Journal of Applied Research in Science and Humanities

Study the mechanical properties of polymer material and its applications

Basma.M.Hassan, Eman.H.Ameen , Essraa.M.Elsayed, Mariam.A.Makram ,Marina.M.beshay,Salma.R.Mohamady ,Yasmeen.S.Elsayed

Supervisor: Fatma El Sayed Abdel Aziz Ibrahim – Lecturer in Physics department

Ain Shams University, Faculty of Education, Bachelor's program in Science and Education (preparatory and secondary), EDU485–Physics_Private (credit hours 2020)

Abstract

An array of water–soluble polymer blends composed of polyvinyl alcohol (PVA) and polyethylene glycol (PEG) have been synthesized by the solution casting technique. The prepared blends were tested using mechanical properties and DSC. The outcomes showed that adding PEG affects the mechanical characteristics of PVA/PEG blends, and the ideal blend was one with 25 wt% of PEG loading, where the value of the percentage elongation at break (78%), Toughness (0.44) and surface energy (0.076) reached the highest values at this blend. Meanwhile, Young's modulus declined from 20.34 MPa for pure PVA to 7.07 MPa at 25 wt% PEG. The results of DSC revealed that T_g decrease from 89.2 °C of PVA to 60.8 °C of 30wt.% PEG

Key Words:

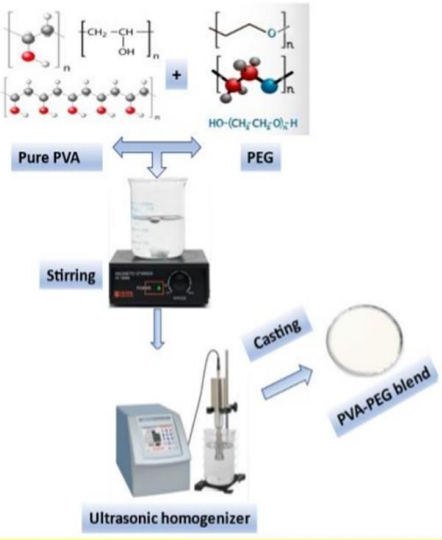
PVA, flexibility, mechanical, thermal parameters

1. Introduction: In the current era of polymer development, polymer blending is crucial to create novel substances with a wide range of desirable qualities. Polymer blends can to adjust the attributes of a finished product to meet the specific needs of the application (Mohammed,2022). The simpler fabrication method and the ability to easily manage the characteristics of polymer electrolytes by varying the blended polymer composition (Mohammed,2023) both suggest that polymeric blends may be preferable.

Polyvinyl alcohol (PVA) is one of the most widely used human–friendly polymers. It's a remarkable synthetic polymer with the added benefits of being non–toxic and biodegradable. PVA is a typical polar polymer with a simple chemical structure and an abundance of attached hydroxyl groups which makes PVA modification possible through simple chemical reactions. PVA has exceptional overall performance, including thermal properties, acceptable biocompatibility, and excellent barrier qualities, making it a potential candidate for some tissue engineering applications, including bone, cartilage, and heart valves (Mohammed ,2023; Mohammed ,2022). Due to its poor mechanical properties, PVA can be blended with plasticizers to improve its flexibility, and stretchability by modifying the mechanical properties making the films more ductile and lowering the T_g of the product without altering the fundamental chemical character of the plasticized material (Caicedo , 2022; Muhammed ,2015). Plasticizer blended with polymer increases the free volume between the polymer chains which allows the chain segments to move and rotate more freely allowing for increased movement of polymer chains to each other, consequently, decreasing the polymer T_g. and tensile strength (TS) while increasing elongation at break (%). Chemicals like sorbitol, citric acid, urea, polyethylene glycol, glycerol and others are commonly employed as plasticizers (Falqi ,2018). One of the most often used plasticizers, polyethylene glycol (PEG) is made up of $(CH_2\text{-}CH_2\text{-}O)$ n linear polymer chains with two hydroxyl groups on each end. Because of its simple structure, it has a high enthalpy and can easily crystallize. PEG is a polymer with the flexible backbone that is water–soluble biodegradable, biocompatible, and nontoxic (Decai Li,2018). Also, its significant physical and chemical properties enable it to be used in various applications in industry.(Hanpin Lim , 2013) investigated the impact of several plasticizers on the mechanical characteristics of Solplus. It was found that the values of T_g and mechanical parameters (tensile strength, Young's modulus, percent elongation, and toughness) were all reduced by all four plasticizers. PEG-6 is the most effective plasticizer at altering the mechanical

characteristics of the films out of all the ones evaluated. (Abd Alla , 2004, 167–176) concluded that the PVA/PEG mixture has shown limited compatibility in the range of 0 to 30% PEG.

