Maximizing Energy Storage in Activated Carbon Supercapacitors

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Introduction

After their invention in the mid-twentieth century, supercapacitors have occupied the intersection between rechargeable batteries, electrolytic capacitors, and normal batteries. Instead of using chemical reactions to create a current like batteries, supercapacitors store their charge in an electrostatic double layer in between their electrodes. They differ from typical electrolytic capacitors in a few ways, mostly due to the structure of the electrodes. In this experiment, activated carbon (AC) was used as an electrode as it has both conductivity and an exceptionally large surface area. Some activated carbon can have a surface area of up to 2630 m^2/g [1]which is roughly the area of two Olympic swimming pools per gram. This large surface area density acts in concert with an electric double layer of charged particles to yield a high capacitance[2]. This high capacitance results in an electrical component that can absorb and discharge large amounts of energy in little time with minimal damage to the environment.

The carbon-electrolyte interaction is one that affects both of the main variables of a capacitor. In a standard electrolytic capacitor, capacitance is found by $C=(\varepsilon A)/D$ with A being area of the base, D being distance between the two plates, and ε, the permittivity of the electrolyte layer. In an activated carbon supercapacitor, the area is not that of the metal plates, but of the carbon exposed to the electrolyte layer. The porous nature of the carbon allows this number to far surpass that of an electrolytic capacitor. Similarly the D value is also very different in an AC supercapacitor, as it is not the distance between bases but the distance between the elements of each double layer. The double layer consists of the charged carbon electrode attracting opposite charge ions to the edge of

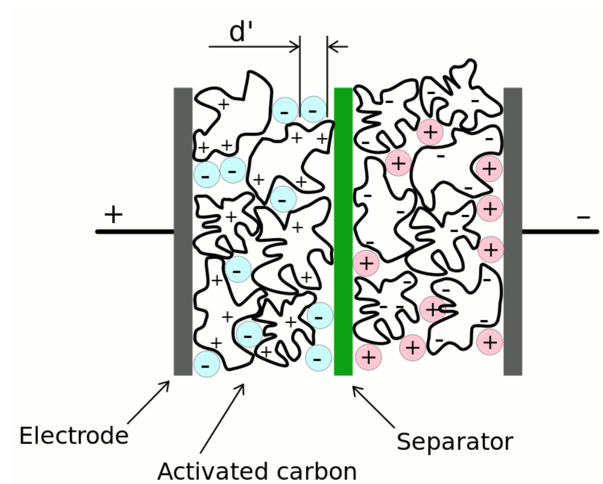

Diagram of AC Supercapacitor

Source: WikiCommons

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[1] Effects of Nano-Scale Characteristics of Graphene on Electrochemical Performance of Activated Carbon Supercapacitor Electrodes

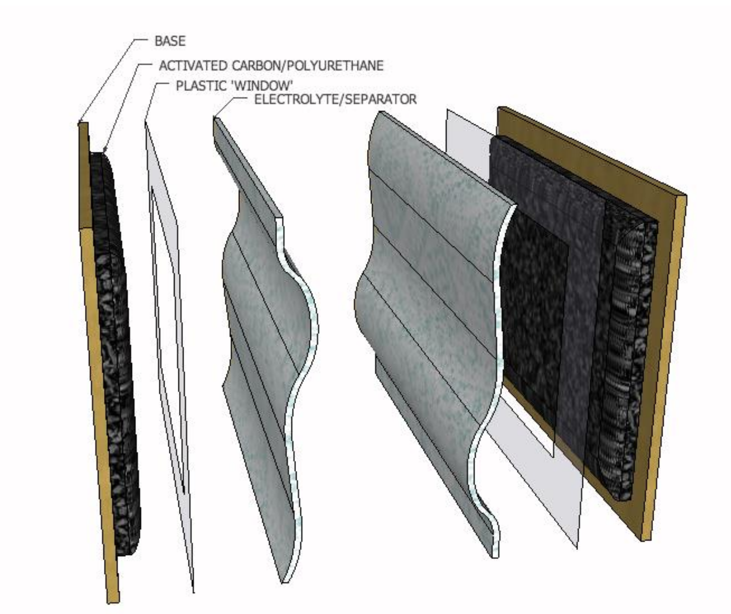
[2] http://www.explainthatstuff.com/how-supercapacitors-work.html

the carbon electrode and electrolyte creating a layer of positive and negative charge with only a few angstroms distance between them[3]. This small distance is the D in the above equation. The ε value is determined by the permittivity of the substance separating positive and negative components of the capacitor, in this case an acidic electrolyte. It is this material that contain the ions required for the formation of a double layer.

