

Research Article

Microstructural and Mechanical Studies of PVA Doped with ZnO and WO₃ Composites Films

N. B. Rithin Kumar,¹ Vincent Crasta,² Rajashekar F. Bhajantri,³ and B. M. Praveen⁴

¹ Department of Physics, Srinivas School of Engineering, Mukka, Mangalore, Karnataka, India

² Department of Physics, St. Joseph Engineering College, Vamanjoor, Mangalore, Karnataka, India

³ Department of Physics, Mangalore University, Mangalagangothri, Mangalore, Karnataka, India

⁴ Department of Chemistry, Srinivas School of Engineering, Mukka, Mangalore, Karnataka, India

Correspondence should be addressed to Vincent Crasta; vcraasta@yahoo.com

Received 6 November 2013; Revised 3 December 2013; Accepted 5 December 2013; Published 21 January 2014

Academic Editor: Dirk Kuckling

Copyright © 2014 N. B. Rithin Kumar et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Polymer composites of ZnO and WO₃ nanoparticles doped polyvinyl alcohol (PVA) matrix have been prepared using solvent casting method. The microstructural properties of prepared films were studied using FTIR, XRD, SEM, and EDAX techniques. In the doped PVA, many irregular shifts in the FTIR spectra have been observed and these shifts in bands can be understood on the basis of intra/intermolecular hydrogen bonding with the adjacent OH group of PVA. The chemical composition, phase homogeneity, and morphology of the polymer composites of the polymer film were studied using EDAX and SEM. These data indicate that the distribution of nanosized ZnO and WO₃ dopants is uniform and confirm the presence of ZnO and WO₃ in the film. The crystal structure and crystallinity of polymer composites were studied by XRD. It was found that the change in structural repositioning and crystallinity of the composites takes place due to the interaction of dopants and also due to complex formation. The mechanical studies of doped polymer films were carried out using universal testing machine (UTM) at room temperature, indicating that the addition of the ZnO and WO₃ with weight percentage concentration equal to 14% increases the tensile strength and Young's modulus.

1. Introduction

The doping of nanoscopic organic or inorganic materials into polymeric matrices represents a strategic route to improve the performance of material characteristics like structural, physical, chemical, optical, electrical, and mechanical properties. These nanocomposites are of new class of materials made with nanosized fillers like metals, metal oxides, and so forth. Thus metal-polymer composites can be obtained by in situ and ex situ techniques [1–4]. In the in situ methods, metal particles are generated inside a polymer matrix by decomposition (e.g., thermolysis, photolysis, radiolysis, etc.) or chemical reduction of a metallic precursor dissolved into the polymer. In the ex situ approach, nanoparticles are first produced by soft-chemistry routes and then dispersed into polymeric matrices [5–9]. For the synthesis of metal-polymer

composites the ex situ techniques are frequently preferred because of the high quality of the film.

Over the past decades, transition metal oxides (TMOs) have been widely investigated for use in applications related to electronic, optical, and mechanical properties. Among these, TMOs, zinc oxide (ZnO), and tungsten oxide (WO₃) are promising materials for the various above mentioned applications [10–13]. When these TMOs are incorporated in polymers, it improves their electrical, mechanical, and optical properties due to their high interfacial interaction between organic moieties and inorganic nanoparticles. The basic idea of this research is preparation of different concentrations of both zinc oxide (ZnO) and tungsten oxide (WO₃) doped PVA composite films and improving the structural and mechanical property of the PVA composite. The preparation of

the nanoparticles doped polymer composite film can be done by many methods, out of which solution casting is the simplest technique.

In the present paper, polyvinyl alcohol (PVA) is chosen as basic polymer because of eco-friendly, nontoxic, water-soluble, degradable nature and the easiness of making thin films with metal oxide. We report the preparation of different concentrations of both zinc oxide (ZnO) and tungsten oxide (WO_3) doped PVA composite films and improve the structural and mechanical property of the PVA composite. The films were characterized with spectroscopic techniques for examining functional group by Fourier transform infrared spectroscopy (FTIR). The crystallinity and morphological properties were investigated using X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDX). The mechanical properties were studied using universal testing machine (UTM).

