6.1 Introduction

The major developments in polymer science during the past few decades have been enriching our knowledge about the relationship between the structure and properties of polymers. Since the 1940s, there has been an ever rising development in the field of synthesis and development of new synthetic polymers, composites and biocomposites. Now a days, the demand for polymers as a complete product or a part thereof is tremendous and many products require a diverse of polymers (e.g. the automotive branch, the information and communication branch, the paint industry, the cosmetics industry, the pharmaceutical industry, in food packaging, and in lightweight metal replacements).

Polymers cover an astonishing wide range of possible product applications, since their properties can be easily tailored to fit specific needs. By changing the polymer and its composition, the mechanical, thermal, structural and electrical properties can be fine-tuned. Even though polymers can easily be prepared and shaped, the mechanical or physical properties of many engineering plastics need to be enhanced by the preparation of multi-phase morphologies.

The production and utilization of crude oil based plastics is increasing and about 150 million tons of plastics are produced annually around the world. These plastics are basically non-degradable polymers which cause serious environmental pollution. In recent years the environmental awareness and consciousness throughout the world has developed an increasing interest in composite, biocomposite, biopolymer and natural polymers. Biocomposite materials are the materials composed of biodegradable matrix and reinforced with natural fiber.

Composite materials are attractive because they combine material properties in ways not found in nature. Such materials often result in lightweight structures having high stiffness and tailored properties for specific applications, thereby saving weight and reducing energy needs. Typically, a man made composite would consist of a reinforcement phase of stiff, strong material, frequently fibrous in nature, embedded in a continuous matrix phase. The advantage of such a coupling is that the high strength and stiffness of the fiber may be exploited.
Biocomposites are composite materials comprising one or more phase(s) derived from a biological origin. In terms of the reinforcement, this could include plant fibers such as cotton, flax, hemp and fibers from recycled wood or waste paper, or even by-products from food crops. Biocomposites offer a significant non-food market for crop-derived fibers and resins.

Considerable growth has been seen in the use of biocomposites in the automotive and decking markets over the past decade or so, but application in other sectors has hitherto been limited. Nevertheless, with suitable development, the potential exists for biocomposites to enter new markets and thus stimulate an increase in demand for non-food crops. Fibers provide strength and stiffness and act as reinforcement in fiber-reinforced composite materials; ultimately the properties of a composite are governed by the inherent properties of these fibers. Natural fibers can be subdivided into vegetable, animal and mineral fibers.

The excellent mechanical properties, particularly good tensile strength and microhardness make the biocomposite suitable for industrial applications. Good electrical properties and good thermal resistance are other promising attributes of the biocomposite. The combination of low cost, biodegradability, desired biocompatibility with superior mechanical and other properties are the main reasons for increasing research interest in the field of biocomposite.

Recently, the research and development activities in the field of polymer science and biocomposite have been centered on the elucidation of the relationship between the structure, thermal, electrical and mechanical properties of polymers. The utilization of polymers and biocomposite in engineering and technological applications is determined by the degree to which favourable mechanical properties, which depend on several factors, are exhibited. Some of these mechanical properties are microhardness, creep, fatigue, tensile and impact strengths.

The indentation technique of microhardness measurement provides a non-destructive and most informative tool for the assessment of mechanical behaviour of the material under consideration. Microhardness has been found to be a bridging parameter between the bulk properties of polymers on one side and micro-structural parameters on the other. The mechanical properties of a polymer involve its behaviour under stress. The mechanical properties of polymers are one of the features that
distinguish them from small molecules. The tensile strength is an important property for polymers that are going to be stretched.

In recent times the polymers and biocomposite in the form of thin films have gained attention, due to their fascinating properties, disordered structure, potential applications and growing need of society. Commodity as well as engineering plastics have found applications in various appliances in substantial quantities. Material exhibiting dielectric relaxation necessarily shows charge storage and electrical behaviour, if an electric field applied to them. A frozen-in polarization or trapped charge can either induce internal effects or create an external electric field.

In the form of electrets, biocomposite can also be used for charge storing material. These requirements may include higher temperatures, high impact strength, mouldable components, improved resistivity and charge storage properties. During the past few years, therefore, the principle efforts have been directed towards the development of blends and biocomposite electrets for widening the range of properties. Biocomposite offers, new type of materials, characterized by controlled reinforcing constitution and morphology, which can be more precisely tailored to specific requirements. The Thermally Stimulated Depolarization Current (TSDC) technique has been widely adopted as tool for probing molecular motion responsible for electrical relaxations in polymer and biocomposite.

