ORIGINAL PAPER

Preparation and characterisation of chitosan extracted from shrimp shell (*Penaeus monodon)* and chitosan-based blended solid polymer electrolyte for lithium-ion batteries

M. Leo Edward[1] · K. C. Dharanibalaji[2] · K. Thileep Kumar[3] ·
A. Raghu Subash Chandrabose[3] · A. M. Shanmugharaj[3] · V. Jaisankar[1]

Abstract

A bioactive and non-toxic biopolymer-based electrolyte has gained attention in recent research for their potential applications in the fabrication of electrochemical devices. In this work, we extracted the chitosan successfully prepared from shrimp shells using Brine's method. The solid polymer electrolyte comprising the blend of chitosan and agar–agar, plasticised with polyethylene glycol (PEG), as host polymer and lithium perchlorate (LiClO$_4$) as a dopant is prepared by solution casting technique. Also, the effect of different weight percentage of the plasticiser PEG at a fixed ratio of perchlorate content is investigated. The obtained chitosan blended film is highly suitable as a electrolyte for electrochemical devices. The prepared polymer electrolyte is characterised using attenuated total reflection–Fourier transform infrared spectroscopy (ATR–FTIR), high-resolution scanning electron microscopy (HR–SEM), X-ray diffraction (XRD) and electrochemical impedance spectroscopy. The ATR–FTIR spectroscopy confirms the presence of particular functional groups present in chitosan and complex formation between blended polymers and lithium perchlorate. The surface morphology and amorphous crystallinity of chitosan and blended polymer electrolytes revealed from HR–SEM and XRD analysis. The ionic conductivity of the prepared materials is studied using AC impedance spectroscopy and compared. The highest ionic conductivity at room temperature obtained for the sample is 4.56×10^{-4} Scm^{-1} (CAP$_3$). The mechanical properties of films have been studied using a Universal testing machine analysis. Wagner's polarisation measurements have estimated the Li$^+$ transport numbers of SPEs. Linear sweep voltammetry was performed on half-cell method to study the electrochemical stability window of the maximum ionic conductivity of SPEs.

Keywords Solid polymer electrolytes (SPEs) · Electrochemical devices · Solution casting · Ionic conductivity · Plasticiser

✉ V. Jaisankar
   vjaisankar@gmail.com

Extended author information available on the last page of the article

🖄 Springer

Introduction

Chitosan is a linear polysaccharide of natural polymer essentially composed by β-(1,4)-linked glucosamine units (2-amino-2-deoxy-β-d-glucopyranose) together with some proportion of *N*-acetylglucosamine units (2-acetamino-2-deoxy-β-d-glucopyranose). It is present in green algae cell walls of fungi such as aspergillus, mucor, the cuticles of insects and arachnids and the exoskeleton of crustaceans cosmetics. Chitosan has an excellent candidate for the medicine [1], pharmacy [2], agriculture [3], food industry, wastewater treatment [4] and many other industrial applications because it can be prepared in films, fibres and micro. Chitosan is a weak base and is insoluble in organic solvent and water, but it is soluble in dilute acidic solutions of many organic and inorganic acids (pH < 6.5) due to the protonation of its amino ($R–NH_3^+$) groups.

Recently chitosan-based blend solid polymer electrolytes (BSPEs), which comprise a polymer matrix and lithium salt, are used in the modern electrochemical devices because of their flexibility, electrochemical stability, dimensional stability, safety and long life span. The most challenging and critical issue for SPEs is to improve its ionic conductivity to approach the level of liquid electrolytes. Methods such as polymer blending [5], plasticisation [6], copolymerisation [7] and the addition of nanofillers [8] into polymer materials have been used to improve the ionic conductivity of solid polymer electrolyte systems. For the past decades, gel polymers electrolyte is studied with (GPEs) with non-biodegradable polymers, such as poly(methyl methacrylate) (PMMA), poly(vinylidene fluoride) (PVdF) and, most recently, poly(vinylidene fluoride-co-hexafluoropropylene) (PVdF-HFP) [9]. Since they are not eco-friendly, which results in the generation of environmental waste, hence the researchers have focused their attention on eco-friendly biodegradable solid-state polymer electrolyte materials, for electrochemical devices.

These reported materials have several advantages, such as abundancy, environment-friendly, non-toxic, biodegradable, biocompatible, and they possess excellent film-forming properties. Among the biopolymers, chitosan, corn starch and carrageenan, agar–agar, chitosan and methylcellulose-based polymer electrolytes have been reported the highest ionic conductivity at room temperature [10–14]. Polymer blends have gained commercial importance over homopolymers and copolymers due to low-cost, simplicity of preparation and easy control of the physical properties by compositional change. Thus polymer blends are the most promising and feasible approach to improve the ionic conductivity of polymer electrolyte [14]. According to the literature, only a few numbers of investigations were carried out by employing chitosan-based blended polymer electrolyte. Salman and Omed [15] have reported a conductivity value of 3.74×10^{-6} Scm^{-1} for chitosan-methylcellulose-LiBF$_4$ polymer electrolyte Sudhakar and Sivakumar [16]. The maximum conductivity is found to be 3.7×10^{-4} Scm^{-1} at room temperature for chitosan/starch with LiClO4, Sunil et al. [17]. The highest ionic conductivity of 3×10^{-6} Scm^{-1} at room temperature is observed for chitosan-poly (vinyl alcohol) with LiClO$_4$ (Scheme 1).

Considering eco-friendly and pollution-free materials, the prospective use of biodegradable polymer is a lithium-ion conducting matrix that has been
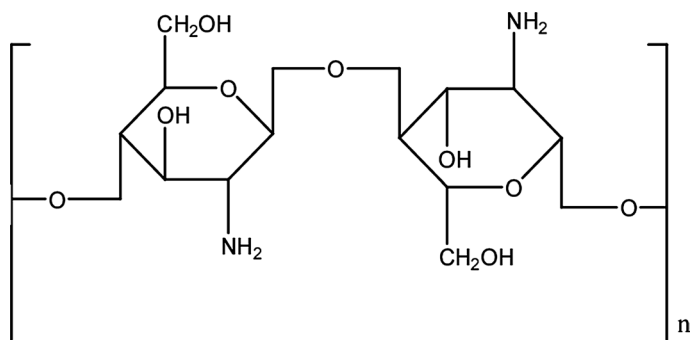
Scheme 1 Chemical structure of chitosan

investigated in this study. To the best of our knowledge, no work has been done chitosan, agar–agar plasticised with PEG blend polymer doped with $LiClO_4$ in biopolymer electrolytes for electrochemical device application. This study presents the result of such investigations on the mechanical, thermal and electrical properties of prepared biopolymer electrolytes. Thus, keeping the chitosan and agar–agar as the same weight percentage and plasticiser are the different varied composition of polyethylene glycol (PEG) solid polymer electrolyte that was prepared. The prepared blend solid-state electrolytes were characterised by a different technique such as X-ray diffraction analysis (XRD), Fourier transform infrared spectroscopy (FTIR), AC impedance analysis, scanning electron microscopy (HRSEM) with EDX, mechanical properties (UTM), transference number measurement (TNM), electrochemical stability analysis.

