

Study of some mechanical and rheological properties of PVA/FeCl₃ by ultrasonic

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Abstract

In this study some of the physical properties of polyvinyl alcohol dissolves in distilled water with different concentration (0.143%, 0.286%, 0.429%, 0.572%, and 0.715%) before and after mixing the appropriate amount of FeCl₃ with aqueous PVA solutions, the Rheological properties such as shear viscosity, relative viscosity specific viscosity and reduced viscosity are measured, after that the ultrasonic velocity had been measured at frequency (40KHz). Other mechanical properties had been calculated such as absorption coefficient of ultrasonic waves, relaxation time, relaxation amplitude, specific acoustic impedance, bulk modules and compressibility. The results show that all these properties are affected with variation in density and viscosity because of the intermolecular interactions and network formation between the two types of molecules and the changes in wave pressure causes molecules to flow into vacancies in the lattice during compression phase and to return to their original positions in the lattice during rarefaction.

Keywords- PVA solution, ultrasound technique, degradation, rheological properties, mechanical properties

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1 Introduction

The use of ultrasound as a tool in material science is increasing; the effect of ultrasound on organic synthesis, polymer reaction, electro plating, electro synthesis and electro polymerization has been exploited to good effect [1]. Ultrasonic technique is one of the basic

non-destructive methods for evaluation of materials and structures, a significant part of every ultrasonic inspection is the way in which the ultrasonic energy is transferred between the transducer and the tested object, different types of commercial liquids and gels are used as a coupling medium. Studies of ultrasonic irradiation show that it can be used for degradation of polymers, the breakage of chemical bonds is due to cavitations into the medium. Cavitations are the formation and violent collapse of small bubbles. This leads to shearing forces of sufficient magnitude to cause the rupture of chemical bonds Solvent effects might therefore be expected to influence the ultrasonic relation behaviour, the absorption of ultrasonic in liquid polymer systems is governed by local modes of motion (segmental conformation change) and cooperative whole molecule movement (normal or Rouse modes), because of the existence of strong intermolecular interaction within the polymer it should be possible to observe cooperative motion in the ultrasonic range [2]. Ultrasonic technique is good method for studying the structural changes associated with the information of mixture assist in the study of molecular interaction between two species [3, 4]

2 Experimental

2.1 Sample Preparation:

PVA (Gerhard Buchman -Germany) with assay (99.8 %) and FeCl_3 were used to prepare PVA/ FeCl_3 solution, the appropriate weights of PVA are (0.5, 1, 1.5, 2, 2.5 and 3 grams) were dissolved in (350 ml) of distilled water under stirring and heat (70°C) for (1 hour) until the PVA solution became a homogeneous viscous appearance at room temperature then leave the PVA solution for (10 min) to get cold at room temperature then mix it with appropriate amount of FeCl_3 , the resulting solution was stirred continuously at room temperature for (15 min.).

2.2 Density and Rheological measurements:

The density of the solution (ρ) was determined by the density bottle method and the viscosity measured before and after adding (FeCl_3) for all concentrations using Ostwald viscometer with accuracy of $\pm 1.05\%$, the method of measurement has been described by [5], elsewhere different types of shear viscosity were determined before and after the adding (FeCl_3) by the equations (1, 2, 3 and 4) [6]. The shear viscosity had been calculated by the following equation [7]:

$$\eta_{sh.} / \eta_o = (t \rho) / (t_o \rho_o) \dots\dots (1)$$

Where (ρ) and ($\eta_{sh.}$) are the solution density and the shear viscosity respectively, (ρ_o) and (η_o) are density and viscosity of distilled water respectively, Relative viscosity ($\eta_{rel.}$) was calculated by the following equation.

$$\eta_{rel.} = (t / t_o) = (\eta_{sh.} / \eta_o) \dots\dots(2)$$

The specific viscosity (η_{sp}) and reduced viscosity (η_{red}) was calculated by the equations where (C) is the concentration:

$$\eta_{spe.} = (\eta_{sh.} - \eta_o) / \eta_o = (\eta_{rel.} - 1) \dots\dots\dots (3)$$

$$\eta_{red.} = \eta_{spe.} / C \dots\dots\dots (4)$$

2.3 Ultrasonic measurements:

Ultrasonic measurements were made at constant frequency (f=40 kHz) using pulse technique of sender-receiver type (SV-DH-7A/SVX-7 velocity of sound instrument) .The receiver quartz crystal mounted on a digital vernier scale of slow motion, the sender and receiver pulses (waves) were displaced as two traces of cathode ray oscilloscope, and the digital delay time of received pulses were recorded with respect to the distance. The pulses height on oscilloscope (CH1) represents incident ultrasonic wave's amplitude (A_0) and the pulses height on oscilloscope (CH2) represents the received ultrasonic wave's amplitude (A) after passing the composite.