The spectrum of application of various characterization techniques in elucidation of structure, thermal, mechanical and electrical property relationship of biocomposite has motivated the author to carry out the detailed study on the biocomposite. Polyvinyl alcohol and Palm leaf are potential material for synthesis of biocomposite. PVA is a water soluble, non-toxic, non-immunogenic polymer with a remarkable film forming property. It has been widely used as a basic material for a variety of biodegradable applications.

Thus, realizing the vital role of PVA the present investigation "Structural, Mechanical and Electrical Study of Some Polymer Biocomposite Films ", aimed at preparing biocomposite of PVA and Palm leaf powder. Palm leaf is best resource of natural fibers, so its powder can be used as reinforcing material. Thus, the author was motivated to develop the biocomposite of PVA and Palm leaf powder to carry out detailed studies on the influence of weight percentage of palm leaf powder on the
various properties of the biocomposite. XRD, DSC, FTIR and AFM studies were utilized to study the crystallization, thermal behaviour, composition and morphology of biocomposites, respectively. The biocomposite films were also investigated for their microhardness and tensile properties. Looking to the possible use of these biocomposite as electrets, they were also investigated for Thermally Stimulated Depolarization Current (TSDC) behaviour and on that basis various parameters have been calculated.

6.2 Summary and Correlation of Results

The results obtained from the systematic studies of the effect of variation of palm leaf powder concentration on its thermal, structural, morphological, mechanical and electrical properties are summarized in this section. The thermal, structural and morphological characterization of prepared biocomposites were obtained from the studies of Differential Scanning Calorimetry (DSC), X-Ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR) and Atomic Force Microscopy (AFM). The effects of variation of palm leaf powder weight percentage on the mechanical properties of reinforced biocomposites were studied from tensile testing and microhardness measurement. The electrical properties of biocomposites were studied with short circuit thermally stimulated discharge current (TSDC).

The Biocomposite of Polyvinyl Alcohol (PVA) and Palm Leaf powder were prepared by sol gel method with varying weight percentage of Palm Leaf Powder. The thermal, structural and morphological characterizations were carried out with Differential Scanning Calorimetry (DSC), X-Ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR) and Atomic Force Microscopy (AFM) and evaluation of various parameters such as glass transition temperature, melting point, enthalpy of fusion and degree of crystallinity, interplanar distance and crystallite size has been calculated and studied.

The heating and cooling run of the DSC at the rate of 10°C/min with nitrogen flow of 10 ccpm were used to characterize the thermal properties of pure PVA polymer film and palm leaf reinforced biocomposite films for temperature range of 55°C to 220°C. The DSC thermographs show that the addition of palm leaf powder in to the PVA polymer initially decreases the glass transition temperature (T_g). In our case the observed glass transition temperature (T_g) of pure PVA polymer is 66°C
while for 5wt% it decreases and it is 58.2°C. For weight percentage ratio beyond 5 wt% the glass transition temperature \( (T_g) \) increases with increasing weight percentage of palm leaf. The maximum glass transition temperature of 68.2°C is observed in the case of 20wt% biocomposite film.

The random variation in peak melting temperature is observed with variation in palm leaf concentration. The maximum \( T_m \) is observed for 5wt% palm leaf concentration. The melting enthalpy of fusion for pure PVA and biocomposites films has been calculated and it is found that the melting enthalpy of fusion increases with increase in palm leaf concentration from pure PVA to 15wt % palm leaf concentration. The crystallinity of pure PVA and palm leaf powder reinforced biocomposite film also shows similar trend of melting enthalpy of fusion. The maximum crystallinity, \( X_c = 31.70\% \), is found for 15wt% polymer biocomposite film.

X-ray diffraction patterns of pure PVA and palm leaf reinforced PVA polymer biocomposite samples have been recorded for \( 2\theta =10^0 \) to \( 50^0 \) ranges. The crystalline peak is observed between \( 2\theta = 19.50^0 \) to\( 19.94^0 \). For pure PVA film, the crystalline peak is observed at 19.50°, which yields crystallinity of 28.1%, interplanar distance, \( d = 4.551\text{Å} \) and crystallite size \( D =42.66\text{Å} \).