Experimental

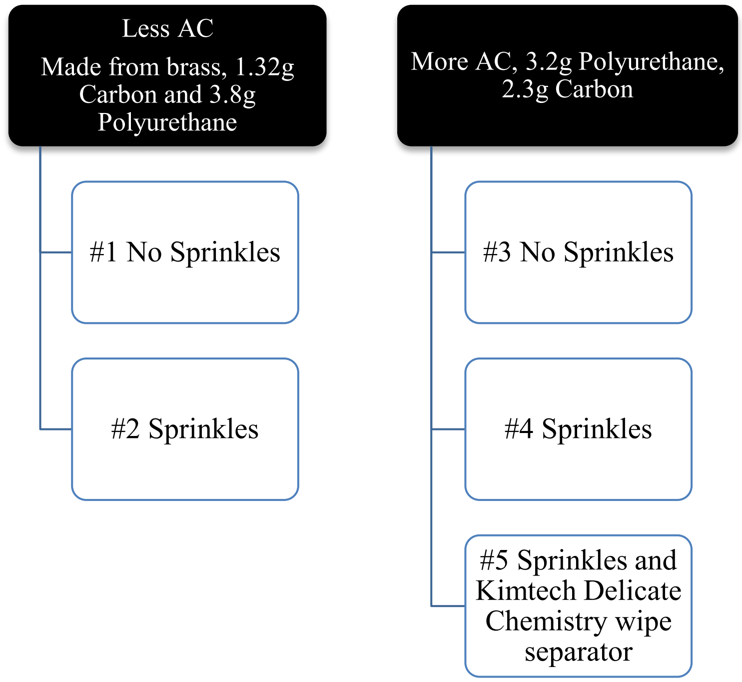
Experimental procedure evolved over the course of the project, with each new built and tested capacitor providing insights into future construction. Originally, a copper base was used, however this material was too malleable and reacted with the original electrolyte (NaOH) so it was replaced with brass and aluminum. While aluminum provided a very flat surface, it was harder to machine and had no other significant advantages to brass, so brass was used in the final batch. The electrolyte was also changed for ease of use, 17% phosphoric acid was used after the original NaOH was found too corrosive.

The center portion, however, is where most of the changes were implemented. after several failed separator models, one with a plastic 'window' and paper towel was used.



AC material was collected from Imaginarium brand aquarium filter pellets and was tested for resistivity before processing, while most pellets exhibited small (<100Ω) resistances, some with larger resistivity were discarded. In order to connect the carbon with the base, polyurethane mixed with differing amounts of finely ground carbon was used as a connecting layer. On top of that layer some of the capacitors were sprinkled with larger course particles[4]. After drying overnight, the capacitor bases are then covered with a paper towel that is then dripped with 17% phosphoric acid. One of the capacitors (#5) was constructed with a Kimtech chemistry wipe instead of paper towel to investigate its possible use. After the paper towels are placed, the two halves are stuck together and sealed in a plastic container with only the wires connected to bases exiting the capacitor. Using these materials, five similarly sized supercapacitors of varying efficacy were fabricated.

[3] Wikipedia
[4] https://www.youtube.com/watch?v=gTt_YBzJ_Dk&feature=youtu.be



Assembly, for the capacitors is relatively straightforward. It begins with the cutting of two small rectangles of brass or copper that are then textured by use of sandpaper to increase adhesion with AC/polyurethane mixture. Wires are then attached to the tops of the plates with both copper tape and soldering to ensure a good connection[5]. Next, polyurethane and AC powder are mixed until dough like and directly applied to the sandpapered side of the metal base[6]. If applicable, a layer of larger carbon particles (~.5mm in length) is placed on the drying mixture and pressed into it to ensure a proper connection. After drying overnight, a paper towel layer is introduced and the electrolyte (bout 10 drops of 17% phosphoric acid) is dropped onto the middle layer until saturated. The whole capacitor is then sealed in polyethylene pouches and charged overnight at 1.2V to begin any chemical reactions that would introduce pseudocapacitance[7]. The sealing is done with a sealing mechanism that uses heat to melt two layers of polyethylene together into an almost airtight seal. Although there is a small gap where the wires exit the pouch, leakage is minimal as the electrolyte is mainly within the separator material and not flowing freely inside the plastic.

