From Kombucha Tea to Sustainable Wearable Electronics

Department of Mechanical Engineering, College of Design and Engineering, National University of Singapore

Saira Billah
Department of Mechanical Engineering
Cooper Union
New York, United States
saira.billah@cooper.edu

***Abstract*—Kombucha tea is a fermented tea drink that is commonly consumed for its beneficial probiotics and health benefits. However, during the production of kombucha tea, the byproduct SCOBY is formed, which stands for symbiotic culture of bacteria and yeast. SCOBY consists of cellulose, which is a green material and biodegradable. This byproduct is usually disposed of after kombucha is made. However, there are many ways to reuse SCOBY in order to cut down on waste and increase its use. For example, in a dried state, SCOBY forms a fabric, leather-like material, that can be consumed or even used in the fashion industry. In order to combat electronic waste, SCOBY is used to create a flexible, wearable, electronic. Experiments are done to purify and manufacture the SCOBY in a standardized method. The material is tested for its mechanical and conductive properties. A printed circuit board to light up an SMD LED (Light Emitting Diode) is made using SCOBY as a non-conductive backing and a conductive material.**

I. Introduction

Electronic waste is a huge problem in our world today. The main problem in the electronics industry is the materials used. Printed circuit boards (PCB) are often made of materials that are not recyclable or biodegradable, and they contribute to around 3-6 wt % of the total electronic waste. Flexible electronics are an up-and-coming topic of research due to their compactness and the ability to bend, roll, fold, etc. Although successful in creating PCBs out of flexible substrates, the industry should have more research conducted on creating a sustainable and biodegradable flexible electronic device in order to combat electronic waste. (Wang, 2020)

In this paper, the use of cellulose extracted during the process of creating kombucha tea is experimented with to test its uses in electronics. Kombucha tea is a fermented tea drink that has been around for centuries. It has many health benefits when consumed, which is why the production cof kombucha tea has increased dramatically. However, during the production of kombucha tea, a symbiotic culture of bacteria and yeast (SCOBY) forms and clumps together. Often, SCOBY is discarded of. However, many have been using SCOBY in a variety of ways, such as incorporating it in a recipe to consume or even using it in a dried state to make clothes! When SCOBY is pressed and dried, it forms a leather-like material that has been proven to be flexible and durable. Because of this, SCOBY was tested for its mechanical properties using a tensile machine and conductivity using an LCR machine to test the various uses of it. Additionally, several methods of manufacturing SCOBY were tested to create a standardized sheet of SCOBY. SCOBY was also used as the backing of a circuit in order to light an LED with a button.

In the past, researchers have experimented with the use of fungal mycelium skin to limit electronic waste. They have combined conventional integrated circuit methods with a biodegradable substrate (the mycelium skin) in order to successfully make a conductive circuit. These scientists have used various methods for making mycelium skin conductive, such as Physical Vapor Deposition (PVD) and galvanization. Additionally, patterns for a circuit were made using laser ablation, which was able to make conductive paths without harming the mycelium skin substrate. The same idea of creating a conductive circuit directly on a biodegradable substrate was used with SCOBY instead of mycelium skin. (Danninger, 2022)

The idea of using SCOBY as the backing for a circuit has already emerged. These researchers have used alternative methods in creating a conductive circuit on SCOBY. They have used aerosol jet printing with a conductive polymer ink and 3D printing to form two different methods in creating a circuit. Aerosol jet printing is advantageous because it is able to create very precise patterns directly on a substrate without ever being in direct contact with the substrate. This is beneficial in their case because the SCOBY they are using kombucha mats, which may have irregular surfaces. The alternative method, 3D printing with a 15% carbon infill to make conductive traces, was successful but not as precise. (Adamatzky, 2023)

II. Materials and Methods

A. Purification Testing

Purification tests were done on samples of SCOBY in order to standardize the purification process for future production. 13 samples of SCOBY were cut out from the same sheet of SCOBY and soaked in varying solutions for the same amount of time, and then soaked with water. After purification, the pH of the water using LAQUAtwin pH Tester was tested to determine the completion of purification. Once the samples all reached a pH of about 7, they were ready to be used.

B. Peeling Test

A fresh sheet of purified SCOBY was folded and pressed together with an inch at the edge of the SCOBY left separated. Once completely dried, the 7 samples were made by cutting the SCOBY into strips of 1 cm thickness. The separated part of the samples were clamped onto the following tensile machine, Zwick/Roell 100094162-0, and pulled apart at a rate of 20 mm/min using ASTM D1876 guidelines. The purpose of this experiment was to test the mechanical properties of the dried SCOBY samples made by lamination.