Experimental

Materials and methods

Agar–agar (SQ. 98% purity), PEG (SRL MW = 600) average molecular weight 600, lithium perchlorate were purchased from Sigma-Aldrich. NaOH, HCl of industrial grade bought from the local market.

Extraction of chitosan from (*Penaeus monodon shell*)

Chitosan is easily obtained from sea sources such as lobsters, crabs and shrimp, and many other organisms, including insects and fungi, especially Dungeness crab (Cancer magister), back tiger shrimp (*Penaeus monodon*), lobster or crawfish shells. These are the most abundant source of chitin and the significant sources of crustaceans that are processed into chitin and chitosan. It is one of the most abundant biodegradable materials in the world. The used raw black tiger shrimp shell (*P. monodon shell*) for the extraction of chitosan was collected from the coastal area in the Bay of Bengal Sea, Chennai Province (India). The samples were first washed with

tap water and distilled water and then dried at 80 °C for 24 h. Finally, this dried bio-mass was ground into small pieces (Scheme 2).
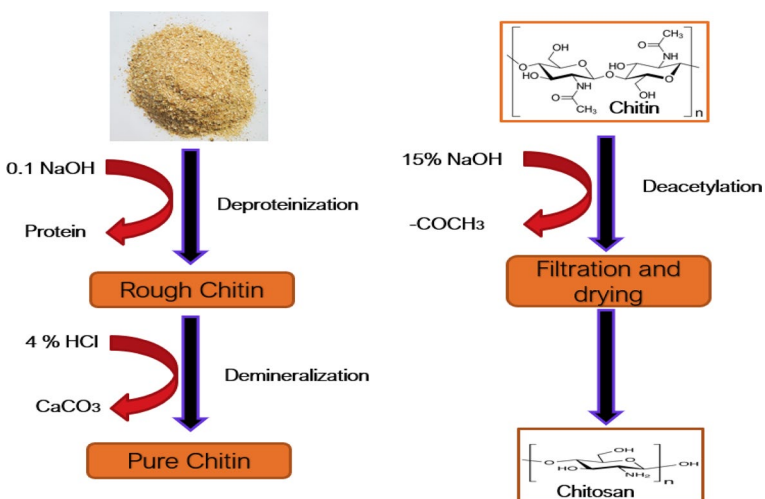
Preparation of solid polymer electrolyte (SPEs)

The SPEs films were prepared by solution casting technique. The blend polymer is made by mixing chitosan, agar–agar and different weight percentages of (x wt%) plasticiser (PEG) with $LiClO_4$ salt. The amount of $LiClO_4$ is added as a constant 10 weight percentage. Chitosan was dissolved in 1 M acetic acid by stirring at room temperature for 1 h to obtain a transparent solution. Then agar–agar was dissolved in 50 mL double de-ionised hot water and heated at 50 °C–70 °C for 20 min with stirring; both solutions mixed continuously stirring by using a magnetic stirrer for 2 h to obtain a homogeneous solution. Then the corresponding amount PEG and $LiClO_4$ dissolved in the above solution, the solution stirring at 7 h. The clear homogeneous solution was cast in a transparent Teflon Petri dish and then evaporated at 70 °C for 8 h in the hot oven; free-standing films were obtained (Scheme 3).

Results and discussion

Fourier transform infrared spectroscopy (FTIR)

The characteristic FTIR absorption spectrum of the prepared chitosan and chitosan-based blended solid polymer electrolytes and films were recorded with Bruker ATR–FTIR spectrometer spectrum. Figure 1 represents the combined spectra for the prepared chitosan and chitosan-based blended SPEs systems.

Scheme 2 Schematic representation of the processes to prepare chitosan from shrimp shell
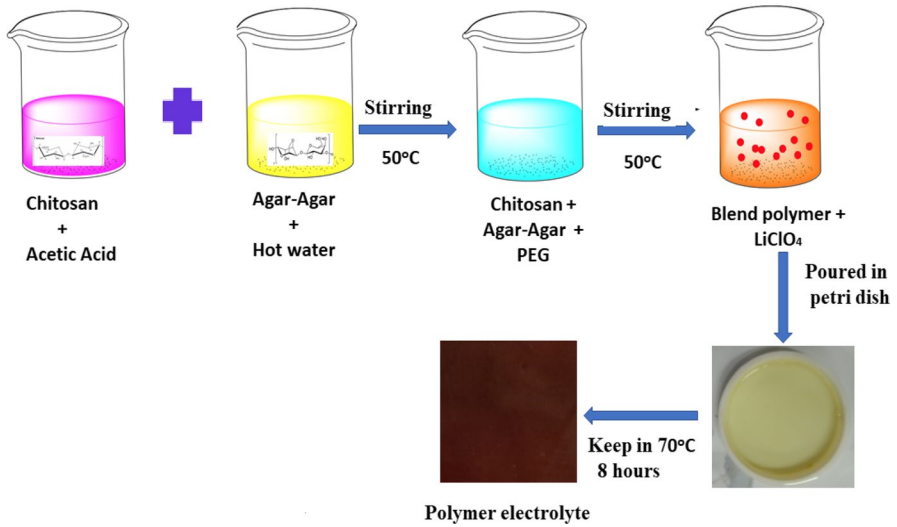
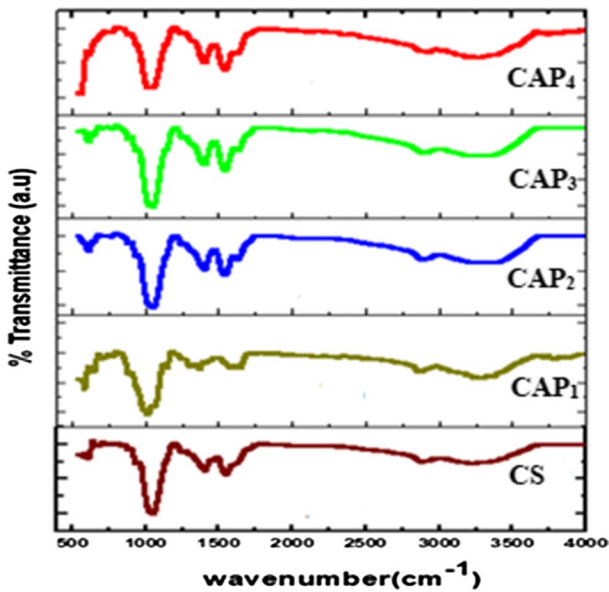**Scheme 3** Schematic representation of the preparation of polymer electrolytes