The addition of palm leaf powder in poly vinyl alcohol (PVA) results shift in crystalline peak toward the higher glancing angle side and sharpness of the peak also increases. For 5%PL+PVA biocomposite film, crystalline peak is observed at \( 2\theta =19.55^0 \), yielding crystallinity 30.5% with interplanar distance, \( d=4.540\text{Å} \), and crystallite size \( D=31.79\text{Å} \). Similar increases in various properties for 10wt% and 15 wt% have been observed. The crystallinity observed for 10 and 15 weight percent films are 33.3% and 33.9%, respectively. For 20wt% biocomposite film, a decrease in various properties has been observed; the crystalline peak has been observed at \( 2\theta =19.64^0 \), i.e. there is a shift towards lower glancing angle; the calculated crystallinity value is 30.7%, interplanar distance, \( d=3.495 \text{ Å} \) and crystallite size \( D=27.48\text{Å} \).

The FTIR spectroscopy studies have been carried out on prepared Pure PVA polymer sample and palm leaf powder reinforced biocomposite samples. The characteristic absorption bands of Pure PVA Polymer films occurs at 4331 cm\(^{-1}\) and 4026 cm\(^{-1}\) (stretching of OH), 2933 cm\(^{-1}\) (asymmetric stretching of CH\(_2\)), 1720cm\(^{-1}\)
(stretching of CO), 1438 cm\(^{-1}\) (stretching of CO), 821 cm\(^{-1}\) (Bending of C-H) and 682 cm\(^{-1}\) (bending of OH). The characteristic absorption bands of palm leaf occurs at 3368 cm\(^{-1}\) (stretching of OH), 2921 cm\(^{-1}\) (stretching of CH\(_2\)), 2364 cm\(^{-1}\) (stretching of OH), 1654 cm\(^{-1}\) (stretching of CO), 1438 cm\(^{-1}\) (stretching of CO), 807 cm\(^{-1}\) (bending of C-H), 618 cm\(^{-1}\) (interaction between C-Cl and C-Br) powder.

The FTIR spectra of palm leaf powder reinforced PVA biocomposite films have been studied and it is found that for 5 wt% palm leaf powder reinforced biocomposite film characteristics absorption band occurs at 4331 cm\(^{-1}\) and 4025 cm\(^{-1}\) (stretching of OH), 2830 cm\(^{-1}\) (stretching of C-H), 1738 cm\(^{-1}\) (stretching of CO), 1570 cm\(^{-1}\) (stretching of N-H), 1415 cm\(^{-1}\) and 862 cm\(^{-1}\) (bending of CH). For 10 wt% palm leaf powder reinforced film the characteristics absorption band occurs at 4223 cm\(^{-1}\) and 4025 cm\(^{-1}\) (stretching of OH), 3278 cm\(^{-1}\) (stretching of OH), and 1438 cm\(^{-1}\) (stretching of CO). For 15 wt% palm leaf powder reinforced film the characteristics absorption band occurs at 4331 cm\(^{-1}\) and 4026 cm\(^{-1}\) (stretching of OH), 2855 cm\(^{-1}\) (stretching of C-H), 1711 cm\(^{-1}\) (stretching of CO), 1468 cm\(^{-1}\) and 862 cm\(^{-1}\) (bending of CH), 824 cm\(^{-1}\) (bending of CH), and 709 cm\(^{-1}\) (bending of C-H, O-H) and for 20 wt% palm leaf powder reinforced film the characteristics absorption band occurs at 4024 cm\(^{-1}\) (stretching of OH) and 1730 cm\(^{-1}\) (stretching of CO).

The various FTIR spectra clearly reveal that Palm leaf is well incorporated with PVA in the biocomposites and the variation in stretching of bonds of various functional groups with increase in wt% of palm leaf powder indicates the strengthening of structural network between the two constituents of biocomposite thereby leading to development of compatible material and confirms stable structure of the biocomposite film.

The surface structure and distribution of Palm leaf powder within biocomposite polymer matrix were characterized with Atomic Force Microscopy. The pure PVA polymer film shows smooth surface structure with its maximum surface height variation of order of 10nm. The various AFM images of biocomposite films also indicate that the developed biocomposite have very smooth surface. The palm leaf powder over the PVA surface is uniformly distributed and its density increases with increase in the wt% of palm leaf in the biocomposite.
The mechanical properties of polymeric blends are influenced by the nature of polymer matrix. In general, constituent polymers are responsible for the surface microhardness. Stressing a polymer may result not only in deformation, but in failure as well. Mechanical failure of a polymer is a complex process developing in time and occurring at a rate which is dependent on stress. In the present case, all the studies were performed at room temperature and the duration of indentation was kept 30 s. The value of Vickers hardness number, $H_V$, can be altered on changing the load range. The value of $H_V$ was found to vary with load in the range of 10-60 g. Beyond 50-60 g, $H_V$ becomes independent of load up to the studied range of 80 g. The load range of 60-80 g is the saturation load range for the biocomposite of PVA and Palm leaf.

