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Research Paper

Effect of Sodium Fluoride and Aluminum Sulfate Salts on PVA Polymer Film Synthesized Using Casting Technology

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Abstract

Polymer films were manufactured from polyvinyl alcohol (PVA) doped with a concentration of sodium fluoride (NaF) and aluminum sulfate ($Al_2(SO_4)_3$) salts via the solution casting method. The differences in crystallinity and transformation temperatures of solid polymer electrolyte sheets were analyzed using differential scanning calorimetry (DSC). The formation of a complex structure between PVA polymer and a salt were confirmed using Fourier transform infrared spectroscopy (FTIR). Absorption spectra were obtained in the wavelength range of 200−1200 nm and analyzed using the absorption equation for amorphous materials. The energy gap values showed a clear dependence on the concentration of sodium fluoride and aluminum sulfate. The indirect energy gap was determined and analyzed in relation to the integration of charge-transfer complexes within the grafted materials.

Keywords

Polymers, PVA, Sodium Fluoride, Aluminum Sulfate, Casting Method

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1. INTRODUCTION

Due to their potential wide-ranging uses, recent polymer research studies are in fact recognized as one of the most fascinating and quickly developing research fields of today. Without polymers, life appears quite difficult (Salman et al., 2019; Hemalatha et al., 2014). Polymers are a very significant class of materials. Water-soluble polymers can be made in a variety of ways or purchased commercially (Dennis et al., 2023). Among the various kinds of polymers, water-soluble polymers interact with polar solvents and other species of high and low molecular weight. These interactions cause the macromolecules in solution to display characteristics that go beyond their chemical structure, such as the confirmation of polymer chains, excluded volume, surface activity, or the formation of higher order structures like aggregates, gels, etc (Salman et al., 2016; Bercea, 2024).

Polymers, including plastics and rubbers, permeate our lives and manifest in various forms, resulting in significant implications for their physical qualities (Chandra Mouli et al., 2024). The significance and comprehension of these features are essential for their applications in technology and engineering (Žigon et al., 2025). Polyvinyl alcohol is characterized by its exceptional chemical resistance, physical properties, and complete biodegradability, making it suitable for numerous practical applications (Huo et al., 2025). It is one of the most widely used synthetic polymers in the world. It is a semi-crystalline polymer, the degree of crystallinity of which is affected by the manufacturing process and physical aging (Jasim, 2025; Swaminathan et al., 2020). It is a water-soluble poly hydroxyl polymer and is known as one of the rare non-halogenated linear aliphatic polymers.

PVA features 2D network structure defined by hydrogen bonding (Mudigoudra et al., 2012; Guirguis and Moselhey, 2012). The preparation process significantly influences the physical and chemical properties of PVA (Jasim et al., 2024b). PVA is extensively utilised and recognised as a host polymer, primarily owing to its availability (affordability), excellent film-forming properties, high flexibility, improved chemical properties, and enhanced thermal stability of materials, along with a greater abundance of polar hydroxyl groups and significant chain flexibility, promote the salt solvation process (Irfan et al., 2020; Pu-You et al., 2014). The capacity of PVA to generate electrolytes is linked to its hydrophilic characteristics and several hydroxyl groups bonded to methane carbons (CH_2-CH) on the PVA backbone (Abdel-Hameed, 2012).

Numerous studies have been conducted on the amalgamation of PVA with various biopolymers, revealing that the incorporation of PVA enhances the film's flexibility and wettability (Verma and Quraishi, 2022). Recently, the general and engineering applications of composite materials have become heavily reliant on their physical properties (Hussein et al., 2024). Therefore, it is essential to study and understand these properties thoroughly to implement necessary improvements (Rabee et al., 2012). Among the physical properties that have garnered significant research attention are glass transition and crystalline melting point (Abdullah et al., 2025a). The primary objective of studying thermal properties is to understand the thermal behavior of these materials in order to determine their appropriate roles in different scientific fields.