2. Experimental Details

2.1. Sample Preparation. 97 to 100 mol% hydrolyzed PVA compound (Mowiol 10–98 fully hydrolysed grade, Sigma Aldrich, Germany) was procured commercially as a basic polymeric material. The procured PVA has molecular weight $M_w = 61000$ g/mol, degree of polymerization $P_w = 1400$, and bulk density of $0.4\text{--}0.6$ g cm^{-3} . For the doping purpose two metal-oxide nanomaterials, zinc oxide (average size < 50 nm, $M_w = 81.39$ g/mol), and tungsten oxide (average size < 100 nm, $M_w = 231.84$ g/mol), were also procured. 6 g of PVA is dissolved completely in 100 mL of distilled water under constant stirring at 1000 rpm for one hour while the mixture is heated up to 90°C until the polymer completely dissolved and formed a clear viscous solution. The viscous solution was cooled down to room temperature and stirring was continued using mechanical stirrer at 180 rpm for 3 hrs to ensure the homogeneity of the composition. The obtained PVA solution was divided into six equal parts and each part of viscous solution of prepared PVA was treated by adding mixed fillers PVA/(x) ZnO (15 - x) WO_3 , where $x = 0\%$, 1% , 5% , 7.5% , 10% , 14% , and 15% weight concentration and then it was mixed ultrasonically by using probe ultrasonicator for 20 minutes with pulse on time 10 s and off time 10 s. To prepare polymer film of treated polymer, the viscous solution was cast onto a Petri dish and left to dry in air for 3 days at room temperature. The films were peeled off from the casting glass plate and kept in vacuum desiccators for further study. The thickness of the prepared polymer composite film is measured by using dial thickness gauge (Mitutoyo, Japan). Three trails of thickness were measured at different places of each polymer film and average thickness of the film was calculated. Thin films of thickness ranging from 100 to 150 μm were obtained.

2.2. Physical Measurements. IR transmittance studies of the PVA, with and without nanoparticles doped films, were carried out using FTIR spectrophotometer. The infrared spectra were recorded using JASCOFTIR 4100 type A spectrophotometer in the wavenumber range $400\text{--}4000$ cm^{-1} with a

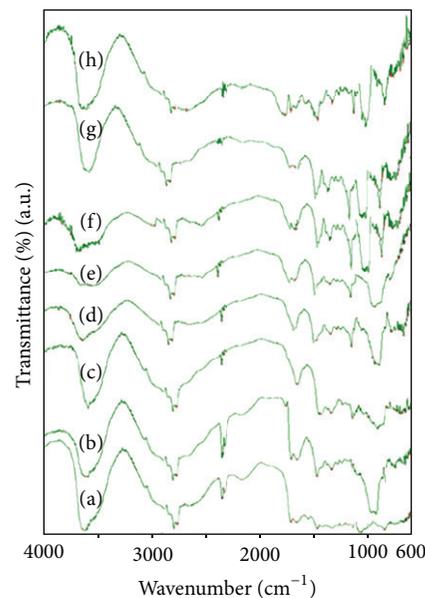


FIGURE 1: FTIR spectra of PVA/(x) ZnO (15 - x) WO_3 with (a) pure PVA, (b) $x = 0$ wt%, (c) $x = 1$ wt%, (d) $x = 5$ wt%, (e) $x = 7.5$ wt%, (f) $x = 10$ wt%, (g) $x = 14$ wt%, and (h) $x = 15$ wt%.

resolution of 4 cm^{-1} . The X-ray diffractograms of the samples were recorded using a Bruker D8 Advance X-ray diffractometer with Ni filtered and Cu Ka radiation of wavelength $\lambda = 1.5406$ Å, with a graphite monochromator. The scanning was taken in the 2θ range $10^\circ\text{--}120^\circ$ with a scanning speed $2^\circ/\text{min}$. The surface morphological properties were investigated using JEOL JSM-6380LA scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDAX). A LLOYDS universal testing machine (LLOYDS—5 KN, London, UK) was used to measure tensile strength, percent elongation (%), and modulus of elasticity. The tests were carried out according to ASTM D-882 standard test (ASTM, 1992) and calculated using NEXYGEN Plus software. Rectangular shaped samples of films (25×100 mm) were taken for the determination of tensile properties.

3. Results and Discussion

3.1. FTIR Spectra of Pure and Doped PVA Samples. The FTIR spectra of pure and ZnO with WO_3 nanoparticles doped PVA samples were obtained using KBr pelleting method and the results are shown in Figure 1. The FTIR spectrum shows a strong absorption broad band at 3624.55 cm^{-1} is assigned to O–H stretching vibration of hydroxyl groups of PVA. The band corresponding to C–H asymmetric stretching vibration occurs at 2996.84 and 2920.66 cm^{-1} whereas C–H symmetric stretching vibration at 2878.24 , 2850.27 , and 2821.35 cm^{-1} . The sharp band at 1151.29 cm^{-1} corresponds to C–O stretching of acetyl group present on the PVA backbone. Corresponding bending deformation and wagging of CH_2 vibrations are at 1479.13 cm^{-1} and C–H wagging at

TABLE 1: Irregular shifts in FTIR spectra of pure and doped PVA composites.