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[5] https://www.youtube.com/watch?v=Ar3C5JgzhgE

[6] https://www.researchgate.net/post/Does_anyone_have_an_idea_about_the_adhesion_of_a_carbon_paste_to_Al_for_supercapacitors

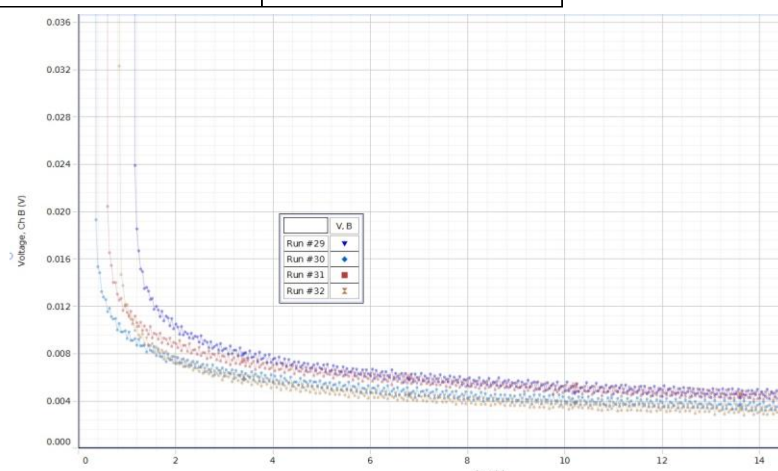
[7] https://www.researchgate.net/post/Does_anyone_have_an_idea_about_the_adhesion_of_a_carbon_paste_to_Al_for_supercapacitors

Capacitance values are calculated by using a resistor and capacitor fully charged in parallel with each other by use of a voltage source set to 1.2V, below the breakdown voltage. After charging, the voltage source is removed and a Pasco voltmeter connected to the capacitor measures the voltage and therefore current passing through the resistor. When collecting data, it is important to remove all data points with voltages at 1.2V as we wish to measure the current leaving capacitor, not voltage source[8]. As capacitance is measured in volts per coulomb, the capacitance can be calculated from the integral of current divided by the change in voltage.

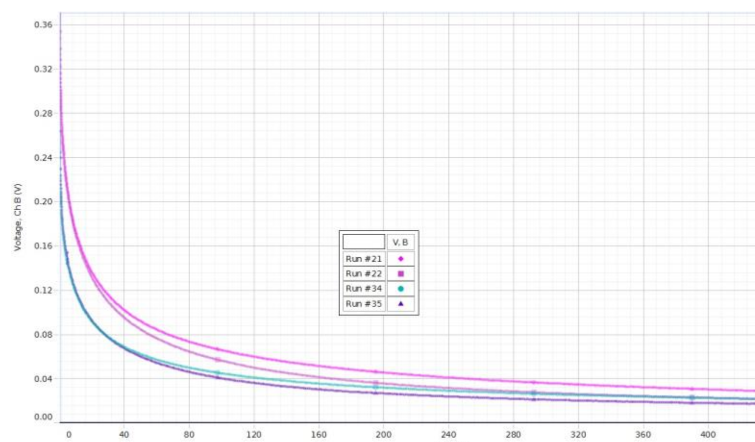
Results

Capacitor	Capacitance	AC/Polyurethane Ratio	Sprinkles
#1	.019F	.34	N
#2	.147F	.34	Y
#3	.001F	.72	N
#4	.841F	.72	Y
#5	.011F	.72	Y

Capacitor #3 Discharge with 1k Resistor



Capacitor #4 Discharge with 100 Ohm



8 https://www.tecategroup.com/ultracapacitors-supercapacitors/ultracapacitor-FAQ.php#How_to_measure_an_ultracapacitor

The results were obtained by using a Pasco box to measure voltage across a resistor connected to the capacitor, by finding the total charge that left the capacitor and its voltage drop, we can find its capacitance. Four discharges were measured for each capacitor, and 100 Ohm resistors were used for most measurements, except for that of #3, as its capacitance was lower and thus its decay faster, a 1k resistor was used to slow the process and gather more accurate data. Decays were recorded for at least five minutes each to ensure full drain, although some runs went for longer.

Conclusion

While they cannot functionally replace batteries at the moment, AC supercapacitors provide a good deal of storage. When constructed properly, one can light an LED for over 10 minutes using a joule thief[9]. We can see from the data, however that not all supercapacitors are created equal. As #2 and #4 have the highest capacitances we can see that the sprinkle method boosts the amount of charge the capacitor can hold. This implies that the more exposed carbon granules allow for a larger surface area for the electrolyte to form the double layer. As there is less area (A) where carbon is directly touching the electrolyte without these sprinkles, capacitance is lowered. Less obvious however is how the ratio of AC/polyurethane affects capacitance. A .72 ratio provides both the largest and smallest capacitances of the batch. The reasons for this are not immediately obvious and invite further study. #5 is considered an informative failure, as it shows that the KimTech material is not a good material for supercapacitors, perhaps it is not entirely ion permeable or does not make contact with the AC electrode in a way that connects the electrolyte. These findings support the model of how these capacitors hold charge and why AC, with its large surface area, is the preferred material for this application.

[9] http://www.howtodotip.com/how-to-do/25810