2. EXPERIMENTAL

2.1 Materials and Samples Preparation

PVA powder, possessing a molecular weight of 14,000 g/mol and a hydrolysis degree ranging from 86% to 89%, was supplied by Central Drug House (P) Ltd., New Delhi, India. It is defined as a translucent, colorless, odorless, and non-toxic substance that is soluble in distilled water. Films with thicknesses between 40 and 140 μm were fabricated at ambient temperature utilizing the casting process from solution. Polyvinyl alcohol (PVA) and hydrated aluminum chloride ($Al_2(SO_4)_3$) were dissolved in a weight ratio of 5 wt%, alongside sodium fluoride (NaF) at a weight ratio of 5%, in distilled water at 80°C. Employing a magnetic stirrer for one hour. The solution is then poured into glass molds and left to dry for (24 h) to get rid of any remaining solvents and obtain a transparent polymer film.

2.2 Composites Preparation

Round (Petri dish) and rectangular glass molds were prepared. The molds were thoroughly cleaned and placed on a level and even surface. The standard dimensions of the samples prepared for the DSC test were (2 mm, 80 mm) and the thickness of the film was (140μm), while the dimensions of the mold for the (FTIR and UV-VIS) test were (0.05 mm, 80 mm) and the thickness of the prepared film was (40μm).

2.3 Differential Scanning Calorimetry (DSC) Test

Thermal behaviour of the prepared films was examined by differential scanning calorimetry model (STA. PT-1000 Linseis). The system was calibrated using (9-19) mg of alumina at a temperature increase rate of 10°C/min with the presence of argon gas.

2.4 FTIR Test

In order to record the (FTIR) spectra of the films, (IR Affinty-1CE (FTIR) spectrophotometer, Shimadzu, Japanese company) was used.

2.5 UV-VIS Test

The absorption spectrum of pure and salt-reinforced polyvinyl chloride (PVA) films was recorded within the wavelength range of 190-1100 nm at room temperature using a UV-Visible 1800 double beam spectrophotometer manufactured by Shimadzu, Japan. A computer program was used to obtain the optical constants (energy gap).