Sl. no.	Sample	C-H asymmetric stretching vibration cm^{-1}	C-H symmetric stretching vibration cm^{-1}	C-O stretching of acetyl group cm^{-1}	CH_2 vibrations cm^{-1}
1	Pure PVA	2996.84	2878.24	1151.29	1479.13
2	PVA/15% WO_3	2992.02	2878.24	1150.33	1476.24
3	PVA/1% ZnO 14% WO_3	2950.55	2907.16	1148.4	1451.17
4	PVA/5% ZnO 10% WO_3	2956.34	2868.59	1150.33	1475.28
5	PVA/7.5% ZnO 7.5% WO_3	2953.45	2877.27	1151.29	1482.99
6	PVA/10% ZnO 5% WO_3	2955.38	2872.45	1149.37	1480.1
7	PVA/14% ZnO 1% WO_3	2955.38	2877.27	1151.29	1479.13
8	PVA/15% ZnO	2992.98	2880.17	1149.37	1475.28

1221.68 cm^{-1} [14–16]. In the case of PVA doped ZnO, PVA doped with WO_3 , and PVA doped with both ZnO and WO_3 , the FTIR spectra show shifts in the corresponding bands with a change in intensities as given in Table 1. The changes in the regularly arranged hydroxyl groups of the polyvinyl alcohol chain are capable of forming chemically more or less stable complex compounds associated with certain substances. This indicates the considerable interaction between PVA doped with ZnO and WO_3 . The new bands may be correlated to the defects induced by charge transfer reaction between the polymer chain and the dopant. These observations suggest that the interaction between ZnO and WO_3 ions with acetyl group dominates (as given in Scheme 1). The shift in bending of CH_2 vibrations, respectively, indicates the chemical interactions of Zn and W ions with PVA matrix. The shift in acetyl C–O stretching of PVA also supports the existence of chemical interaction. This modification may be understood by invoking to the intra/intermolecular hydrogen bonding and complex formation of the PVA molecules with ZnO and WO_3 as shown in Scheme 1. It also modifies the wagging, bending, skeletal, and out of plane vibrations. Further, the vibrational peaks found in the range 800–600 cm^{-1} can be attributed to Zn–O or W–O, which indicates the mixed dopants are complexed with the polymer matrix. Hence, it can be concluded that the OH group of the PVA interact with Zn and W forms a complex. Due to this interaction and complex formation, the frequencies corresponding to other vibrations in PVA such as $-\text{CH}_2$, $-\text{CH}$ group, and C–O groups will be affected.

3.2. XRD Studies of Pure and Doped PVA Samples. The XRD studies in the range ($2\theta = 10$ to 120°) reveal that all the films under study show semicrystalline structure. There is a broad intense peak appearing at scattering angle ($19 < 2\theta < 20$), corresponding to “ d ” spacing of 4.57 Å for PVA. The crystalline nature of PVA is due to the strong intermolecular interaction between PVA chains through intermolecular hydrogen bonding [17]. The crystalline peaks observed at $2\theta = 31.73, 34.39, 36.93, 48.49, 57.66, 64.23, 67.67,$ and 69.35 degrees correspond to the hexagonal phase of zinc oxide (ICSD Collection Code: 154490; JCPDS code: 36-1451, 89-7102, and 65-3411) and peaks at $2\theta = 23.1, 24.4, 26.5, 33.2,$

$34.39, 36.22, 47.50, 55.6, 62.3,$ and 66.9 degrees correspond to tungsten oxide (ICSD Collection Code: 836; JCPDS code: 05-0363 and 33-1387). The peaks at $2\theta = 22.8, 23.8, 37.8, 49.75, 55.44,$ and 62.51 degrees (ICSD Collection Code: 153197) do not belong to PVA crystalline spectra but it may arise from scattering atomic planes of some crystalline patterns of the PVA-ZnO and/or PVA- WO_3 complex. The intensity of the diffraction peak and also the size of the crystals in PVA are determined by the number of PVA chain packed together. After complexation with dopants, the intensity of the PVA diffraction peaks is further decreased. This may be due to the interaction between PVA and mixed dopants, which leads to decrease in the intermolecular interaction between PVA chains. The diffraction pattern confirms the presence of ZnO and WO_3 in the film. The change in intensity of sharp peaks for different values of “ x ” can be attributed to the change in the content of the mixed dopants when added to the PVA matrix.