This research aim is to overcome the brittleness and enhance of the flexibility of the PVA membrane by using different concentrations of PEG and determining the ideal concentration of PEG that can increase the flexibility. The improvement of flexibility will be verified by studying the effect of PEG concentration on T_g . The effect of PEG concentrations on the degree of crystallinity of films will be calculated by XRD analysis. The effect of PEG as a plasticizer on the mechanical properties of PVA will be studied and the mechanical parameters will be calculated such as Young's modulus (E), tensile strength (σ), toughness, ductility, and surface energy (γ).



Scheme 1: Schematic diagram of the synthesis of PVA–PEG blend

2.Experimental

2.1Materials and film preparation

Polyethylene glycol (PEG) (powder, molecular weight = 4000 g/mol) and polyvinyl alcohol (PVA) (degree of hydrolysis = 99%, molecular weight = 27,000 g/mol) were provided by Sigma–Aldrich Company, USA. The solution cast method was used to prepare the films of pure PVA and PEG/PVA blends with PEG loadings of 5, 10, 15, 20, 25, and 30 wt. percent were found to produce acceptable films with good transparency after numerous experiments. The blends were able to obtain films with satisfactory transparency (as determined by visual observation). Scheme 1 represents a Schematic diagram of the synthesis of the PVA–PEG blend. Characterization and investigation of the resulting films were carried out.

2.2Characterization techniques and devices

Differential scanning calorimeters were used to evaluate the glass transition temperature (T_g), and composite melting behavior (T_m) at a heat rate of 10 °C/min under N_2 from 50 to 220 °C (Shimadzu DSC–50).

The mechanical behavior of pure PVA and PVA/PEG blends was determined by using a tensile testing machine (AMETEK, USA). The strain measurement precision was approximately 0.1 mm. Throughout the experiment, the elongation rate was kept constant at 6 mm/min.

3. Results of Research

Differential Scanning Calorimetry (DSC) of PVA/PEG blends.

For studying polymeric materials' thermal characteristics, DSC is an excellent technique. There are thermograms of polyvinyl alcohol and PVA/PEG blends with varying concentrations of PEG (as shown in Fig. 1). The predicted values of the glass transition temperature (T_g) and melting temperature (T_m) are recorded in Table 1.

Fig. 1 shows T_g, endothermic peak, of Pure PVA and PVA/PEG blends in the low-temperature area. One can see from Table 1 the significant decrease in the glass transition temperatures with the addition of PEG: it drops from 89.2 °C for pure PVA film to 60.6 °C for PVA/PEG containing 30 wt% of PEG. The inclusion of PEG into the PVA polymer led to an increase in free volume between the polymer chains thereby a lowering of T_g values, allowing the chain segments to move and rotate more freely relative to one another (Sakellariou , 1994; Ping Liu , 2019). From the data on the decrease of the PVA glass