Fig. 1 FTIR spectra of prepared chitosan: **a** CS and **b** CAP$_1$, **c** CAP$_2$, **d** CAP$_3$, **e** CAP$_4$ polymer blended electrolytes

The structure of chitosan, extracted from shrimp shell, was analysed using FTIR spectroscopy. Chitosan has significant peaks according to the functional groups contained in its structure shown in Table 1 and Fig. 1a, which showed a stretching vibration band in chitosan in the range of 3450–3200 cm^{-1}

Table 1 Composition of solid polymer blend electrolyte films

Sample code	Chitosan solution		Agar–agar solution		Plasticiser	LiClO$_4$	
	Powder (g)	Solvent (ml)	Powder (g)	Solvent (ml)	%	Weight %	Weight (g)
CS	0.90	100	–	–	–	10	0.1
CAP$_1$	0.425	80	0.425	50	5	10	0.1
CAP$_2$	0.4	75	0.4	50	10	10	0.1
CAP$_3$	0.375	75	0.375	50	15	10	0.1
CAP$_4$	0.35	75	0.35	50	20	10	0.1

corresponding to NH (primary and secondary) and hydroxyl (OH). The NHCO- in pyranose ring was observed in the range of 2880–2960 cm^{-1}. The peak at 1024 cm^{-1} showed C–O stretching of polysaccharide bond (Table 2).

The ATR–FTIR studies were conducted on the blend solid polymer electrolytes film samples. The spectral details suggested that conjugated peptide bond formed by amide NH and CO groups shown in all figures, 1639, 1583, 1552, 1632, 1546, 1633, 1546, 1630, 1548 cm^{-1}, and also obtained that the peaks at 1631, 1632, 1633, 1630 are attributed to perchlorate salt [20]. The absorption band at about 3400 cm^{-1} is associated with O–H stretching [21].

The characteristic peak of prepared chitosan observed at 3295 cm^{-1} is due to O–H group stretching. When there is addition of LiClO$_4$, PEG and AA in chitosan the O–H peak has been shifted to a lower-frequency respective. This shows the formation of hydrogen bond in the blend polymer. The absorption peak at 2871, 2884, 2886, 2914, 2928 cm^{-1} resembles CH$_2$ stretching of chitosan with blend polymer electrolytes. The peak at 1410, 1408, 1408, 1407 cm^{-1} assigned to CH$_2$ bending of both samples [22]. A sharp strong peak due to C–O–C asymmetric stretching vibrations of an ester group of pure CS is observed at 1020 cm^{-1}. This frequency is shifted to 1056, 1057, 1053, 1024 cm^{-1} in the LiClO$_4$-blended polymer electrolytes complex [23]. From these ATR–FTIR results, it can be concluded that complexation has taken place between LiClO$_4$ salt and the polymer blend.

Table 2 FTIR spectral data of prepared chitosan

Absorption frequency (cm^{-1})	Assignment	References
3295	O–H overlapped on N–H	
2871	–CO stretching of the amide group	
1639, 1583	–CO stretching of the proton amide group	
1418	O–H stretching of the CH$_2$OH group	[17–19]
1372	–CH stretching of the CH$_3$CONH group	
1148	–C–O–C stretching of the glycosidic linkage	
1020	–C–O vibration of the polysaccharide bond	

HR-SEM study

The observed structural and morphology of prepared chitosan and chitosan-based blend solid polymer electrolytes have been investigated using a high-resolution scanning electron microscopy (HRSEM). The surface morphology of the chitosan can be noted in Fig. 2 CS; it was taken with different magnifications, and different areas can exhibit almost smooth surface and layers of flakes [24–26]. Comparison of the surface morphology of solid polymer electrolytes CAP_1, CAP_2, CAP_3, CAP_4 is shown in Fig. 2, and its composition is shown in Table 1. CAP_1 and CAP_2 reveal the perspective of some structures that have suspended out of the film surface, and the presence of uneven spherical-like structure may be due to the presence of plasticiser in the concentration of 5% and 10%, respectively, as shown in Fig. 2 [27]. Increasing the concentration of plasticiser CAP_3 15% and CAP_4 20% blend solid polymer electrolyte film exhibited almost homogeneous and smooth structural surface that pronounced that the salt and polymer blend is miscible with each other to show a
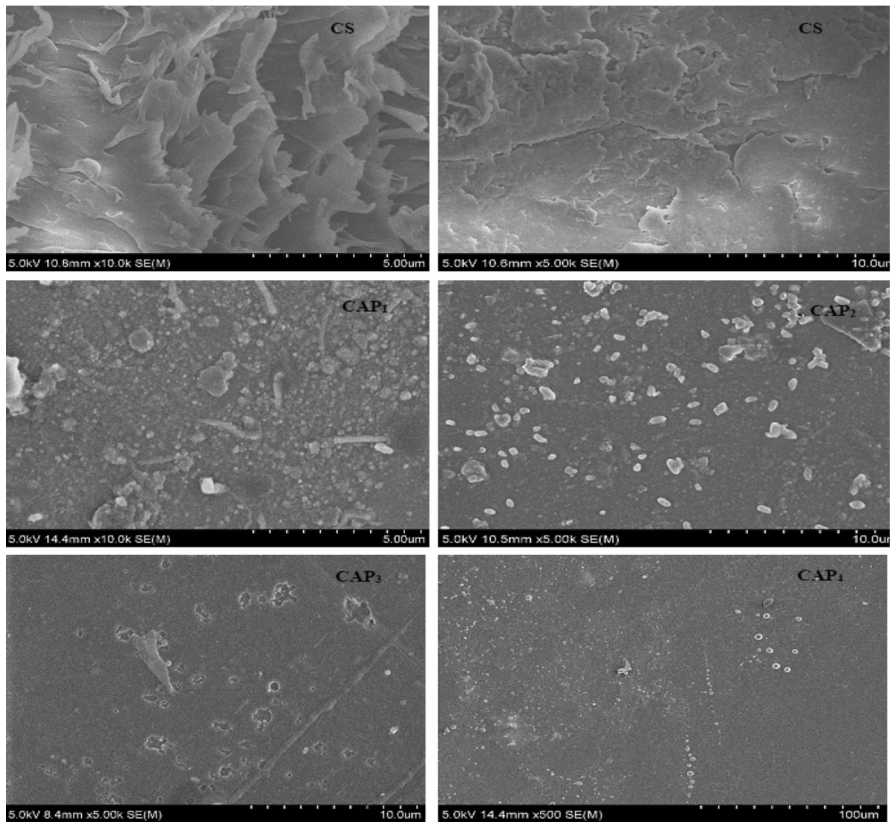

Fig. 2 Surface morphology characterisation of prepared chitosan and polymer electrolyte. Top view HRSEM image of the CS, CAP_1, CAP_2, CAP_3, CAP_4 polymer blended electrolytes

uniform distribution of Li ions without any aggregation of $LiClO_4$ particles can be observed in Fig. 2 [28, 29].