The attainment of saturation value of $H_V$ with increasing load is explained on the basis of strain hardening phenomenon which is attributed to micromodes of deformation. Further, the $H_V$-load dependence in different load regions is explained with the help of logarithmic index, $n$, also known as Meyer's constant which is a measure of rate of strain hardening. The value of $n$ is obtained from the plot of log L versus log d for pure PVA, and Palm leaf powder reinforced biocomposite.

The strain hardening index has two values: one for the low load region ranging from 10 to 40 g and the other for the high load region ranging from 40 to 80 g. The strain hardening index ($n$) is increasing at higher load region. The variation in strain hardening index shows that the material becomes tough at higher load region due to formation of crystalline region inside the specimen. The increase in strain hardening index in low load region was observed due to increase in tensile strength and microhardness of material, while at higher load region strain hardening index decreases with increase in concentration of palm leaf powder, this change in index is observed because the material is becoming hard as well as brittle.

The effect of addition of palm leaf powder into the biocomposite on their microhardness has been studied by varying the concentration of palm leaf powder from 5 wt% to 20 wt% into the biocomposite. The result shows that the value of $H_V$ increases with increase in palm leaf content. The value of $H_V$ increases with increase in the applied load. It is also greater for biocomposite with higher weight percentage of palm leaf powder.
The microhardness of all the biocomposites are found to be higher than that of pure PVA specimen. The increase in Hv with increase in weight percentage of palm leaf powder increases the crystallinity in the biocomposite system, which is also confirmed from the XRD and DSC studies described in Chapter 3. The stable and smooth texture of the surface of biocomposite as detected from the AFM studies discussed in Chapter 3, also contributes to the strengthening of material with stiff and hardened surface as depicted with increase in the microhardness. Hence, Palm leaf powder is compatible with PVA in developing structural network in biocomposite having mechanically stable and smooth surface.

The mechanical properties of pure PVA polymer film and Palm leaf powder reinforced biocomposite films, like tensile strength, Young’s Modules and percentage elongation at break were Studied. The tensile strength and Young’s modulus of the films increases significantly from 7.40 MPa to 34.42 MPa and from about 435.64 MPa to 2926.05 MPa with increasing palm leaf content from 0 to 20%, whereas the elongation at break decreases from 9.55% to 2%. The increase in Tensile strength and elongation shows that the developed biocomposites have improved mechanical properties. While from decrease in elongation, it is clear that the increasing weight percentage of palm leaf powder makes the biocomposite film hard and brittle in nature.

The mechanical behaviour of the biocomposite is related to its morphology as observed from AFM image. It is observed that the tensile strength and modulus increases with increase in palm leaf powder content in the biocomposite. The microhardness of these specimens also reveal hardening due to palm leaf powder. The increase in Palm leaf powder content causes decrease in % elongation in the biocomposite. The specimen with 20wt% of Palm leaf powder content shows maximum tensile strength (34.42 MPa) and the value of Young’s modulus for this specimen is 2926.05 MPa, which is maximum amongst all the biocomposites and pure PVA. The increase in Young’s Modulus and tensile strength can be attributed to the increase in proportion of palm leaf powder which is confirmed from XRD and DSC studies, described in Chapter 3.
However, the increase in crystallinity leads to the embrittlement of the material as the % elongation at break decreases, although, this decrease in elongation tends to stabilize beyond the 10% of palm leaf specimen.

