Competency of Sri Lankan natural rubber for electrolytes in energy storage devices

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Abstract

Natural rubber which is obtained from latex of rubber tree is widely known as an insulator and an elastomer. But, now it has been found out that it is a viable substitute for commercial polymers and as such, it can be employed for preparation of electrolytes. This paper is about an investigation carried out to prepare an electrolyte with Sri Lankan natural rubber (NR) and the salt, ammonium trifluoromethanesulfionate ($NH_4(CF_3SO_3)$). The electrolyte showed an ionic conductivity of 3.8 x 10^{-4} S cm^{-1} at room temperature which is of utmost importance to be considered for applications. A super capacitor was fabricated using two conducting polymer electrodes. A single electrode specific capacitance value of 20.13 F g^{-1} was obtained upon analyzing the impedance data. At low frequencies, capacitive features were dominant well matching with theoretical explanations. The results are very encouraging and can be used to make the way for a conceptual revolution for natural rubber in the arena of power and energy challenging the traditional views.

Key words : natural rubber, conductivity, electrolytes, super capacitors, single electrode specific capacitance

1. Introduction

Much of the world's natural rubber (NR) is made from the latex found in the sap of the tree 'rubber' (Hevea Brasiliensis) even though there are a lot of trees that has the latex. It is inherently a polymer consisting with the monomer, isoprene as the building block [1]. Due to the polymeric nature, NR is known as an insulator as well as an elastomer. NR is being used for a diverse range of products covering vehicle tyres, erasers, water proof clothes and shoes etc.

Thailand, Indonesia, India, Malaysia and Sri Lanka are considered as some of the giant NR producers in the globe. But unfortunately, NR production in Sri Lanka has gone down at an alarming rate due to the fluctuations of price which seriously affects the lifestyle of so many people. Since the introduction of this crop to the country in British colonial era, rubber cultivation has been done in small, medium and large scales. Not only the export process but also the other manufacturing industries have been severely hit by the lowering of production. Under this scenario, attempts should be launched to add value to Sri Lankan NR in many other ways.

In the recent past, NR has been identified as a viable substitute for commercial polymers use for preparing electrolytes. With that, research groups in many countries have focused their attention on this line [2,3]. However, being an insulator, NR should be modified to serve as an electrolyte. Basically, two methodologies are in practice namely methyl grafting and epoxidization [4]. The latter results in slightly sticky samples and hence, methyl grafting has been the promising and accepted method of modification in the field of electrolytes. Different amounts of methyl groups are grafted to the polyisoprene backbone to obtain methyl grafted (MG)

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NR. Almost all the research groups which are engaging in investigating NR for electrolytes have employed NR from India and Malaysia. Sri Lankan NR rubber has not yet been considered by none. We have commenced investigations on using Sri Lankan NR for preparing electrolytes to be used for electrochemical devices such as batteries and super capacitors [5,6].

This paper reports about an investigation carried out on an electrolyte with NR and ammonium trifluoromethanesulfionate ($NH_4(CF_3SO_3)$) and its application in a super capacitor.

2. Experimental

NR samples were obtained from Associated Speciality Rubbers (PVT) Ltd, Undugoda, Kegalle, Sri Lanka. Required amount of NR sample was weighed and minced into tiny pieces. Tetrrahydrofuran (Aldrich) was added and left overnight for dissolving NR. Stirring was done using a magnetic stirrer. Ammonium trifluoromethanesulfionate ($NH_4(CF_3SO_3)$), (Aldrich) was mixed with the NR solution and magnetic stirring was continued further allowing NR and the salt to be mixed well. The homogeneous resultant solution was poured in to a glass petry dish and allowed solvent evaporation under normal atmospheric conditions. A circular shaped sample was cut from the electrolyte film and loaded in between two stainless steel (SS) electrodes in a brass sample holder. Impedance measurements were taken using a frequency response analyser (Metrohm Autolab – M101). Sample thickness and diameter were measured before taking impedance data.

Pyrrole (Aldrich) was polymerized in the presence of propylene carbonate (Aldrich) and $NH_4(CF_3SO_3)$ on two fluorine doped tin oxide (FTO) glass slides. The area and the thickness of the electrodes were of 1 cm^2 and 1 μm respectively.