Energy-dispersive X-ray spectroscopy

The EDS spectrum scrutinised the composition of prepared chitosan and chitosan-based blend solid polymer electrolyte, and the result is represented in Fig. 3, and the percentage composition is tabulated in Tables 3, 4).

Figure 3 shows energy-dispersive X-ray spectra (EDS) of extracted chitosan and polymer electrolyte for CS and CAP_3, which confirm the elemental composition. The EDS analysis confirms the presence of C, N, O for chitosan and C, N, O, Cl in the solid polymer electrolyte sample with no other impurity element.

X-ray diffraction analysis

This technique has investigated the crystalline or amorphous nature of the prepared materials. The X-ray diffraction measurements obtained for the prepared chitosan and chitosan-based blended polymer electrolyte studied in the 2θ ranging from $10°$ to $80°$ are shown in Fig. 4. It clearly says information about the nature of chitosan and intercalation of polymer salt complex with plasticiser. The diffraction pattern of extracted chitosan has 2 crystalline major peaks of strong reflections at $2\theta = 10.01°$ and $20.03°$ [30] and confirms that the crystallinity of prepared chitosan is shown in Fig. 4 CS. On the addition of agar–agar in the chitosan matrix plasticised with polyethylene glycol (PEG) reduces the crystallinity of the chitosan. The interaction of hydrogen bond between chitosan, agar–agar and plasticiser with salt which partially destroying the original crystal structure of chitosan is suggested. No crystalline peaks in the blend polymer electrolytes are suggested [31] (Fig. 5).

Figure 4 CAP1, CAP_2, CAP_3 and CAP_4 show the respective XRD diffractograms of blended solid polymer electrolyte systems which reveals that the effect of increasing plasticiser concentration brings a significant change in SPEs films. By the addition of PEG in the blend polymer, the XRD peak shifted at a higher angle (CAP_1, CAP_2, CAP_3) up to 15% plasticiser concentration and above 15% the XRD peak shifts at a less high angle (CAP_4) compared to CAP_1, CAP_2, CAP_3 [27]. The XRD patterns value is of CAP_1 (11.06, 21.05), CAP_2 (11.29, 21.67,
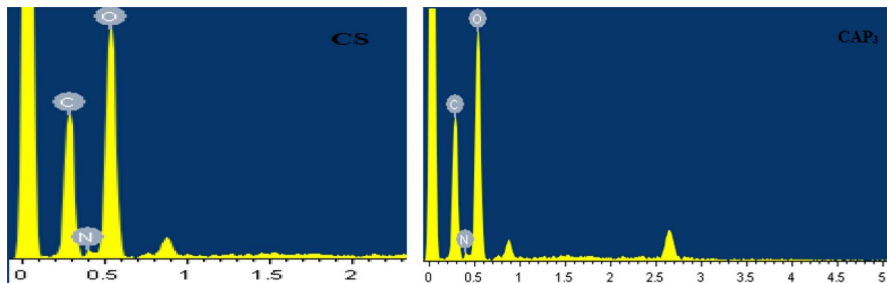

Fig. 3 EDS spectrum of CS and CAP_3

Table 3 FTIR spectral data of blend polymer electrolyte

Wave number (cm^{-1})				Assignment	References
CAP$_1$	CAP$_2$	CAP$_3$	CAP$_4$		
3247	3371	3243	3265	O–H overlapped on N–H	[5, 13–16]
2884	2886	2914	2928	–CH$_2$ stretching	
1631, 1552	1632, 1546	1633, 1546	1630, 1548	–CO vibration of the amide(I,II)	
1410	1408	1408	1407	–CH$_2$ bending	
1253	1256	1257	1250	NHCO vibrations of the amide(II)	
1056	1057	1053	1024	–CO vibration of the bindings C–OH, C–O–C,CH$_2$CO	
940	939	936	–	Vibration of 3,6-anhydro-galactose bridge	
892	891	890	887	Vibration of the pyranose ring	
847,740	775,655	776,654	–	Vibration of NH, NH$_2$	
614	616	615	620	Frequency of δ (OH) out of plane	

Table 4 Percentage composition of CS and CAP$_3$

Sample	Element	Weight %	Atomic %
CS	C	35.88	42.54
	N	3.13	3.19
	O	60.93	54.28
CAP$_3$	C	32.59	38.88
	N	5.93	6.06
	O	61.48	55.06
	Cl	7.82	2.81

Fig. 4 XRD patterns of polymer and polymer blend electrolyte CS, CAP$_1$, CAP$_2$, CAP$_3$, CAP$_4$
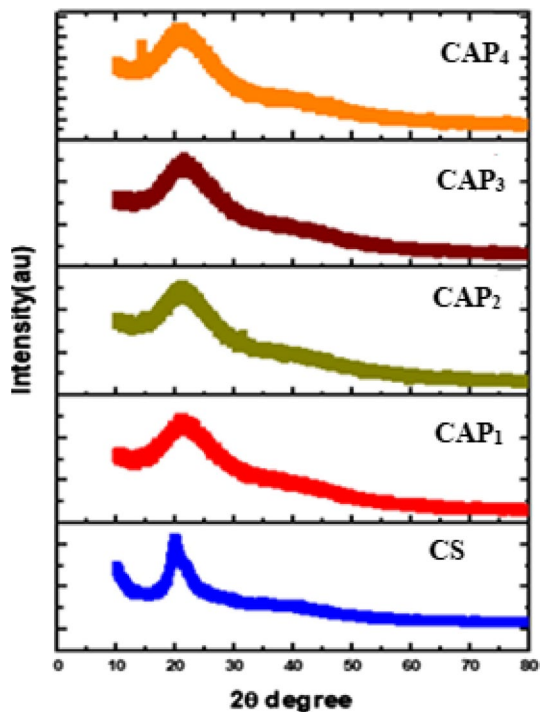
36.04), CAP$_3$ (11.53, 21.86, 36.13), CAP$_4$ (10.56, 20.01, 35.45). This may be due to the formation of intermolecular hydrogen bonding interaction between the blended polymers with the LiClO4 [32], blend chains through ion polymer interactions with lithium cations and functional groups in blend polymers, as lithium salt exhibits a cryptic nature, but CAP$_4$ has some sharp peaks that have arrived. It can be concluded that there is a some crystalline phase formed.