3. RESULTS AND DISCUSSION

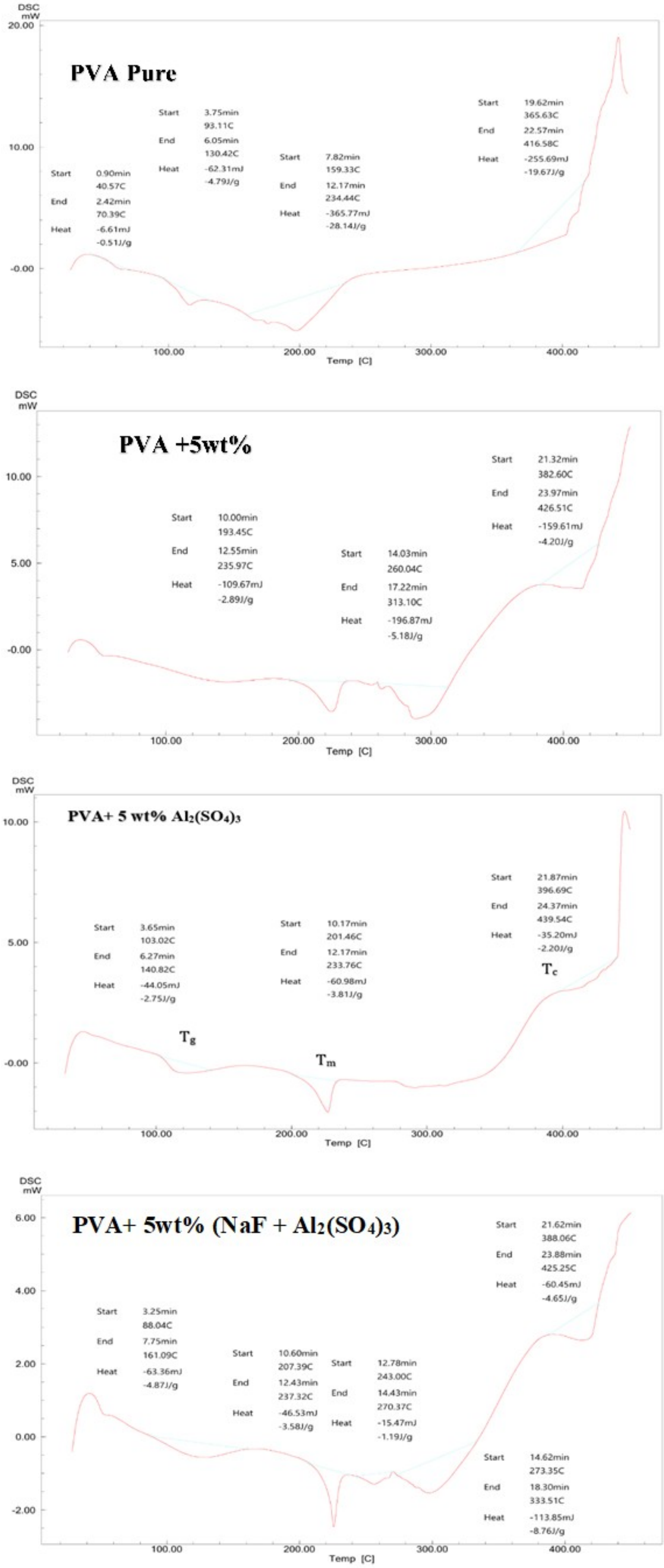

Figure 1. DSC Curve for Prepared Films Composites

3.1 Glass-Transition Temperature (Tg)

One of the characteristics of the glassy state in polymers is that their mechanical and physical properties change at a specific temperature called the glass transition temperature, usually denoted as (Tg). This can be defined as the temperature at which the polymer transforms from a strong solid to a flexible material. Above the glass transition temperature, the polymer is flexible (Miao et al., 2021). The glass transition temperature of pure polymer (PVA) films reinforced with 5 wt% NaF, 5 wt% $Al_2(SO_4)_3$, and 5 wt% (NaF/$Al_2(SO_4)_3$) salts in various weight ratios was determined using a differential scanning calorimeter (DSC). The thermal characteristics of the samples were analyzed utilizing DSC (Figure 1). The glass transition temperature (Tg) and melting temperature (Tm) elevated with the incorporation of salts in the nanocomposites. This is further clarified by the strong interactions and excellent compatibility between the reinforcing phase and the matrix. Figure 1 depicts the glass transition values for all composite films, as specified in Table 1. The glass transition temperature of the pure PVA film is recorded at 55.48°C (Jasim et al., 2021). Following the reinforcement with 5 wt% (NaF/$Al_2(SO_4)_3$) salts, we detect a consistent increase in the glass transition temperature, culminating in a peak value of 124.56°C for the composite. The erratic rise in the glass transition value is attributable to the intermolecular interactions (hydrogen bonding) between the PVA polymer and the salts (Ismail et al., 2025).

3.2 Crystalline Melting Temperature (Tm)

The crystalline melting point is utilized to ascertain the material's characteristics and its level of purity (Luo et al., 2015). Figure 1 and Table 1, displays the crystalline melting points of all composite films, as detailed in Table 1. The crystalline melting point of the pure PVA film is observed to be 111.76°C. Following the incorporation of 5 wt% NaF salt, we see a consistent increase in the crystalline melting point, culminating at a maximum value of 214.71°C. The points of melting attained was 217.61°C with the incorporation of 5 wt% $Al_2(SO_4)_3$, while the crystalline melting point was 222.35°C. The increasing elevation of the melting point of the crystals is ascribed to the enhancement of the crystalline phase of the PVA polymer due to the fortifying effects of salts (Abdullah et al., 2025b; Elashamwi et al., 2014).