An electrolyte sample was sandwiched between two polypyrrole (PPy) electrodes to fabricate a super capacitor. Impedance data were collected in the frequency range from 0.0025 Hz to 0.4 MHz at room temperature using a frequency response analyser (Metrohm Autolab – M101).

3. Results and Discussion

Conductivity (σ) of the electrolyte was calculated using the equation, $\sigma = (1/R_b)(t/A)$ where R_b is the bulk electrolyte resistance obtained from impedance data, t and A are the thickness and the cross sectional area of the electrolyte respectively [8]. The resulting conductivity was 3.8 x 10^{-4} S cm^{-1}. This is an alluring value for a sample to serve as an electrolyte. Apart from the conductive nature, the electrolyte was a mechanically stable thin film. This is also a key feature to be used for applications.

Fig 1 shows the impedance plots resulted for the super capacitor.

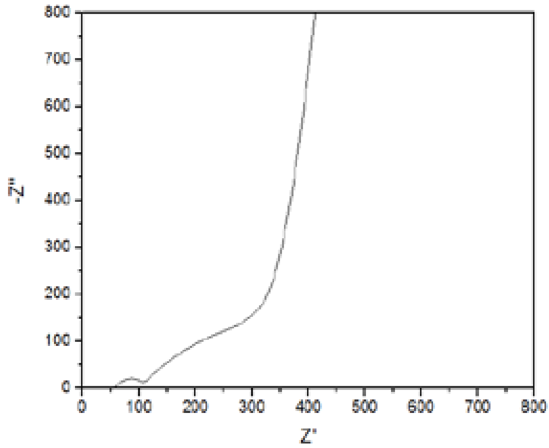

Fig. 1 Nyquist plot of the super capacitor in the configuration, PPy / NR based electrolyte / PPy

In general, an impedance plot of a super capacitor should consist with two spikes having different inclinations at low frequency range [9]. Among them, the one at the lowest frequency region should preferably be vertical highlighting the capacitive properties. According to the resulting Nyquist plot, both those spikes are visible. The lowest frequency region does not have a perfect vertical line due to non-uniformity of the electrode pore size as well as electrode surface roughness.

Fig. 2 shows the bode plot drawn between the real capacitance and the frequency using the impedance data taken for the super capacitor at room temperature.

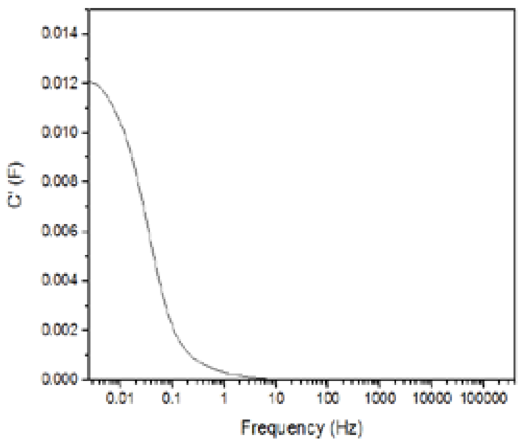

Fig. 2 Variation of real capacitance with the frequency for the super capacitor in the configuration, PPy / NR based electrolyte / PPy

The peak of the curve is related to the capacitance of the super capacitor [7]. This value was divided by the mass of a single electrode to calculate the single electrode specific capacitance. The resulted value is 20.13 F g^{-1}. Though the resulting value is somewhat lower, it is a significant value attracting consideration on the possibility of using NR for such applications. As per our literature survey, no any other group has engaged in searching avenues to employ NR in the field of power and energy and also Sri Lankan NR has not been used by any international research group in this line. In addition, almost all groups have paid their attention to apply NR based electrolytes only for batteries.

Conclusion

A Sri Lankan NR based electrolyte with $NH_4(CF_3SO_3)$ was successfully prepared having a conductivity of 3.8 x 10^{-4} S cm^{-1} at room temperature. The resulting film was mechanically stable and thin. A super capacitor was fabricated using two polypyrrole electrodes and it showed a single electrode specific capacitance of 20.13 F g^{-1}. Further studies are in progress to enhance the performance of the electrolyte as well as the super capacitor.

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