Fig. 5 XRD patterns of polymer and polymer blend electrolyte CS, CAP$_1$, CAP$_2$, CAP$_3$, CAP$_4$ magnified between 10° and 30°
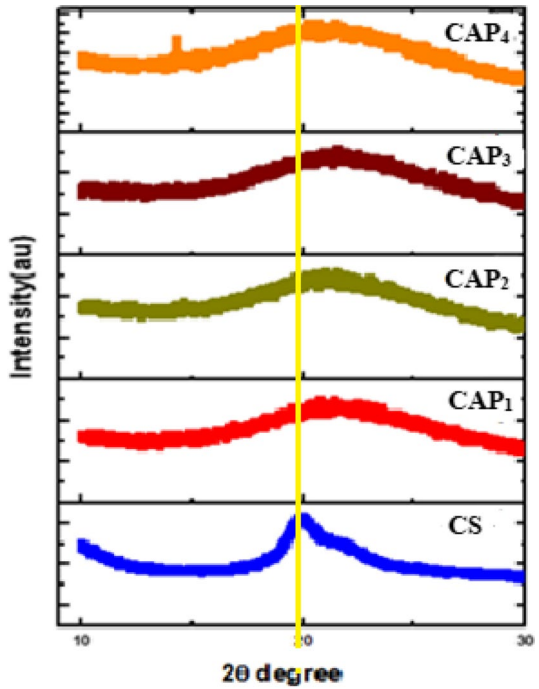
Universal testing machine analysis

The mechanical properties of chitosan and blend polymer electrolytes, including tensile strength (TS), elongation (%E) and toughness, are described in using a Hounsfield H50KS, QMAT software testing machine. Specimens had a width of 25 and ~0.2000 mm thickness. The gauge length is 70 mm. The effect of plasticiser concentration changes in mechanical properties for prepared samples using solution casting method.

In this work we concluded 2 things: first we measured plasticiser-free prepared chitosan, its elongation and tensile strength, and toughness shown in Table 5. Second the amount of polyethylene glycol added in blend polymer showed a

Table 5 Tensile stress and elongation at break of chitosan and blended polymer electrolyte

Sample code	Polymer ratio	Plasticiser (PEG) (%)	Electrolyte (%)	Tensile stress (MPa)	Elongation %	Toughness (J m^{-3})
CS	90 wt%(CS)	–	10	14.00	35	674.75
CAP$_1$	85 wt%(CS + AA)	5	10	19.00	6.16	204.69
CAP$_2$	80 wt%(CS + AA)	10	10	13.30	7.58	146.99
CAP$_3$	75 wt%(CS + AA)	15	10	8.80	9.90	295.54
CAP$_4$	70 wt%(CS + AA)	20	10	7.0	8.98	62.90

conventional action of plasticisers, increasing elongation break and decreasing the tensile stress, due to a decrease in intermolecular attraction, increasing polymer mobility and reducing the intermolecular Vander Waals force of the blend polymers [33–35]. However, CAP_3 (15% of PEG and 75% blend polymer 10% salts) has a significant value of elongation, tensile strength and toughness than CAP_1, CAP_2, CAP_4. This may be due to the stronger interaction between polyethylene glycol and blended polymer electrolytes (Fig. 6).

Transport number measurement by Wagner's polarisation method

In order to support the ionic conductivity data, the transference number measurements have been taken as a complimentary test for all blend polymer electrolyte samples. Transference number is one of the fundamental methods for ionic and electronic contributions of prepared polymer electrolyte system. The transference number is calculated by using the equation.

$$T_{\text{ions}} = \frac{(I_f - I_i)}{I_i} \tag{1}$$

$$t_c = \frac{I_f}{I_i} \tag{2}$$

where I_i Initial is the total current of the ions and electron, I_f Finial residual of the electron [36] and electrons (t_e) is calculated using Eq. 2 [37]. In the sample, a DC potential of 5 V at ambient temperature was used, containing the cell of polymer
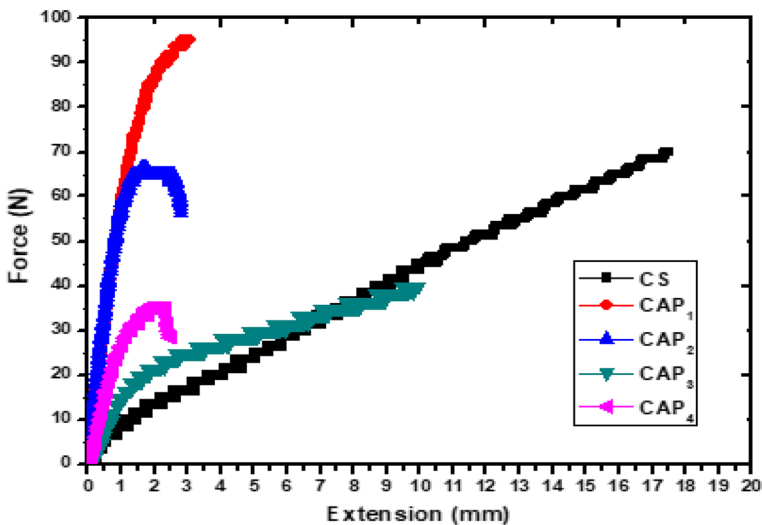

Fig. 6 UTM studies for prepared chitosan CS, CAP_1, CAP_2, CAP_3 and CAP_4 polymer blended electrolyte

electrolyte membrane sandwiched between 2 blocks of stainless steel as electrodes are used in the measurement at electrochemical impedance spectroscopy (EIS) at room temperature. As well as DC voltage is passed through the sample, it is observed that the initial current rapidly falls with time due to migration of ions [38]. The polarisation method has been carried out by high ionic conductivity of blend polymer electrolyte system (CAP_3). Transference number of the polymer electrolyte value measured is 0.94 (Fig. 7).

Electrochemical analysis

The electrochemical stability of the highest conductivity CAP_3 blend solid polymer electrolyte was analysed using the linear sweep voltammetry with two blocking electrolyte system and a potential range of 5 V at a scanning rate of 1 mV/s. The curvature of the plot is in response to the current vs voltage [39]. Electrochemical stability of the polymer electrolyte membrane is stable up to 3.1 V in the literature review based on iota-carrageenan [38] in our work; CAP_3solid polymer electrolyte film stable up to 3.3 V is observed and beyond that electrolyte was decomposed. Figure 6 shows the linear sweep voltammogram curve of the CAP_3 system (Fig. 8).