To characterize the mechanism responsible for polarization in pure polyvinyl alcohol (PVA), and palm leaf powder reinforced biocomposite, thermally stimulated depolarization currents (TSDC’S) were recorded as a function of electric field stress ($E_p$) and temperature. The different samples prepared were pure PVA and palm leaf powder reinforced biocomposite in different weight ratios 100:00; 95:05; 90:10, 85:15 and 80:20, and are designated as P1, P2, P3, P4 and P5, respectively. The TSDC thermograms for Pure PVA samples polarized under various fields of 10, 15, 20 and 25 kV at temperatures 50, 70, 90 and 110°C. It is found that, the temperature dependence of the short circuit TSDC thermograms are characterized by a high initial value of TSD current and they are characterized by a well resolved peak located between 150-190°C. The magnitude of the TSD current as well as peak is, in general, found to increase with the polarizing temperature. In the case of biocomposite’s thermograms it is evident that for biocomposite samples polarized at high temperatures of 90 and 110°C, the magnitude of the TSD current as well as the peak current is considerably decreased in magnitude.

From field dependence short circuit TSDC spectra for specimens, it is clear that, for pure PVA, a well defined TSDC peak located in the temperature range of 130 - 190°C is observed. The TSDC current is decreased as the forming field is increased; however, for still high values of polarizing field, current again increases. For biocomposite samples, the TSD current magnitude as well as peak current magnitude show a complex field dependence.
6.3 Conclusion

The conclusions drawn from various studies and the results reported in this thesis are as follows:

1. The DSC thermogram for pure PVA shows that glass transition temperature ($T_g$) occurs at 66°C. Regarding the melting ($T_m$) of the pure PVA, the onset melting peak ($T_{m}^{on}$) arises at 148.9°C, peak melting temperature ($T_{m}^{p}$) occurs at 185°C and final (or offset) melting temperature ($T_{m}^{f}$) occurs at 207.1°C.

2. The DSC thermograms of various palm leaf powder reinforced PVA biocomposite films shows that the glass transition temperature ($T_g$) initially decreases for 5%PL+PVA, beyond this concentration glass transition temperature ($T_g$) increases and it is maximum for higher concentration of palm leaf powder i.e. 20%PL+PVA polymer biocomposite film.

3. In the melting part of the biocomposite films, the onset melting peak ($T_{m}^{on}$) initially shifts toward higher temperature range up to 10%PL+PVA film then it shifts toward lower temperature range, and the maximum onset melting is $T_{m}^{on} = 159.3$°C. In the peak melting temperature ($T_{m}^{p}$) for biocomposite films random variations occurs, the maximum peak melting temperature ($T_{m}^{p}$) is $T_{m}^{p} = 189.7$°C for 5%PL+PVA biocomposite polymer film. In the offset melting temperature part of the biocomposite film, similar variations observed as for onset melting peak ($T_{m}^{on}$), the maximum final (or offset) melting temperature is $T_{m}^{on} = 211.8$°C for 10%PL+PVA biocomposite film.

4. The calculated melting enthalpy ($\Delta H_m$) of pure PVA polymer film and Palm leaf reinforced biocomposite film shows that the melting enthalpy increases with increasing the concentration of Palm leaf powder within PVA matrix up to 15%PL+PVA biocomposite film, this change leads to change in crystallinity ($X_c$) of the biocomposite films. The maximum melting enthalpy $\Delta H_m = 43.93$ J/g and crystallinity $X_c = 31.70\%$ is found for the same sample.
It is observed from XRD study, that pure PVA and Palm leaf powder reinforced biocomposite film shows crystalline peak between $2\theta = 19.50^0$ to $19.94^0$, which suggests the presence of ordered crystalline phase.

The XRD pattern of pure PVA has quite broad peak, suggesting lower crystalline nature, while small crystalline size ($D$) in the polymer.

The presence of Palm leaf powder into the biocomposite film increases the sharpness of the peak, which suggests that the crystallinity of biocomposite increases with increasing concentration of Palm leaf powder. The maximum crystallinity $C_r$ = 30.7% found for 20%PL+PVA biocomposite film.

The crystalline peak shifts toward higher glancing angle which leads to change in the interplanar distance ‘$d$’ and Crystallite Size ‘$D$’, both the parameters decreases with the increase in glancing angle.

In FTIR study for pure PVA, a broad peak appears at 4331 cm$^{-1}$ and 4026 cm$^{-1}$, indicating the presence of hydrogen bonding and hydrophilic nature of pure PVA and a sharp adsorption peak at 1720 cm$^{-1}$, this shows presence of C=O stretching.