The average particle size can be calculated using the first approximation of Debye-Scherrer formula [17]:

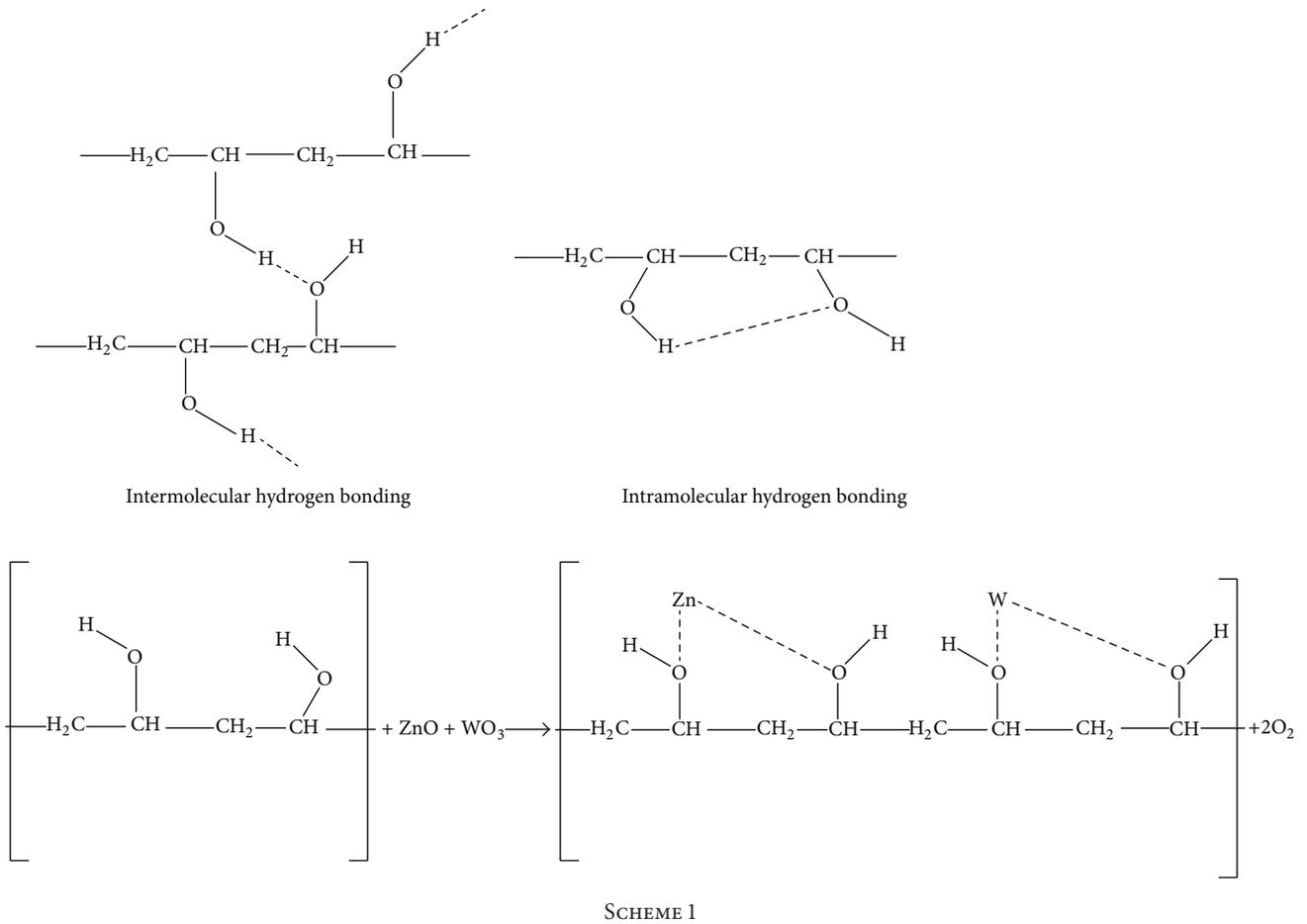
$$D = \frac{0.9\lambda}{B \cos \theta}, \quad (1)$$

where D is the average size of the particles, λ is the wavelength of X-ray radiation, B is the full width at half maximum intensity of the peaks, and θ is the diffraction angle.