AC impedance analysis

The electrochemical impedance spectroscopy (ESI) analysis is the most powerful technique for characterising the electrical properties of the prepared CS and blend solid polymer electrolyte samples. In polymer electrolyte system, impedance spectra have been obtained at room temperature. Nyquist plot for CS, CAP_1, CAP_2, CAP_3, and CAP_4 was fitted with an equivalent circuit (line) to estimate the bulk resistance
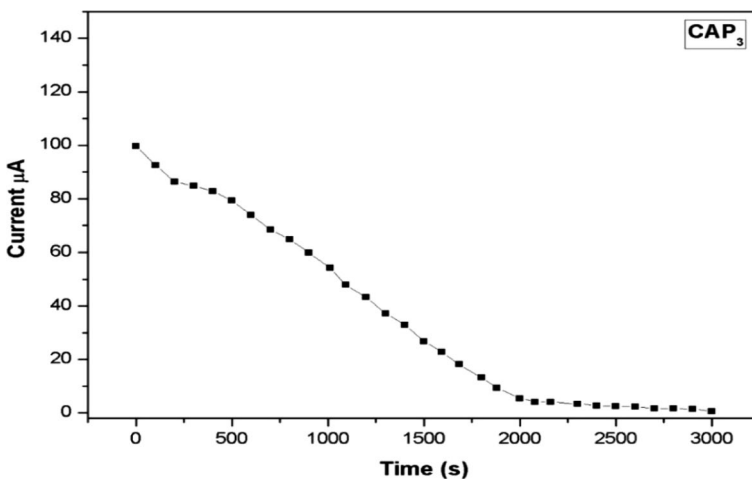

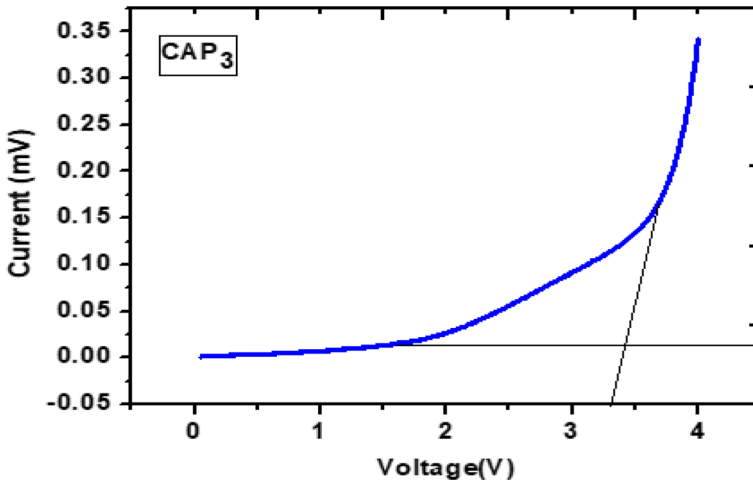**Fig. 7** Wagner's method polarising current for polymer electrolyte CAP_3

Fig. 8 Linear sweep voltammogram of the highest conducting salted and plasticised membrane

of the polymer electrolyte. The ionic conductivity of the blend polymer electrolyte films was calculated using the formula given below

$$\sigma = L/RbA$$

where σ ionic conductivity, L = thickness, A = contact area, Rb = bulk resistance. The decrease of R_b value leads to the enhanced ionic conductivity after the introduction of plasticiser in blend polymer electrolyte because of the reduction of crystalline nature of chitosan matrix, as shown in the XRD studies [40]. Ionic conductivity plays one of the significant roles for the availability of the mobility of lithium ions in the polymer blend matrix during the electrochemical device.

Table 6 shows that the ionic conductivity of the CS and blend solid polymer electrolyte, CAP$_3$ has maximum ionic conductivity value than the CS, CAP$_1$, CAP$_2$, and CAP$_4$. The ionic conductivity of CAP$_3$ is influenced by plasticising of CS and AA blend polymer using PEG. The ionic conductivity increases with increases in plasticiser composition of blended solid polymer electrolytes due to reduced crystallinity of Chitosan (Fig. 9).

Table 6 Ionic conductivity of blend polymer electrolytes at room temperature

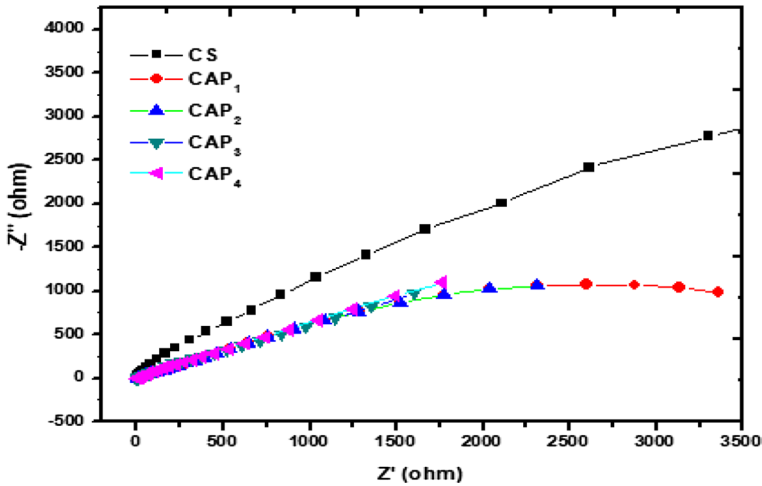| Sample code	Polymer with perchlorate ratio	Plasticiser (%)	Ionic conductivity Scm^{-1}
CS	CS 90% + 10%LiClO$_4$	–	5.91×10^{-5}
CAP$_1$	CS-AA 85% + 10%LiClO$_4$	PEG-5	1.8×10^{-4}
CAP$_2$	CS-AA 80% + 10%LiClO$_4$	PEG-10	2.8×10^{-4}
CAP$_3$	CS-AA 75% + 10%LiClO$_4$	PEG-15	4.56×10^{-4}
CAP$_4$	CS-AA 70% + 10%LiClO$_4$	PEG-20	2.01×10^{-4}

Fig. 9 Ionic conductivity of blend solid polymer electrolytes

Conclusions

In this investigation, bioactive polymer chitosan was prepared from shrimp shells which is fairly soluble in acetic acid with adequate physical–chemical properties. Chitosan-based blend solid polymer electrolyte plasticised with various weight percentages of polyethylene glycol (PEG) and the $LiClO_4$ was successfully prepared by a solution casting method. FTIR studies revealed the complexation between polymer blend and lithium salt. X-ray diffraction results showed that the prepared composite having composition CAP_3 was highly amorphous in nature. The surface morphology of the prepared chitosan and chitosan-based blend solid polymer electrolyte was studied using high-resolution scanning electron microscopy. Further, mechanical studies showed that the prepared blend polymer electrolyte, CAP_3, has comparatively high elongation behaviour.