The FTIR study of Palm leaf powder shows small peak at 3368 cm$^{-1}$ due to hydrophilic nature confirming presence of water in palm leaf powder, other peaks appears at 2921 cm$^{-1}$ (stretching of CH2), 2364 cm$^{-1}$ (stretching of OH), 1654 cm$^{-1}$ (stretching of CO), 1438 cm$^{-1}$ (stretching of CO), 807 cm$^{-1}$ (bending of C-H), 618 cm$^{-1}$ (interaction between C-Cl and C-Br) powder.

The FTIR spectra of palm leaf powder reinforced PVA biocomposite films clearly reveals that Palm leaf is well incorporated with PVA in the biocomposites and the variation in stretching of bonds of various functional groups with increase in wt% of Palm leaf powder indicates the strengthening of structural network between the two constituents of biocomposite, thereby leading to development of compatible and stable structure of the biocomposite film.

The surface structural studies on the basis of AFM exhibits development of compatible and smooth structures of palm leaf and PVA in the biocomposite leading to morphological texture with uniform distribution of palm leaf over the
PVA surface in nano domain globular structures with varying heights of the hills in nanometer range with the increase in the wt% of palm leaf.

(13) The density of the globular morphology in nano domain increases with increase in wt% of palm leaf in the biocomposite. Thus the results of FTIR and AFM are in good correlation.

(14) The AFM also illustrates the presence of palm leaf and PVA in the biocomposite in nano domain structures providing smooth and stable surface to the developed biocomposite films.

(15) In the load-Hv profile the rate of increase in Hv is more in the load range of 10-50 g. The value of Hv tends to saturate beyond a certain load in the range of 40-60 g depending upon the specimens.

(16) The Hv-load profile signifies that pure PVA is soft in comparison to Palm leaf powder reinforced biocomposite films. The morphology of biocomposite films with lower content of PVA yields more hardened material.

(17) The value of Hv increases with increase in palm leaf content. The value of Hv increases with increasing the applied load. It is also greater for higher weight percentage of palm leaf powder.

(18) The increase in Hv with increase in weight percentage of palm leaf powder increases the crystallinity in the biocomposite system, which is also confirmed from the XRD and DSC studies.

(19) The stable and smooth texture of the surface of biocomposites are detected from the AFM studies, which contributes to the strengthened material with stiff and hardened surface as depicted with increases in microhardness.

(20) The strain hardening index \((n)\) is increases at higher load region. The different value of \(n\) for pure PVA and palm leaf reinforced biocomposite are observed in two regions. The variation in strain hardening index shows, the material becomes tough at higher load region due to formation of crystalline region inside the specimen.
The increase in strain hardening index in low load region observed due to increase in tensile strength and microhardness of material, while at higher load region strain hardening index is decreasing with increase in concentration of palm leaf powder, this change in index is observed because the material is becoming hard as well brittle. The increase in crystalline region is also confirmed by DSC and XRD characterization.

In tensile study of pure PVA, it has been observed that PVA is soft in nature and shows maximum % elongation (9.55%).

The tensile strength and Young’s modulus of the biocomposite films increases significantly from 7.40 MPa to 34.42 MPa and from about 435.64 MPa to 2926.05 MPa with increasing palm leaf content from 0 to 20%, whereas the elongation at break decreases from 9.55% to 2% with respect to pure PVA polymer film.

The increase in Tensile strength shows that the developed biocomposites have mechanically improved exhibiting greater strength with good mechanical properties. The increase in Young’s Modulus and tensile strength of biocomposites leads to the development of material having good elastic properties with greater strength.

The decrease in % elongation at break with increase in the wt% of Palm leaf suggests the decrease in the elastic region of deformation leading to relatively brittle material. The increase in Young’s Modulus and tensile strength can be attributed to the increase in the crystallinity of biocomposites with increase in proportion of Palm leaf which is confirmed from XRD and DSC studies.

The increase in crystallinity leads to the embrittlement of the material as the % elongation at break decreases, although, this decrease in elongation tends to stabilize beyond the 10 wt% of palm leaf specimens.

The thermally stimulated depolarization currents in the present investigation, in all cases are found to flow in the normal direction i.e. opposite to the charging current. Thus, processes involving heterocharge formation are mainly responsible for polarization in pure PVA and PVA + PL biocomposite films.
(28) The high initial value of current indicates towards the occurrence of a relaxation process below room temperature ($T_{\text{ROOM}} \approx 250^\circ\text{C}$).

(29) No relaxation peak around the glass transition temperature of the polymer or composite was observed; however, dipolar relaxation associated with segmental motion of the main chain together with space charge were considered for high value of TSD current observed in this range.