The particle size of ZnO and WO_3 embedded in polymer matrix obtained for different dopants is in the same range of procured nanoparticles for doping with polymer matrixes shown in Table 2. The apparent fluctuation of the particle size of ZnO and WO_3 phase may be attributed to the particles aggregation and complexation of ZnO with WO_3 in PVA polymer matrix.

Crystallinity is defined as the weight fraction of the crystalline portion of a polymer. The physical and mechanical properties of polymers are considerably dependent on this parameter. XRD is most frequently used to measure the crystallinity in the polymers:

$$\% \text{ crystallinity} = \frac{(\text{total area of crystalline peaks})}{(\text{total area of all peaks})}. \quad (2)$$



SCHEME 1

TABLE 2: Variation of degree of crystallinity as a function of different concentrations of the ZnO and WO₃ as calculated from the X-ray patterns.

Sl. no.	Sample	Percentage of crystallinity	Average crystallinity size D (nm)	Average intercrystalline separation R (Å)
1	Pure PVA	56.86	2.92	5.70
2	PVA/15% WO ₃	46.53	24.675	4.77
3	PVA/1% ZnO 14% WO ₃	38.72	20.726	4.70
4	PVA/5% ZnO 10% WO ₃	35.51	16.45	4.55
5	PVA/7.5% ZnO 7.5% WO ₃	32.81	11.048	4.65
6	PVA/10% ZnO 5% WO ₃	37.46	15.42	4.63
7	PVA/14% ZnO 1% WO ₃	48.02	14.92	4.79
8	PVA/15% ZnO	45.86	30.18	5.57

Table 2 illustrates the variation of degree of crystallinity as a function of different concentrations of the ZnO and WO₃ as calculated from the X-ray patterns (Figure 2) by using (1). It is clear from the table that maximum value for the PVA/(x) ZnO (15 - x) WO₃ where $x = 14\%$ is detected. The values of degree of crystallinity of PVA/(x) ZnO (15 - x) WO₃ where $x = 0\%$, 1%, 5%, and 7.5% doped samples decrease and increase for $x = 10\%$ and 14%. This implies changes in

the structural regularity of the main chains of the polymeric molecules on doping.

The average intercrystallite separation (R) in the amorphous region of the sample was evaluated using the relation [18]

$$R = \frac{5\lambda}{8 \sin \theta}, \quad (3)$$

TABLE 3: Tensile properties of pure and doped PVA films.

Sample	Tensile strength (MPa)	Stiffness (kN/m)	Young's modulus (MPa)	Percentage total elongation at fracture
Pure PVA	2.901	5.3490	45.330	92.53
PVA/15% WO ₃	5.175	3.3851	58.872	90.309
PVA/1% ZnO 14% WO ₃	11.375	5.1376	70.864	263.99
PVA/5% ZnO 10% WO ₃	10.979	6.1740	100.390	150.45
PVA/7.5% ZnO 7.5% WO ₃	6.964	5.8880	90.585	50.304
PVA/10% ZnO 5% WO ₃	11.971	7.0552	176.380	60.279
PVA/14% ZnO 1% WO ₃	13.806	6.4073	183.067	64.952
PVA/15% ZnO	12.517	9.8261	196.523	195.74

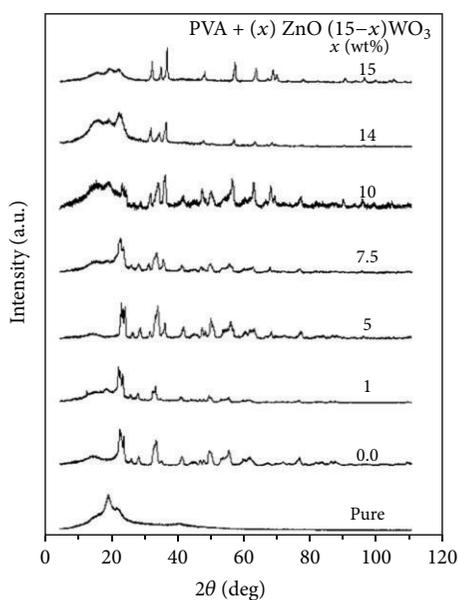


FIGURE 2: X-ray diffraction patterns of PVA films.