The ionic conductivity results revealed that the addition of plasticiser composition plays vital role in conductivity values. The enhancement in ionic conductivity value can be attributed to the increase in chain flexibility in CS–AA–LiClO4 electrolyte with the presence of polyethylene glycol. The maximum ionic conductivity of CAP_3 (4.6×10^{-4} Scm^{-1}) is measured for the blend polymer electrolyte with composition of 75% (CS, AA), 15% PEG, 10% $LiClO_4$ at room temperature. Also, the transference number of ions for the polymer electrolytes measured using Wagner's polarisation method showed that the CAP_3 polymer electrolyte exhibits the highest ionic transference number of 0.94. The electrochemical stability window of the highest conducting sample measured by linear sweep voltammetry and film was stable up to 3.3 V, and then, the electrolyte was decomposed on further applying voltage. All these results implied that the prepared solid polymer electrolyte can be effectively used as a promising material for the fabrication of solid-state lithium-ion batteries.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Bouhenna M, Salah R, Bakour R, Drouiche N, Abdi N, Grib H, Lounici H, Mameri, (2015) Effect of chitin and its derivatives on human cancer cells lines. Environ SciPollut Res 22:15579–15586. https ://doi.org/10.1007/s11356-015-4712-3

2. Ahmed TA, Aljaeid BM (2016) Preparation, characterisation, and potential application of chitosan, chitosan derivatives, and chitosan metal nanoparticles in pharmaceutical drug delivery. Drug Des Dev Ther 10:483–507. https://doi.org/10.2147/DDDT.S99651

3. Agronomy SRG (2013) A review of the applications of chitin and its derivatives in agriculture to modify plant-microbial. Interact Improv Crop Yields 3:757–793. https://doi.org/10.3390/agron omy3040757

4. No LHK, Meyers SP (2000) Application of chitosan for treatment of wastewaters. Environ Contam-Toxicol 1:1–27. https://doi.org/10.1007/978-1-4757-6429-11

5. Abreha Merhawi, Purushotham Gebreyesus (2016) Preparation and characterisation of lithium ion conducting polymer electrolytes based on a blend of poly(vinylidene fluoride-co-hexafluoropropyl-ene) and poly(methyl methacrylate). Heliyon 2:7. https://doi.org/10.1016/j.heliyon.2016.e00134

6. PradeepaPrabakaran RP, Gurusamy MS, EdwinrajSebasthiyan, (2017) Plasticized polymer electrolyte membranes based on PEO/PVdF-HFP for use as an effective electrolyte in lithium-ion batteries. Chin J PolymSci 35(3):407–421. https://doi.org/10.1007/s10118-017-1906-9

7. Wei Z, Chen S, Wang J, Wang Z, Zhang Z (2018) Superior lithium ion conduction of polymer electrolyte with comb-like structure via solvent-free copolymerisation for bipolar all-solid-state lithium battery. J Mater Chem 6:13438–13447. https://doi.org/10.1039/C8TA04477E

8. Wang Z, Gu Hui, Wei Zhenyao (2018) Preparation of new composite polymer electrolyte for long cycling all-solid-state lithium battery. Ionics 25:907–916. https://doi.org/10.1007/s11581-019-02852-6

9. Wang Furi, Li Libo, Yang Xueying, You Jun (2018) Influence of additives in a PVDF-based solid polymer electrolyte on conductivity and Li-ion battery performance. Sust Energy Fuels. https://doi.org/10.1039/C7SE00441A

10. Selvalakshmi S, Vijaya N, Selvasekarapandian S, Premalatha M (2017) Biopolymer agar-agar doped with NH4SCN as solid polymer electrolyte for electrochemical cell application. J ApplPolymSci 1–10:44702. https://doi.org/10.1002/app.44702

11. Ramesh S, Shanti R, Morris E (2012) Plasticising effect of 1-allyl-3-methlyimidazolium chloride in cellulose acetate based polymer electrolytes. CarbohydPolym 87:2624–2629. https://doi.org/10.1016/j.carbpol.2011.11.037

12. Yusof YM, Kadir MFZ (2016) Electrochemical characterisations and the effect of glycerol in biopolymer electrolytes based on methylcellulose-potato starch blend. MolCrystLiqCryst 627(1):220–233. https://doi.org/10.1080/15421406.2015.1137115

13. Liew CW, Ramesh S (2015) Electrical, structural, thermal and electrochemical properties of corn starch-based biopolymer electrolytes. CarbohydrPolym 124:222–228. https://doi.org/10.1016/j.carbpol.2015.02.024

14. Aziz SB, Hamsan MH, Abdullah RM (2019) A promising polymer blend electrolytes based on chitosan: methyl cellulose for EDLC application with high specific capacitance and energy density. MDPI Mol 24:2503. https://doi.org/10.3390/molecules24132503

15. Salman YAK, Abdullah O (2018) Conductivity and electrical properties of chitosan: methylcellulose blend biopolymer electrolyte incorporated with lithium tetrafluoroborate. Int J ElectrochemSci 13:3185–3199. https://doi.org/10.20964/2018.04.25

16. Sudhakar YN, Selvakumar M, Krishna Bhat D (2013) LiClO4-doped plasticised chitosan and poly(ethylene glycol) blend as biodegradable polymer electrolyte for supercapacitors. Ionics 19:277–285. https://doi.org/10.1007/s11581-012-0745-5

17 Rathod SG, Bhajantri RF, Ravindrachary V, Poojary B, Pujari PK (2016) Influence of transport parameters on conductivity of lithium perchlorate-doped poly(vinyl alcohol)/chitosan composites. J ElastomPlast. https://doi.org/10.1177/0095244315580457

18. Negrea P, Caunii A, Sarac I, Butnariu M (2015) The study of infrared spectrum of chitin and chitosan extract as potential sources of biomass. Dig J NanomaterBiostruct 4:1129–1138

19. Dilyana, Zvezdova (2010) Investigation of some physicochemical properties of chitin from crab shells НАУЧНИ ТРУДОВЕ НА РУСЕНСКИЯ УНИВЕРСИТЕТ , том 49, серия 9