3.3 Fourier Transforms Infrared (FTIR)

Fourier transform infrared (FTIR) spectroscopy was employed to examine the composition, structure, and possible interactions among the functional groups of PVA polymer, as well as to analyze the interaction between the polymer and the molecule. We were able to do this by watching how the position, shape, and intensity of the infrared transmittance bands changed in the 400–4000 cm^{-1} wavenumber range. Figure 2 shows how the vibrational bands of the pure PVA film (OH, CH, C=O, C=C, CH) stretch and bend. The graphic displays the absorption band of the free hydroxyl group (−OH) in PVA at a wavenumber of 3600 cm^{-1}. This means that hydrogen bonds, both between molecules and within molecules, usually hold the hydroxyl groups in PVA chains together. It also indicates that the wavenumber of the absorption band for the hydroxyl group (−OH) in PVA moves to higher values after being strengthened with NaF and $Al_2(SO_4)_3$. The figure shows that there is a band at wavenumber (2945 cm^{-1}) that is due to the asymmetric (C−H) expansion bond of the pure PVA film. When aluminum salts are added, the value of this bond wavenumber moves to a lower value of (2943 cm^{-1}) and (2939 cm^{-1}), with a weight percentage of (5 wt%) for NaF and $Al_2(SO_4)_3$ salts, respectively. We also see two bands at wavenumbers (1710 cm^{-1}) and (1657 cm^{-1}). These bands are due to the (C=O) and (C=C) expansion vibrational bonds of the pure PVA film. These are due to the acetate groups that are left over from the process of making polyvinyl chloride (PVA) (Risodkar, 2023; Jasim et al., 2024a). When salts are added to acetate to make it stronger, we see that the values of these two wavenumbers of the bonds (C=O) and (C=C) go toward lower values. This suggests that the salts that were introduced also react with the acetate groups in the vinyl acetate units of (PVA). We also see a band at wavenumber (1568 cm^{-1}) that is caused by the bending vibration bond (−CH_2) of the pure (PVA) film. The reinforcing process with additional salts also modified the wavenumber of these two bonds. Based on the foregoing, the reaction between salts and polymer (PVA) has broken the hydrogen bond of (PVA). These results are in line with what other research have found (Ahmed et al., 2024b,a). Table 2 displayed the values of the absorption band wavenumbers for all composite film bonds.

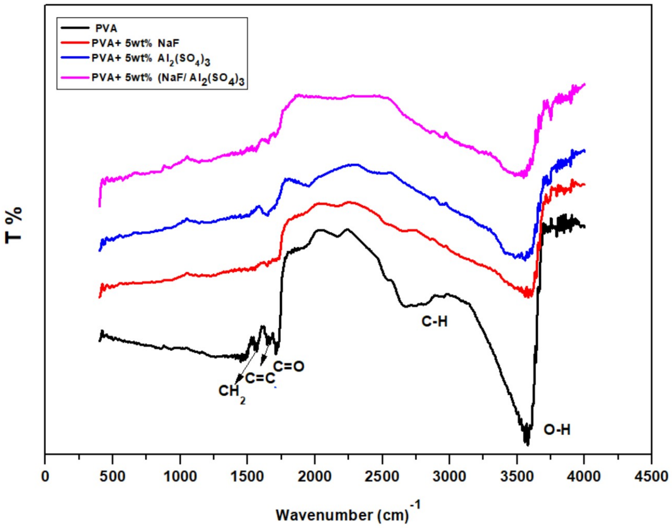

Figure 2. FTIR Spectra for Prepared Films Composites

3.4 Absorption Spectrum

Figure 3 shows the absorbance spectra as a function of wavelength for pure (PVA) polymer films and those reinforced with salts (NaF and $Al_2(SO_4)_3$) at a weight ratio of 5 wt%. The figure indicates that adding salts to the (PVA) polymer makes the absorbance peak stronger. Adding the weight ratio of the salts shifts the peaks toward the long (red) wavelengths. This rise in absorbance is in line with what was found in the earlier study (Sabri et al., 2024; Anis et al., 2019). This is because the ions in

Table 1. DSC Measurements of the Prepared Films Composites

Concentration (wt%)	Glass-Transition Temperature Tg (°C)	Crystalline Melting Temperature T_{m1} (°C)	Crystalline Melting Temperature T_{m2} (°C)
Pure (PVA)	55.48	111.76	196.88
PVA + 5wt% Na F	57.5	214.71	286.57
PVA + 5wt% $Al_2(SO_4)_3$	121.92	217.61	---
PVA + 5wt% (Na F and $Al_2(SO_4)_3$)	124.56	222.35	256.68

Table 2. Absorption Bands for All Composite Film Bonds

Bond	Wavenumbers (cm^{-1})			
	PVA Pure	PVA + 5 wt% Na F	PVA + 5 wt% $Al_2(SO_4)_3$	PVA + 5 wt% (Na F / $Al_2(SO_4)_3$)
O–H Stretching Vibration	3565	3496	3543	3512
C–H Asymmetric Stretching	2945	2943	2939	2941
C=O Stretching Vibration	1717	1723	1712	1717
Acetyl C=C group	1657	1654	1648	1659
Bending of CH_2 Vibration	1568	1573	1515	1562

the additional salts soak up the light that hits them.