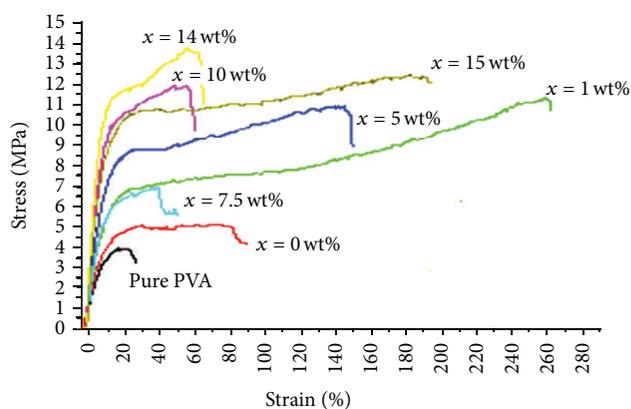
where λ is the wavelength of X-ray radiation and θ is the diffraction angle.

The calculated distance between the hydroxyl groups of crystalline PVA is 5.7056 Å.

The decrease in the crystallinity separation indicates the weak intermolecular hydrogen bonding, which is responsible for the disappearance of molecular movements and causes less dense molecular packing in the crystal. As a result the crystallinity decreases.

3.3. Mechanical Studies of Pure and Doped PVA Samples.

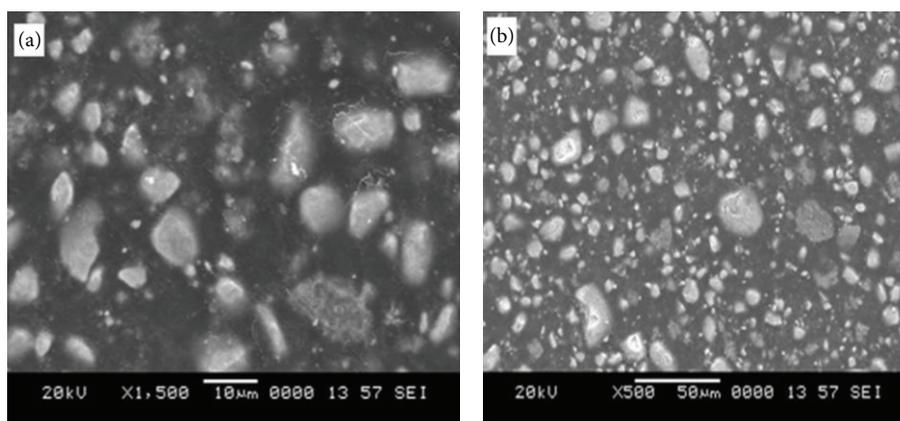
Mechanical properties were carried out to study the tensile properties of nanoparticles doped polymer composites films by using universal testing machine (UTM). The two metallic grips were attached for gripping both ends of the test specimen of the film. The lower grip was stationary and the upper grip moved upward with constant rate of extension 25 mm/min keeping constant initial grip separation 100 mm for all samples. An automatic speed controller was attached to keep the

FIGURE 3: Stress-strain curves of PVA/(x) ZnO (15 - x) WO₃ with (a) pure PVA, (b) $x = 0$ wt%, (c) $x = 1$ wt%, (d) $x = 5$ wt%, (e) $x = 7.5$ wt%, (f) $x = 10$ wt%, (g) $x = 14$ wt%, and (h) $x = 15$ wt%.

speed of the upper grip. The machine was electrically driven. All measurements were carried out at room temperature in air. The tensile strength, Young's modulus (modulus of elasticity), and percent of elongation could be used to describe how the mechanical properties are related to their chemical structure. Tensile strength was calculated by dividing the maximum load for breaking the film by cross-sectional area and elongation at break is the maximum change in length of a test film before breaking. Then, the modulus of elasticity (Young's modulus) is calculated by the ratio of stress to strain at the linear portion of the curve. The mechanical properties may be used to assess the doping of nanoparticles on polymer matrix through a comparison of experimental results. The mechanical properties of doped polymer depend on the intermolecular forces, complex formation due to interaction of dopants, chain stiffness, and molecular symmetry of the individual polymer. From Table 3 and Figure 3 it is obvious that PVA/(x) ZnO (15 - x) WO₃ where $x = 14$ wt% exhibit high tensile strength. Tensile strength also depends on molecular weight because of the effect of entanglement. The degree of crystallinity and the morphology of the crystalline material also have profound effects on the mechanical behavior of polymers, since these factors can be varied over a wide range.

TABLE 4: Percentage distribution of nanosized ZnO and WO₃ dopants in the film.