(30) The short circuit TSDC thermograms for pure PVA shows a well resolved peak located between 130-190$^\circ\text{C}$. The magnitude of the TSD current as well as peak is, in general, found to increase with the polarizing temperature. The peak position is, in general, found to shift towards high temperature side with increase in the polarizing temperature.

(31) For biocomposite samples, from the temperature dependence of short circuit TSDC thermograms it is evident that for samples polarized at high temperatures of 90 and 110$^\circ\text{C}$, the magnitude of the TSD current as well as the peak current is considerably decreased in magnitude.

(32) From the field dependence of the short circuit TSDC spectra for pure PVA, the TSD current as well as the peak, in general, increases initially with increase in polarizing field. For high values of field, the TSDC current is decreased, however, for still high value of polarizing field, current again exhibited increasing trend.

(33) In the case of biocomposite samples, TSD current magnitude as well as the peak current magnitude exhibited a complex field dependence. Further, the peak position was independent of polarizing field.

(34) The peak observed between 130-190$^\circ\text{C}$ has been attributed to $\alpha'$ relaxation process.

(35) Water absorption property of PVA has been observed to play important role in the electrical behaviour of PVA and composite.

(36) From the various TSDC thermograms, it has been concluded that presence of Palm leaf in biocomposite samples facilitates further crystallization of polymer.
PVA which significantly modifies the charge storage and hence the electrical behaviour of polymer in the studied temperature and electrical field range.

6.4 Remarks and Future Prospects

The present thesis entitled "Structural, Mechanical and Electrical Study of Some Polymer Biocomposite Films" is a detailed and systematic study of the various structural, morphological, thermal and mechanical properties of biocomposite of Polyvinyl alcohol and Palm leaf powder and suggests its utility for various automobile, electrical, and mechanical applications. The prepared and studied biocomposites have also been judged for thermal, structural, mechanical and electrical properties. The results obtained from various characterizations reveals that the developed biocomposites find support from the literature available on PVA and similar types of investigations.

The conclusions of the present dissertation on the microhardness and tensile strength are in good agreement with the literature on mechanical properties of polymers. The utilization of indentation technique in the present investigation is found to be a reliable tool for the investigation of morphological and structural changes in biocomposite. Also, the Vicker's microhardness testing which has been reported to be useful for the study of various physical properties of polymers is found to be true in PVA and Palm leaf biocomposite system as well. Likewise polymers, biocomposites also comprise of the crystalline as well as the amorphous regions. The phase morphology and crystalline properties are determined by AFM and XRD techniques.

To get the more insight into the morphological changes and crystalline characteristics as well as the domain size with reference to the nano-scale, further studies would be helpful with the scanning electron microscopy (SEM). In the present investigation, the microhardness and the tensile strength measurements were carried out at room temperature. These studies can further be extended by undertaking measurements at different temperatures. The thermal stability of biocomposite could also be studied using OTA and TGA techniques. Further, the tensile strength measurements carried out after various treatments will also help in studying the enhanced mechanical properties.
The application of indentation techniques to polymers is relatively new approach but one with great potential for the characterization of these biomaterials. Though the correlation between microhardness and tensile strength have been made, but a detailed correlation between microhardness results and the data obtained by all other available physical and chemical methods of characterization is required. There exists a lot of scope also to correlate structure of a material with other mechanical properties like impact strength, creep and fatigue, etc. to gain a true understanding of structure property relationship.

In the present investigation, charge storage behaviour of PVA and biocomposites has been studied using short circuit TSDC technique. To characterize the material for applications involving charge storage behaviour and also for microelectronics applications, a detailed study of electrical behaviour of biocomposites is essential. Dark-and photo-conduction current measurements, isothermal depolarization current measurement and dielectric behaviour studies under different conditions of electric field frequency and temperature should therefore be carried out. Also, detailed studies should be carried out to understand the role of water absorption in determining the electrical behaviour of PVA and biocomposites.

From the environmental point of view the biocomposites are important due to their biodegradable aspect. The biocomposites based on different waste material can be developed for various applications, based on their thermal, mechanical, structural and electrical properties.

However the various studies carried out and the result obtained can be considered to be of sufficient importance and add to our current understanding of structural, mechanical and electrical behaviour of biocomposite in general, and Polyvinyl alcohol and Polyvinyl alcohol + Palm leaf biocomposites, in particular.