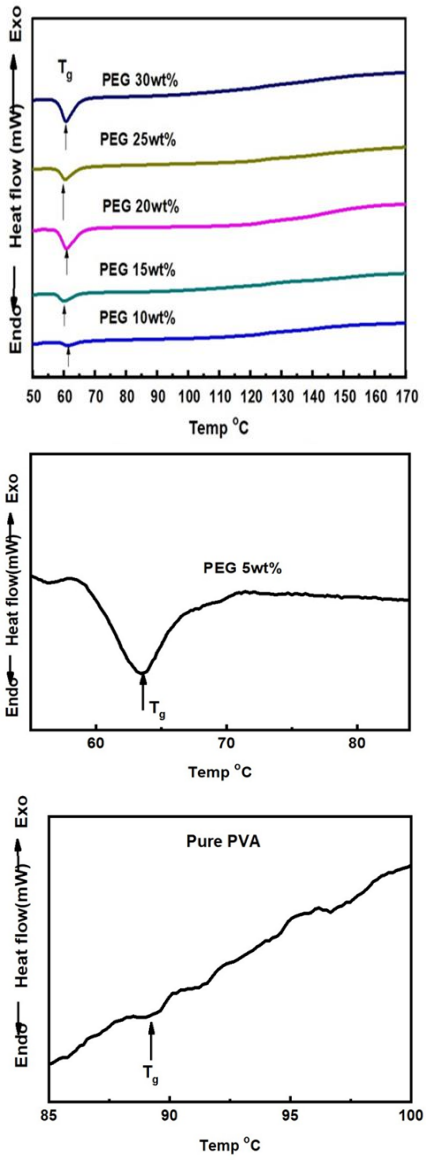


Fig. 1 DSC thermograms of pure PVA and PVA / PEG blend films

The as-produced Polymeric films	Tg, °C	Tm, °C	ΔHm, (J/g)	Refs.
Pure PVA	89.2	188.6	5.25	Present work
PVA/PEG (5 wt%)	63.6	180	4.62	
PVA/PEG (10 wt%)	61.4	179	4.12	
PVA/PEG (15 wt%)	60.3	176	4.12	
PVA/PEG (20 wt%)	60.8	190	6.35	
PVA/PEG (25 wt%)	60.6	188.3	2.59	
PVA/PEG (30 wt%)	60.8	187.8	3.79	
PVA	83	211.78	51.35	Fahad et al. (2018)
PVA/PEG blends	53.85–54.47	214.43–214.21	55.21–42.23	
PVA	82	215	-	Ping et al. (2019)
PVA/PEG blends	52–23	199–171		
PVA	69	224	-	Prajapati et al. (2010)
PVA/H3PO4/PEG (10–40%)	64–68	220–222		

Table 1 DSC results of PVA /PEG blend films

transition temperature with the increase of PEG content, one can conclude that this plasticizer is very effective for PVA (Aharoni ,1998,169–201). These data are in good agreement with the previous studies. (Falqi , 2018) showed that T_g decreased from 83°C of pure PVA to 51.34°C by adding 15wt % of PEG into PVA. (Ping Liu , 2019) detected that the T_g of pure PVA is 82 °C and T_gs for WPVA/PEG composites are significantly lower and show a continuous descent with the rising of PEG content.(Puyou et al. 2016) showed that (T_g) for PVA declined by adding $AlCl_3 \cdot 6H_2O$/polyglycerin) and $AlCl_3 \cdot 6H_2O$/polyglycerin. (Prajapati . 2010) noticed that T_g decreased from 69 °C of pure PVA to 56°C for PVA-H_3PO_4- 30%PEG. (see Table1).

The second endothermic peaks observed were the melting temperatures T_m for pure PVA and PVA/PEG blends shown in Fig. 2. Table 2 shows that the values of Tm of all blends were not significantly different from those of pure PVA, and its values are equal to 188.6, 180,179,176,190,188.3 and 187.8 oC for 0, 5,10,15,20,25 and 30 wt% of PEG content, correspondingly. From the results, one can conclude that PEG did not effect on the Tm of PVA. A similar finding was reported for PVA/PEG blends (Falqi , 2018).

Stress–strain behavior of PVA /PEG blends.

Mechanical properties play a major role in both the quality and application of blends. Fig. 2 illustrates the stress–strain curves of pure PVA and PVA/PEG blend at room temperature under the strain rate of $3.3x10^{-3}$ sec^{-1} The mechanical characteristics of PVA and PVA/PEG blend are calculated and tabulated in Table 2. It was noticed from Table 2 that the values of Young's modulus of PVA/PEG blend are less than the value of pure PVA. This result is due to the presence of PEG which increase the chain mobility, thereby, the plasticized polymer would deform at a lower force than without the plasticizer (Hanpin , 2013). Also, compared to pure PVA, the inclusion of PEG decreased the tensile strength (as seen in Table 2). This decrease can be due to the plasticizing impact of PEG on pure PVA matrix (Durmaz et al,2021, 313–322). This result is agreed with other reported findings (Falqi , 2018); Hanpin Lim , 2013); Ali ,2014) .