20. Sim LH, Gan SN, Chan CH, Yahya R (2010) ATR-FTIR studies on ion interaction of lithium perchlorate in polyacrylate/poly(ethylene oxide) blends. SpectrochimActa 76:287–292. https://doi.org/10.1016/j.saa.2009.09.031

21. Rumengan IFM, Suryanto E, Modaso R, Wullur S, Tallei TE, Limbong D (2014) Structural characteristics of chitin and chitosan isolated from the biomass of cultivated rotifer, Brachionusrotundiformis. Int J Fish AquatSci 3(1):12–18

22. Junga MR, David Horgena F, Orskib SV, Rodriguez V, C.b, Kathryn L. BeersbMarine, (2018) Validation of ATR FT–IR to identify polymers of plastic marine debris, including those ingested by marine organisms. Pollut Bull 127:704–716. https://doi.org/10.1016/j.marpolbul.2017.12.061

23. SamanehSaber-Samandari Mustafa Gazi Elvan Yilmaz (2012) UV-induced synthesis of chitosan-g-polyacrylamide semi-IPN superabsorbent hydrogels. Polym Bull 68:1623–1639. https://doi.org/10.1007/s00289-011-0643-4

24. Gutha Y, Pathak JL (2017) Antibacterial and wound healing properties of chitosan/poly(vinyl alcohol)/zinc oxide beads (CS/PVA/ZnO). Int J BiolMacromol. https://doi.org/10.1016/j.ijbiomac.2017.05.020

25. AygulKucukgulmez MC, YasemenYanar DS, HurriyetPolat EslemKadak (2011) Physicochemical characterisation of chitosan extracted from Metapenaeusstebbingi shells. Food Chem 126:1144–1148. https://doi.org/10.1016/j.foodchem.2010.11.148

26. Ibitoye EB, Lokman IH, Hezmee MN, Goh YM, Zuki Z, Jimoh AA (2018) Extraction and physicochemical characterization of chitin and chitosan isolated from house cricket. Biomed Mater 13(2):025009. https://doi.org/10.1088/1748-605X/aa9dde

27. Pradhan DK, Samantaray BK, Choudhary RNP, Karan NK, Thomas R, Katiyar RS (2007) Effect of plasticiser on structural and electric properties of polymer nanocomposite electrolytes. Int J ElectrochemSci 2:861–871. https://doi.org/10.1007/s11581-010-0491-5

28. Salman YA, Abdullah OG, Hanna RR, Aziz SB (2018) Conductivity and electrical properties of chitosan: methylcellulose blend biopolymer electrolyte incorporated with lithium tetrafluoroborate. Int J ElectrochemSci 13:3185–3199. https://doi.org/10.20964/2018.04.25

29. Rathod SG, Bhajantri RF, Ravindrachary V, BojaPoojary PK, Pujari TS, Naik J (2015) Influence of transport parameters on conductivity of lithium perchlorate-doped poly(vinyl alcohol)/chitosan composites. J Elastomers Plast. https://doi.org/10.1177/0095244315580457

30. Boudouaia N, Bengharez Z, Jellali S (2019) Preparation and characterisation of chitosan extracted from shrimp shells waste and chitosan film: application for Eriochrome black T removal from aqueous solutions. Appl Water Sci 9:91. https://doi.org/10.1007/s13201-019-0967-z

31. Ling-haoHea RX, Yanga D-B, Liua Y, Son R (2009) Effects of blending chitosan with peg on surface morphology, crystallisation and thermal properties. Chin J PolymSci 27(4):501–510

32. Bhoopathi G, Nithya N, Arun AP, Ranjith-Kumar E (2018) Effect of biopolymer blend matrix on structural, optical and biological properties of chitosan-agar blend Zno nanocomposites. J InorgOrganometPolym Mater 28:1528–1539. https://doi.org/10.1007/s10904-018-0848-1N

33. AgilAbrahama PA, Solomanb VO Rejinib (2016) Preparation of chitosan-polyvinyl alcohol blends and studies on thermal and mechanical properties. ProcTechnol 24:741–748. https://doi.org/10.1016/j.protcy.2016.05.206

34. Suyatma NE, TighzertCopinet LA (2005) Effects of hydrophilic plasticizers on mechanical, thermal, and surface properties of chitosan films. J Agric Food Chem 53:3950–3957. https://doi.org/10.1021/jf048790+

35. Ziani K, Oses J, Coma V, Maté JI (2008) Effect of the presence of glycerol and Tween 20 on the chemical and physical properties of films based on chitosan with different degree of deacetylation. Food SciTechnol 41:2159–2165. https://doi.org/10.1016/j.lwt.2007.11.023

36. Sampath-Kumar L, Christopher-Selvin P, Selvasekarapandian S, Manjuladevi R, Monisha S, Perumal P (2018) Tamarind seed polysaccharide biopolymer membrane for lithium-ion conducting battery. Ionics 24:3793–3803. https://doi.org/10.1007/s11581-018-2541-3

37. Chitra R, Sathya P, Selvasekarapandian S, Meyvel S (2019) Synthesis and characterisation of iota-carrageenan based biopolymer electrolyte with lithium perchlorate and succinonitrile (plasticiser). Polym Bull. https://doi.org/10.1007/s00289-019-02822-y

38. Lin Y, cheng Yun, Li Jie, Jan D (2017) Biocompatible and biodegradable solid polymer electrolytes for high voltage and high temperature lithium batteries. RSC Adv 7:24856. https://doi.org/10.1039/C7RA01601H

39. Zhang Jianjun, Yue Liping, Hu Pu, Liu Zhihong, Qin Bingsheng, Zhang Bo, Wang Qingfu (2014) Taichi-inspired rigid-flexible coupling cellulose-supported solid polymer electrolyte for high-performance lithium batteries. Sci Rep 4:6272. https://doi.org/10.1038/srep06272

40. Hirankumara G, Mehtab N (2018) Effect of incorporation of different plasticisers on structural and ion transport properties of PVA-LiClO4 based electrolytes. Heliyon 4(12):e00992. https://doi.org/10.1016/j.heliyon.2018

Affiliations

M. Leo Edward[1] · K. C. Dharanibalaji[2] · K. Thileep Kumar[3] · A. Raghu Subash Chandrabose[3] · A. M. Shanmugharaj[3] · V. Jaisankar[1]

M. Leo Edward
leoedward382@gmail.com

[1] PG and Research Department of Chemistry, Presidency College (Autonomous), Chennai 600 005, India

[2] Department of Chemical Engineering, IIT Madras, Chennai 600 036, India

[3] Department of Chemistry, Vels Institute of Science, Technology and Advanced Studies, Chennai 600 117, India