-S battery can be obtained by performing charging and discharging cycles. Figure 4a shows the 1st, 2nd, 3rd, and 50th discharge/charge profiles of Li-S batteries fabricated using recycled cotton from a mattress. There were two plateaus which are typical of the sulfur cathode as they represent the formation of polysulfides with long chain (Li2Sx at which $4 \leq x \leq 8$) around 2.3 V along with short-chain polysulfides (Li_2S_2 and Li_2S) at around 2.1 V. It was notable that, the battery's specific capacity was almost constant even after 50 cycles. Lastly, the electrochemical stability of the Li-S battery containing the MRC-Cot as the anode is displayed in Figure 4b. It could be observed that the cell presented an overlapping discharging and charging behavior. Also, the specific capacity is maintained at about 700 $mAhg^{-1}$ accompanied by a Coulombic efficiency of nearly 100%, displaying a remarkable electrochemical performance.

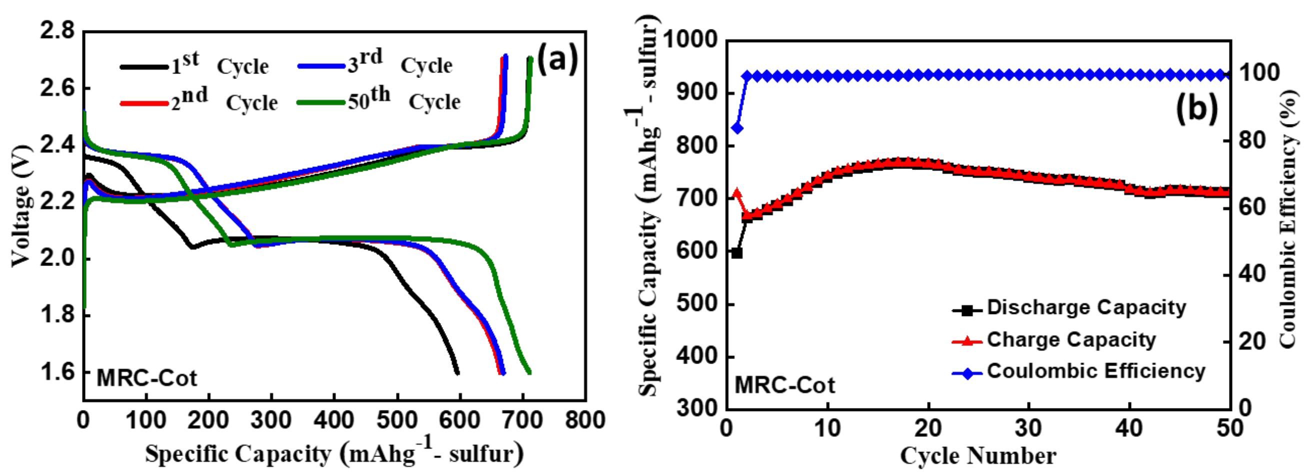

Figure 4: (a) Discharge and charge profile of the 1st, 2nd, 3rd, and 50th cycle, and (b) electrochemical stability and Coulombic efficiency for the cell containing MRC-Cot.

In conclusion, the novel rechargeable batteries (dual carbon and Li-S) presented remarkable electrochemical performance in terms of specific capacity as well as stability. These achievements showed a feasible route to tackle the inherent challenges of rechargeable batteries and incorporate this technology into the market. This research suggests that recycled mattress textiles are excellent carbon feedstocks for battery and supercapacitor electrodes. Being recycled materials, they have a much lower carbon footprint relative to other feedstocks used today. A simple and cost-effective process was developed which generates high-performance electrodes for rechargeable batteries. These rechargeable batteries perform equal to or better than conventional batteries and do not require scarce metals such as nickel, manganese, and cobalt. In addition, the use of end-of-life materials as feedstocks is a win-win. Most textiles (not only mattresses but other textiles such as clothing) are currently landfilled. In the U.S., there is a critical need to develop a domestic supply chain for high-performance rechargeable batteries.

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