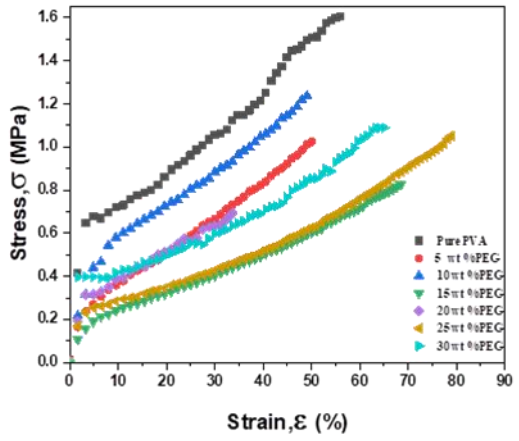


Fig. 2 Stress–Strain curve of pure PVA and PVA/PEG blends

Table 2 Mechanical characteristics of PVA/PEG blend films

The as-produced Polymeric films	Young's modulus E, (MPa)	Tensile strength (σ)	Elongation at break, (ε%)	Toughness	Surface energy (γ
Pure PVA	20.34	1.58	56	0.58	0.047
PVA/PEG (5 wt%)	10	1.01	50.1	0.39	0.051
PVA/PEG (10 wt%)	13.2	1.22	49.1	0.38	0.056
PVA/PEG (15 wt%)	6.54	0.81	68.5	0.31	0.05
PVA/PEG (20 wt%)	9.57	0.66	33.6	0.15	0.022
PVA/PEG (25 wt%)	7.07	1.04	78.8	0.44	0.076
PVA/PEG (30 wt%)	23.99	1.09	65.1	0.42	0.024

On the contrary, PEG increased the film's elongation at break by up to 25 weight percent due to its ability to increase free volume between polymer chains and hence boost chain mobility and make the films more ductile and flexible (Hanpin Lim ,2013). These findings were supported by DSC, which found that increasing the PEG concentration decreased the T_g values of PVA films, enhancing the flexibility of PVA chains. Consequently, Young's modulus dropped and the percentage of elongation at the break rose. (Mudigoudra ,2012) showed that the content of PEG changed pure PVC from hard and brittle to soft and tough within PVC/PVAc/PEG blended films. (Luo . 2015) concluded that the T_g of PVA reduced and the flexibility of the PVA chains increased as a result of the addition of $Al(NO_3)_3.9H_2O$ (Pu-you . 2014). It was observed that adding glycerol to the PVA film caused the T_g to move towards a lower temperature. As a result, the elongation at break increased from 210.58 to 360.20%.

Opposite scenario was seen for the blend containing 30% PEG, the film produced was hard, brittle, and displayed phase separation because of the high PEG content. This caused a substantial fall in its mechanical characteristics, where Young's modulus rose and elongation at break fell (Hanpin Lim , 2013).

The total area under the stress–strain curve, which measures the amount of energy a sample can withstand before failing, is a measure of the film's toughness (Davis ,2004). The film's strength and ductility are both factors that affect how tough it is (Hanpin Lim ,2013). From Table 2, it was noticed that film containing 25wt% of PEG shows the highest toughness, where this film has higher strength and ductility. (Puyou , 2016) observed that,

with the addition of the complex plasticizer ($AlCl_3 \cdot 6H_2O$/glycerin and $AlCl_3 \cdot 6H_2O$/polyglycerin), the plasticized PVA films appeared to be tougher than pure PVA films.

Another helpful parameter for predicting the crack resistance of a film is the tensile strength to Young's modulus ratio (Okhamafe ,1985,449–54). The resistance of a film to the initiation of the fracture process is a measure of the surface energy (γ) and is calculated by (Hanpin Lim , 2013): $\gamma = \left(\frac{\sigma^2 \pi C}{2E}\right)$
where σ is the tensile strength, C is the flaw or crack size before the initiation of the failure process, and E is Young's modulus. Since the crack size is difficult to measure, the ratio of tensile strength to Young's modulus $\left(\frac{\sigma^2}{2E}\right)$ provides an estimate of crack resistance if C and π are ignored (Okhamafe ,1985, 449–54 ; Jackson, 1967). From Table 2, it was noticed that film containing 25wt% of PEG shows the highest ratio of tensile strength to Young's modulus, exhibiting the greatest resistance to cracking (0.076). (Hanpin Lim , 2013) observed that films with 20% w/w PEG–6 have the highest tensile strength to Young's modulus ratio and the highest crack resistance.