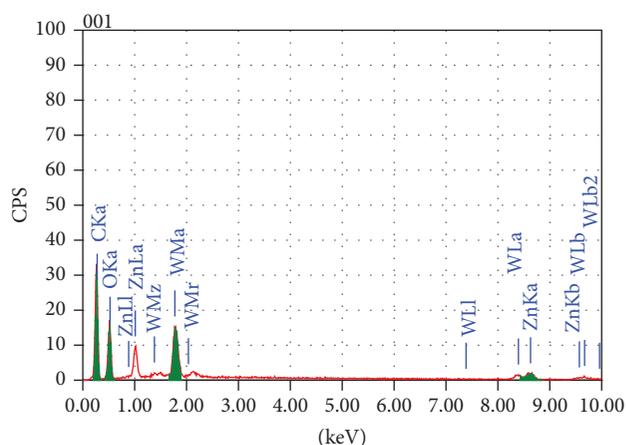
ZAF method standardless quantitative analysis					
Fitting Coefficient: 0.3711					
Element	(keV)	Mass%	Error%	At%	K
C K	0.277	49.13	0.13	66.23	37.6617
O K	0.525	30.54	0.44	30.91	28.7637
Zn K	8.630	6.69	1.21	1.66	12.3502
W M	1.774	13.64	0.49	1.20	21.2211
Total		100.00		100.00	

FIGURE 4: SEM images of PVA/(x) ZnO ($15 - x$) WO₃ where (a) $x = 7.5\%$ and (b) $x = 10\%$ weight polymer composites.

It was found that degree of crystallinity was high for $x = 14\%$ and crystallinity of a polymer increases with the degree of crystallinity increases because of secondary bonding. This in turn increases the stiffness (elastic modulus) and strength of the polymer. On the other hand, ductility declines as crystallinity increases. It is observed that maximum percentage total elongation at fracture was found for PVA doped with WO₃ and ZnO nanoparticles for concentration $x = 1\text{ wt}\%$. Elongation at break is the maximum change in length of a test film before breaking. The results indicate that the addition of the ZnO and WO₃ with weight percentage $x = 14\%$ increases the tensile strength and Young's modulus.

3.4. SEM and EDAX Studies. Scanning electron microscopy has been used to study the compatibility between various components of the polymer composites through the detection of phase separations and interfaces. It has great influence on the physical properties of the polymer composite. Figures 4(a) and 4(b) show the SEM photograph of nanocomposite polymer composite. The films exhibit uniform density of grain distribution at surface morphology. The surface morphology of the PVA/(x) ZnO ($15 - x$) WO₃ polymer composite films shows many aggregates or chunks randomly distributed on the top surface. The results indicate that the nanosized ZnO and WO₃ particles tended to form aggregates and dispersed into the PVA polymer matrix.

The chemical composition and homogeneity of PVA doped with ZnO and WO₃ polymer composite film is studied

FIGURE 5: Distribution of nanosized ZnO and WO₃ dopants in the film.

by an analytical technique called energy-dispersive analysis of X-rays (EDAX). Polymer composites films were sputter covered by gold particles to oppose the artifacts produced above the surface because of charging. Figure 5 indicates that the distribution of nanosized ZnO and WO₃ dopants is uniform and confirms the presence of ZnO and WO₃ in the film. The Percentage distribution of nanosized ZnO and WO₃ dopants in the film is given in Table 4.

4. Conclusions

We have studied the effect of ZnO and WO₃ nanoparticles on the semicrystalline polymer PVA matrix allowed us to draw the following conclusions.

- (i) The FTIR study shows that the Zn and W ions of the dopant interacts with the OH groups of PVA and form a complex via intra/intermolecular hydrogen bonding.
- (ii) The XRD results show that, due to the interaction of dopant and hence the complex formation, the structural repositioning takes place, which changes the crystallinity.
- (iii) The SEM and EDAX data indicates that the distribution of nanosized ZnO and WO₃ dopants is uniform and confirms the presence of ZnO and WO₃ in the film.
- (iv) The mechanical studies indicate that the addition of the ZnO and WO₃ with weight percentage concentration $x = 14\%$ increases the tensile strength and Young's modulus.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

