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Prototype Development for Fabric Sodium Sensor

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Executive Summary

Dehydration is a major issue that athletes face during training and games. Dehydration is a complex issue that includes the loss of important electrolytes through sweat without replenishment, which can lead to cramping, fatigue, and even death in more serious cases. The importance of finding a way to monitor an athlete's electrolyte levels during activity is crucial for allowing an athlete to reach their peak performance. The development of the nonwoven fabric sensor that is discussed in this paper is the first of its kind to determine the sodium electrolyte levels of an athlete through their sweat with real-time monitoring.

The nonwoven fabric that forms the basis of this sensor is a nylon-6 material that is prepared through a nanofiber production process called electrospinning. While a very innovative process with the ability of providing materials with optimal properties, electrospinning is impacted by multiple parameters that are therefore very important to control. In the study described in this paper, the effect of solution properties on the material properties were considered. The solution properties were nylon concentration, the ratio of formic acid (FA) and acetic acid (AA) used in the solvent and the mixing temperature of the solution. The resulting material properties studied were the solution viscosity, coat weight, fiber diameter and sensor response and were analyzed using three-factor ANOVA and regression analysis. The results showed that the FA/AA ratio had an impact on coat weight with a p-value of 0.017, nylon concentration had an effect on solution viscosity and fiber diameter with a p-value of 1.42×10^{-5} and 0.049, respectively, and no significant relationships were seen between the solution properties and sensor response with all p-values being much higher than 0.05. It was found that a higher FA/AA ration resulted in a lower coat weight and a higher nylon concentration resulted in a higher solution viscosity and fiber diameter. In addition, the effect of fiber diameter and coat weight on tensile properties was also examined. It

was shown that an increase in coat weight resulted in an increase in max force, strain % and displacement and a decrease in elastic modulus. And an increase in fiber diameter showed no relationship with max force, an increase in displacement and strain % and a decrease in elastic modulus. The R^2 and correlation coefficient (r) values can be found in **Table 6 and 8** and the detailed regression results can be found in **Appendix H.** While these results were very helpful since they further indicated the importance of controlling certain parameters on the ultimate material properties and gave some indication of how certain solution parameters may affect the properties of the electrospun material, it is important to note that this study was done without proper insulation in the electrospinning box or humidity and temperature control. Improper insulation and humidity and temperature can have many effects on material consistency and fiber diameters which may have skewed some of the results obtained in this study. Therefore, it is strongly suggested to implement these controls in future studies and electrospinning in order to obtain optimal electrospun material that is prepared for the next step of functionalization.

The current procedure used for nylon functionalization is effective but has possibility for improvement. The process is individualized to make one sensor at a time, each with its own separately made solutions. Though possible for a lab-scale setting, implementing a batch process is theorized to save cost in materials and labor by decreasing the amount of time needed to fabricate sensors for scaled up manufacturing. Two separate studies were conducted to begin the development of a batch process: decreasing the amount of chemicals needed to create one of the solutions needed for the process and fabricating one “large sensor” that can be separated into ten individual sensors upon conclusion of the process. In decreasing the amount of toluene/calix[4]arene used in solution, percent error in sensor response dropped from 43.0% to 24.4% and SEM imaging did not show significant change in carbon nanotube (CNT) attachment.

In the second study, the percent error for batch sensors dropped even lower to 11.6% for the first batch and 27.7% for the second batch compared to the 43.0% error from the control group. The SEM images for the batch sensors showed slightly smaller amount of CNT attachment to the nylon, but this did not affect the sensor response results. Based on these results, the recommendation to move forward with making sensors using the described amounts of toluene/calix[4]arene and creating the sensors in a batch process rather than individually is acceptable. For future improvements, increasing the batch size and eliminating a need for toluene entirely will be the next focuses in moving forward to large-scale production.

The sensor that has been developed has been turned into a fully functioning prototype for human testing. The design of the prototype has gone through many phases, with issues arising and being resolved at every step. The main focuses for the design of the prototype were the conductive thread used, the full stitch pattern, ways to embroider the prototype including the needle used, stabilizer, tension and speed of the embroidery machine, whether an iron on stabilizer needed to be used, establishing the best connection from the prototype to the tiny circuit board device, leakage currents, calibration methods, placement on the body, ways to hold the prototype in place during exercise, and how to validate the data from the tiny circuit board device. The optimal design up until this point in the project is an embroidery design with three millimeters of fabric removed from behind the sensor, metal prong snaps as the connection to the housing unit of the tiny circuit board device, and a two and half millimeter backing added to the prototype. Human testing has been conducted with this design. Further research will need to be conducted regarding armband material, integration of backing, tiny circuit board device placed into the armband, and reusability as well as washability of the prototype.

The uniqueness of this project was the teamwork involved to accomplish the common goal of creating this sensor. The development of soft skills including communication, work ethic, flexibility, and leadership have given the researchers a competitive edge in the workforce while making each of us a more well-rounded investigator. Major accomplishments and progress have been made by each contributor to moving the entire project forward over the last several years of involvement. We each were able to lead our own project during our time within this group and have had to learn to overcome the challenges that we were faced with to be able to be successful.