4. Conclusion

PEG was used as a plasticizer to modify the mechanical properties of PVA film. By analyzing DSC data, it was found that polyethylene glycol (PEG) significantly reduces the T_g of PVA blends. The mechanical studies revealed that the addition of PEG enhances the mechanical characteristics of PVA/PEG blends and 25 wt% PEG loading was the optimum blend.

Acknowledgement

we begin by expressing my gratitude to the divine grace of ALLAH, whose benevolence has guided and blessed the progress and completion of this research.

Our group would like to thank Dr. Fatma Al–Sayed for the effort she gave us in doing the graduation project, making it easy for us to overcome the difficulties, and providing us with the data that enabled us to complete the research, in addition to providing us with a new experience and benefit.

We thank Professor Dr. Heba Al–Gharib for her cooperation in the Physics Department for always making progress.

References and Sources

Abdallah, S. G., Said, H. M., El-Naggar, M., El-Naggar, A. W. M(2004). Structural properties of γ-irradiated poly(vinyl alcohol)/poly(ethylene glycol) polymer blends Appl. Polym. Sci. 94(1), 167–176.

Aharoni, SM, Polym (1998). Adv Technol., 9(3), 169–201.

Ali, Z. I., Essa, W.H(2014).Characterization of electron beam irradiated poly vinyl alcohol / Poly ethylene glycol blends. Sci. Res. 6 (1), 29-42

Journal of Polym. Sci. 10, 8527693

Caicedo,C. , Claudio Cruz, C.A. , Regalado, E.J.J., Rocio Yaneli Aguirre-Loredo, R.Y.A(2022). Effect of plasticizer content on mechanical and water vapor permeability of maize starch/PVOH/chitosan composite films. Materials 15, 1274

Hanpin Lim, Stephen Hoag(2013): Plasticizer effects on physical–mechanical properties of solvent cast soluplus® films" AAPS Pharm. Sci. Tech. 14(3)

Choudhary, S(2018). Structural, morphological, thermal, dielectric, and electrical Properties of alumina nanoparticles filled PVA–PVP blend matrix-based polymer nanocomposites. Polym. Comp

Jackson,W.J., Caldwell, J.R(1967), Appl. Polym. Sci. 11(2), 227–44

Pu-you, J., Cai-ying, B., Li-hong,H., hong, Z. Y., Forest , J (2014) .Products Industries.3(3), 151-153

Durmaz, B. U., Aytac,A(2021).Efects of polyol based plasticizer types and concentration on the properties of polyvinyl alcohol and casein blend films. Polym. Envi. 29, 313–322

Mohammed, M. I, Yahia, I. S. (2022). Towards multifunctional applications of Fullerene-filled (PVA- PEG) polymeric nanocomposite films: structural, optical, and electrical properties. Physica Scripta, 97 (6)

Fahad, H., Falqi, F.H., Bin-Dahman, O.A., Hussain, M., Al-Harthi, M. A. : (2018). preparation of miscible PVA/PEG blends and effect of graphene concentration on thermal, crystallization, morphological, and mechanical properties of PVA/PEG (10wt%). Blend Hindawi International

Mohammed, M. I (2021) .Dielectric dispersion and relaxations in (PMMA/PVDF)/ZnO Nanocomposites. Polym. Bulletin

Mohammed, M. I. , Yahia, I. S. , El Sayed, F(2022).study the microstructure, optical,

mechanical, and dielectric characteristics of Cu2+/Zn2+ codoped PVA for CUT OFF laser filters. Polym. Bulletin

Mohammed, M.I, Yahia, I.S, , Abd El-Mongy, S.(2023). Simple fabrication of PVA/PEG blend doped with methyl blue dye with superior optical limiting performance: Enhanced luminescence property, structural, and dielectric properties. Mater. Sci. Eng: B, 291, 116390

Mudigoudra, Masti, S.P., Chougale (2012).investigation of mechanical properties of ternary polymer PVC/PVAc/PEG blended films. Res. Engin. Sci.1(2), 63-65

J., Meng, Z., Lihong, H. , Yong-hong, Z. (2016). The Plasticizing mechanism and effect of aluminium chloride and glycerin on poly(vinyl alcohol) films.Iran. J. Chem. Chem. Eng.35(2)

Luo, Y., Jiang, X., Zhang W., Li, X(2015).Polym Polym Composites 23(8)