- [1] Z. H. Mbhele, M. G. Salemane, C. G. C. E. van Sittert, J. M. Nedeljković, V. Djoković, and A. S. Luyt, "Fabrication and characterization of silver-polyvinyl alcohol nanocomposites," *Chemistry of Materials*, vol. 15, no. 26, pp. 5019–5024, 2003.
- [2] I. Latif, E. E. AL-Abodi, D. H. Badri, and J. Al Khafagi, "Preparation, characterization and electrical Study of (carboxymethylated polyvinyl alcohol/ZnO) nanocomposites," *The American Journal of Polymer Science*, vol. 2, pp. 135–140, 2012.
- [3] Z. Guo, D. Zhang, S. Wei et al., "Effects of iron oxide nanoparticles on polyvinyl alcohol: interfacial layer and bulk nanocomposites thin film," *Journal of Nanoparticle Research*, vol. 12, no. 7, pp. 2415–2426, 2010.
- [4] R. Ricciardi, F. Auriemma, C. De Rosa, and F. Lauprêtre, "X-ray diffraction analysis of poly(vinyl alcohol) hydrogels, obtained by freezing and thawing techniques," *Macromolecules*, vol. 37, no. 5, pp. 1921–1927, 2004.
- [5] A. H. Lu, G. H. Lu, A. M. Kessinger, and C. A. Foss Jr., "Dichroic thin layer films prepared from alkanethiol-coated gold nanoparticles," *Journal of Physical Chemistry B*, vol. 101, no. 45, pp. 9139–9142, 1997.
- [6] Y. Dirix, C. Darribère, W. Heffels, C. Bastiaansen, W. Caseri, and P. Smith, "Optically anisotropic polyethylene: gold nanocomposites," *Applied Optics*, vol. 38, no. 31, pp. 6581–6586, 1999.
- [7] L. Zimmerman, M. Weibel, W. Caseri, U. W. Suter, and P. Walther, "Polymer nanocomposites with "ultralow" refractive index," *Polymers For Advanced Technologies*, vol. 4, no. 1, pp. 1–7, 1993.
- [8] G. L. Fisher and R. W. Boyd, *Nanostructured Materials Cluster, Composites, and Thin Films*, The American Chemical Society, Washington, DC, USA, 1998.
- [9] R. D. Harris and J. S. Wilkinson, "Waveguide surface plasmon resonance sensors," *Sensors and Actuators B*, vol. 29, no. 1–3, pp. 261–267, 1995.
- [10] D. Manno, A. Serra, M. di Giulio, G. Micocci, and A. Tepore, "Physical and structural characterization of tungsten oxide thin films for NO gas detection," *Thin Solid Films*, vol. 324, no. 1–2, pp. 44–51, 1998.
- [11] D. Kumar, S. Karan Jat, K. P. Khanna, N. Vijayan, and S. Banerjee, "Synthesis, characterization, and studies of PVA/Co-Doped ZnO nanocomposite films," *International Journal of Green Nanotechnology*, vol. 4, no. 3, pp. 408–416, 2012.
- [12] C. R. Gorla, N. W. Emanetoglu, S. Liang et al., "Structural, optical, and surface acoustic wave properties of epitaxial ZnO films grown on (0112) sapphire by metalorganic chemical vapor deposition," *Journal of Applied Physics*, vol. 85, no. 5, pp. 2595–2602, 1999.
- [13] S. Ashraf, C. S. Blackman, R. G. Palgrave, and I. P. Parkin, "Aerosol-assisted chemical vapour deposition of WO₃ thin films using polyoxometallate precursors and their gas sensing properties," *Journal of Materials Chemistry*, vol. 17, no. 11, pp. 1063–1070, 2007.
- [14] M. Soliman Selim, R. Seoudi, and A. A. Shabaka, "Polymer based films embedded with high content of ZnSe nanoparticles," *Materials Letters*, vol. 59, no. 21, pp. 2650–2654, 2005.
- [15] E. J. Shin, Y. H. Lee, and S. C. Choi, "Study on the structure and processibility of the iodinated poly(vinyl alcohol). I. Thermal analyses of iodinated poly(vinyl alcohol) films," *Journal of Applied Polymer Science*, vol. 91, no. 4, pp. 2407–2415, 2004.
- [16] L. Dai, J. Li, and E. Yamada, "Effect of glycerin on structure transition of PVA/SF blends," *Journal of Applied Polymer Science*, vol. 86, no. 9, pp. 2342–2347, 2002.
- [17] H. M. Zidan, "Structural properties of CrF₃, and MnCl₂-filled poly(vinyl alcohol) films," *Journal of Applied Polymer Science*, vol. 88, no. 5, pp. 1115–1120, 2003.
- [18] P. P. Kundu, J. Biswas, H. Kim, and S. Choe, "Influence of film preparation procedures on the crystallinity, morphology and mechanical properties of LLDPE films," *European Polymer Journal*, vol. 39, no. 8, pp. 1585–1593, 2003.



Hindawi

Submit your manuscripts at
<http://www.hindawi.com>