C. Tensile Test

A dog bone cutter was used to create 7 samples shaped like a dog bone from a dried sheet of SCOBY. This experiment was done on both a regular sheet of dried SCOBY and a dried sheet of blended SCOBY, which is discussed later. Each sample was clamped onto the tensile machine, Zwick/Roell 100094162-0 and pulled apart at a rate of 1mm/min. This time was chosen to ensure that the sample would break from within 30 seconds to 3 minutes. The purpose of this experiment was to test the mechanical properties of both dried SCOBY and dried blended SCOBY.

D. Dielectric Test

Three samples of dried SCOBY were cut out to make a circle of 2cm diameter. They were then placed in the LCR machine, Alpha-A High Performance Frequency Analyzer, and the dielectric constant of the samples were retrieved. The purpose of this experiment was to know how conductive dried samples of SCOBY were.

E. Blended Sample

Fully purified SCOBY samples were placed in the blender, Memmert UN55, with an additional 100 grams of purified water. This was then blended for 2 minutes at 30 second intervals. 100 grams of pulp was placed into a circular mesh strainer with an additional 100 grams of distilled water. This was allowed to drain for a few hours and then placed in an oven until fully dried. The purpose of this experiment was to standardize the production of sheets of blended SCOBY.

F. Printed Circuit Board

A circuit design was printed onto a sheet of printer paper using the laser printer LaserJet Pro MFP M227fdw. A sample of dried blended SCOBY was taped directly onto the print and sent to print again. Then, the sample was coated the gold using the sputter coater Cressington Sputter Coater 108 auto, in order to make the sample conductive. After the sample was coated with gold, the toner was removed by soaking in ethanol for 30 minutes and placing in an ultrasonic cleaner, Elmasonic P Ultrasonic Cleaner. The purpose of this was to create conductive tracks that mimic a circuit onto a sheet of SCOBY. and removed the toner using ethanol and an ultrasonic cleaner.

III. Results and Discussion

A. Purification Test Results

During the purification test, the samples of SCOBY were divided into 7 groups, as shown in Figure 1. 3 groups contained a 1M concentration of NaOH with a ratio of 1:15 mass of SCOBY to solution. 2 bottles contained a .1M concentration of NaOH with the same ratio. Another bottle contained a solution of NaCl with the same ratio, and the control was soaked with deionized water. The samples were all soaked for one hour, replaced with an alternate solution depending on the sample number for one hour, and then replaced with another solution for one hour. The purpose of this was to determine the safest and most effective way to purify SCOBY. The optimal procedure was to soak the SCOBY in a 1M concentration of NaOH for 1 hour, followed by deionized water for 1 hour, and then followed by another soaking of deionized water for 1 hour. This procedure was chosen due to its limited use of NaOH, which is a hazardous substance.

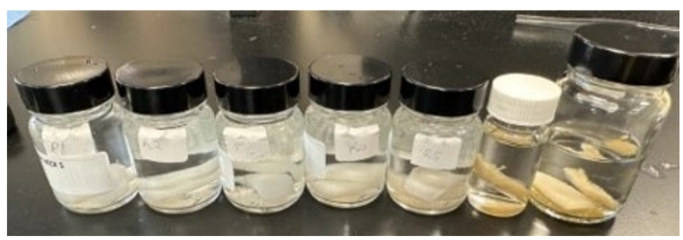

Figure 1. Purification tests on SCOBY samples

From left to right, 1st bottle is soaked in 1M NaOH, 1M NaOH, and deionized water. 2nd bottle is soaked in 1M NaOH, .1M NaOH, and water. 3rd bottle is soaked in 1M NaOH, water, and water. 4th bottle is soaked in .1M NaOH, .01M NaOH, and water. 5th bottle is soaked in .1M NaOH, water, and water. 6th bottle is soaked in water three times. 7th bottle is soaked in NaCl, water, and water.

B. Peeling Test Results

A peeling test was conducted on sheets of SCOBY that were laminated and pressed together using a tensile machine. Figure 2 shows the peeling strength of 5 samples as 2 of the samples broke off before any data could be made. The peeling strength of the samples showed a loose trend around 1N of force. However, not enough samples were tested to get a concrete answer. Additionally, there were many air bubbles present in the samples that led to inconsistencies.

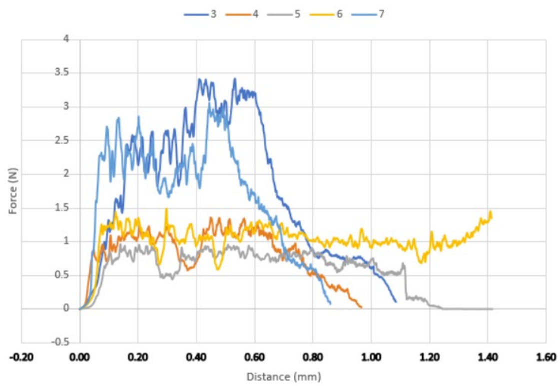

Figure 2. Peeling test of 5 samples of laminated SCOBY

C. Tensile Test Results

A tensile test was conducted on many different forms of dried SCOBY. As seen in Figure 3, the blended sheet of SCOBY is compared to pressed and dried sheets of SCOBY. The blended SCOBY does not behave as well in tension and tends to break earlier. However, blended the SCOBY and forming sheets out of them leads to a more consistent sheet that can overlook the weaker mechanical properties.