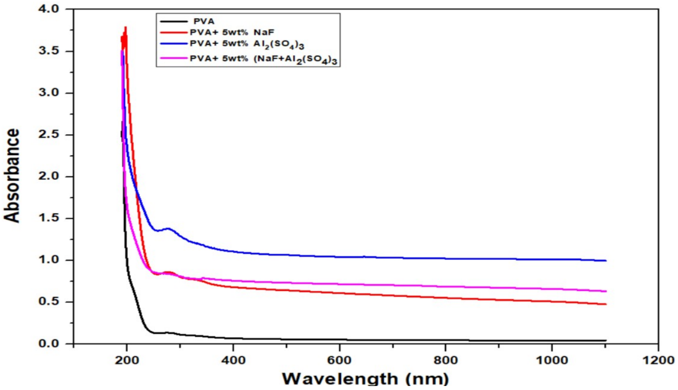

Figure 3. The Absorbance as a Function of Wavelength for Prepared Films Composites

3.5 Energy Gap

The energy gap (Eg) for the allowed indirect transition was calculated using Equation 1 (Jasim et al., 2025).

$$\alpha h\nu \approx B(h\nu - E_g)^r \quad (1)$$

A tangent is drawn from the best straight line that crosses most points beyond the absorption edge. Figure 4 shows the energy gap values for all of the composite films. The figure shows that the energy gap value for the pure PVA film is 6 eV. However, when more salts are added, the energy gap value goes down a little. This result is in line with what was found in earlier studies (Madhuranthakam et al., 2024). Adding small amounts of reinforcement material to the base material (PVA) makes the energy gap value lower. This is because the reinforcement material makes groups of transmitted charge. These clusters improve electrical conductivity by adding more charges. Moreover, the presence of different reinforcement materials leads the reinforced molecules to close the gap between two local energy levels. This lowers the potential barrier and makes it easier for charge carriers to move between these levels (Madhuranthakam et al., 2024).

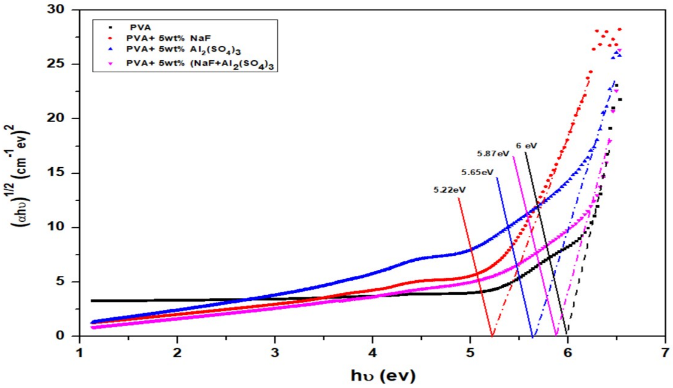

Figure 4. Energy Gap for Prepared Films Composites

4. CONCLUSIONS

Using the in-situ casting approach, we were able to make samples using pure PVA polymer and 5 wt% salts that were strong. Differential scanning calorimetry (DSC) thermal imaging showed how the thermal transitions of the films that were made were changed. FTIR spectroscopy demonstrated the continuity of the primary vibrational band, which corresponds to the overlapping principal structural groups inside the polymer. This indicates both homogeneity and the creation of complex structures between the polymer and the additional reactant salts. After adding the salts, UV-VIS spectroscopy indicated that the energy gap value went down. This was because the bonds formed in the amorphous phase of the PVA polymer, where the electron transition was indirect.

5. ACKNOWLEDGEMENT

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