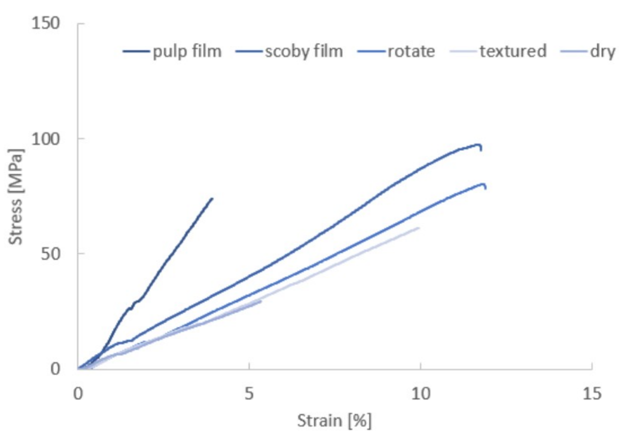

Figure 3. Tensile test of blended SCOBY samples compared to regular SCOBY samples

D. Dielectric Test Results

A dielectric test was conducted to determine if the blended SCOBY was non-conductive in a dried state. As seen in Figure 4, the blended SCOBY had a very small dielectric constant, suggesting that it is not conductive. This makes the blended SCOBY ideal to use as a backing of a circuit so that no current can flow through the SCOBY.

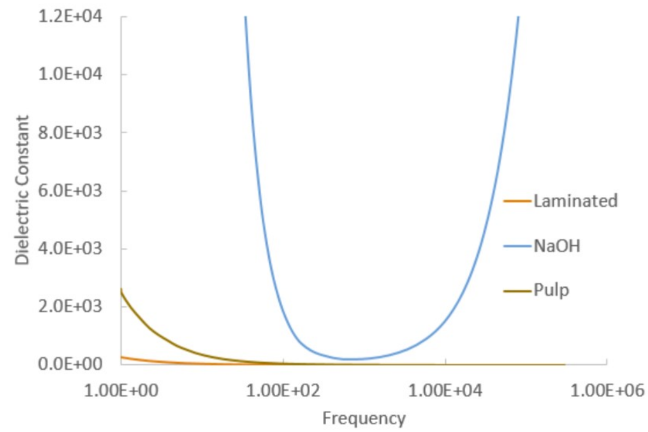

Figure 4. Dielectric test of blended, laminated, and NaOH SCOBY

IV. Conclusion

The peeling test, tensile test, and dielectric test were completed to determine the reliability of using SCOBY sheets as a backing for circuits. From these tests, it was concluded that sheets of SCOBY formed by blending the SCOBY into a pulp leads to reliable, consistent sheets of SCOBY. Additionally, the blended SCOBY sheets have a small dielectric constant, proving that they are not conductive. This is ideal as a backing for circuits because it allows for no current to flow through. As a result, a printed circuit board was made using a blended sheet of SCOBY, as seen in figure 5. The sheet was coated gold to make conductive traces, and a simple circuit using a surface mounted device (SMD) LED and push button was made. This proved that non-continuous conductive tracks can be made and are effective in carrying current. The SCOBY sheets are abundant, flexible, and durable, which make them an ideal candidate for flexible printed circuit boards. This experiment proves that SCOBY sheets have a variety of uses, including being used in flexible circuits. The applications of SCOBY sheets are endless, and in the future, SCOBY sheets may be used to create a flexible, wearable, electronic device like shown.

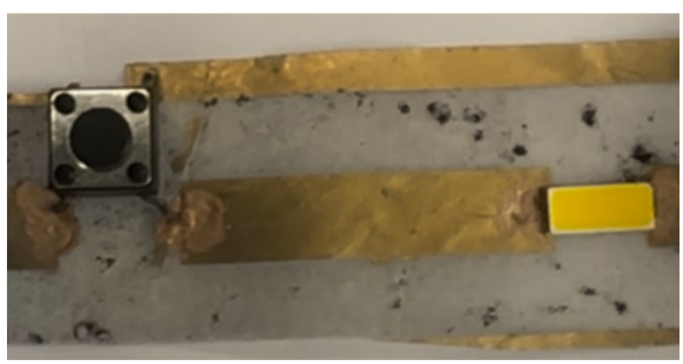

Figure 5. Circuit made from blended SCOBY

Figure 6. Circuit made from SCOBY lit up

V. Preface and Acknowledgements

I would like to thank Chan Xin Ying for guiding me throughout the entire process and giving assistance when needed. I would like to thank Professor Yu Jun Tan for having weekly meetings with me and giving advice when needed.

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