2.4 Theoretical calculation:

The ultrasonic wave velocity was calculated using the following equation [8]:

$$v = x / t \dots\dots (5)$$

The absorption coefficient (α) was calculated from Lambert – Beer law [9]:

$$A/A_0 = e (- \alpha x) \dots\dots (6)$$

Where (A_0) is the initially amplitude of the ultrasonic waves, (A) is the wave amplitude after absorption and (x) is the thickness of the sample, the transmittance (T) is the fraction of incident wave at a specified wavelength that passes through the composite was calculated from the following equation where (I_0) is the initial ultrasonic intensity and (I) the received intensity [10]:

$$T = I / I_0 \dots\dots\dots (7)$$

Where (t) is time that the waves need to cross the samples. Attenuation is generally proportional to the square of sound frequency so the relaxation amplitude (D) was calculated from the following equation [11, 12]:

$$D = \alpha / f^2 \dots\dots\dots (8)$$

Bulk modulus (B) of a composite is the substance's resistance to uniform compression, it was calculated by Laplace equation where (ρ) is the density [13]:

$$B = \rho v^2 \dots\dots\dots (9)$$

Compressibility (β) was calculated by the following equation [14]:

$$\beta = (\rho v^2)^{-1} \dots\dots\dots (10)$$

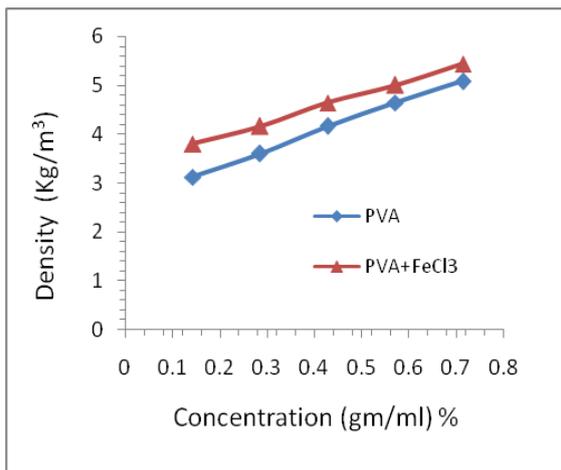
The acoustic impedance of a medium (Z) was calculated by equation [15, 16]:

$$Z = \rho v \dots\dots\dots (11)$$

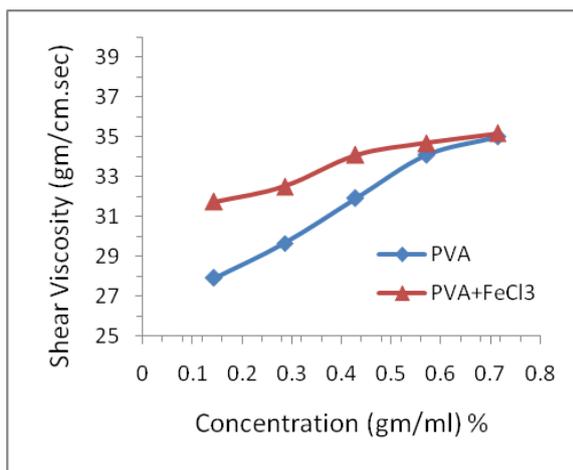
3 Results

3.1 Rheological properties:

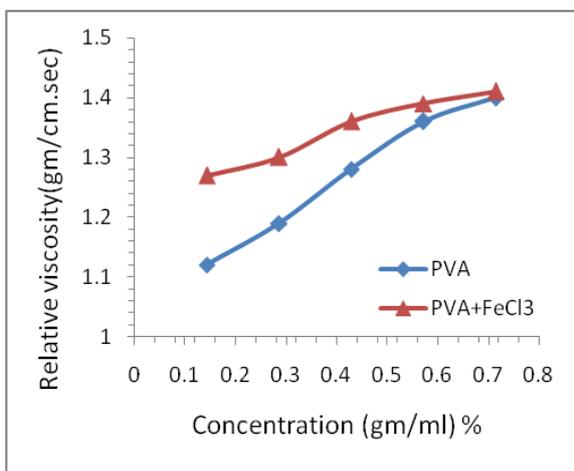
(Fig.1 and Fig.2) show the measured density and the shear viscosity to the sample before and after adding FeCl_3 to the PVA solution. (Fig.2) shows that shear Viscosity is increasing with concentration this attributed to the mechanism that hydrogen bonding of water attached to oxygen sites, this leads to salvation sheaths and increase in the size of the molecules, so its viscosity furthermore water act as plasticizer will reduce tensile strength and increase its chains [6, 17]. Relative and specific viscosities show in (Fig.3) and (Fig.4) respectively possess the same behaviours of shear viscosity because they derived from it as shown in equations (2 and 3), the reduce viscosity show in (Fig.5) depended on the concentration as shown in equation (4) so there is decrease in this viscosity whenever the concentration increase.



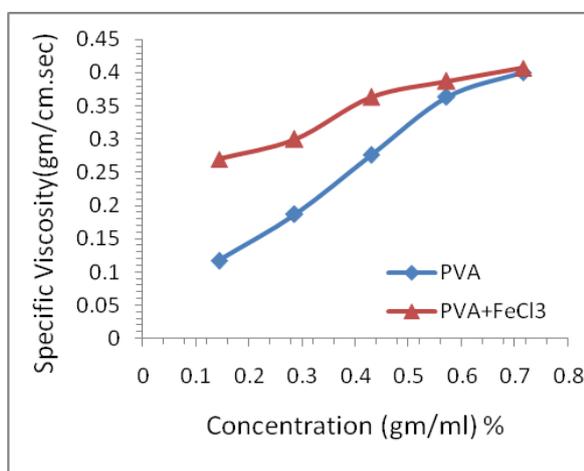
(Fig.1) Density vs. concentration



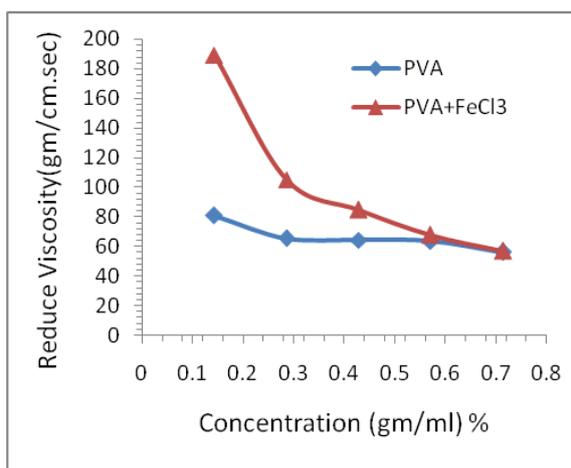
(Fig.2) Shear viscosity vs. concentration



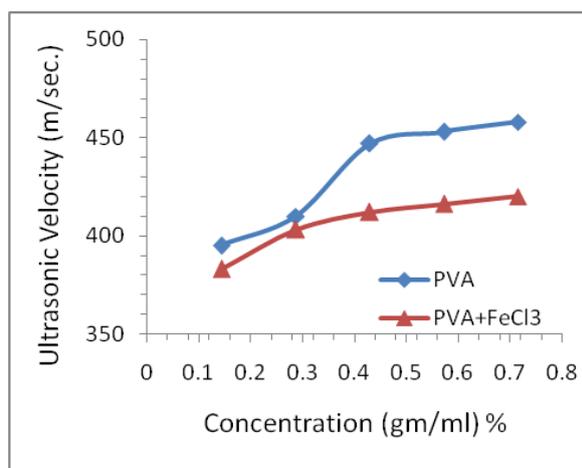
(Fig.3) Relative viscosity vs. concentration



(Fig.4) Specific viscosity vs. Concentration



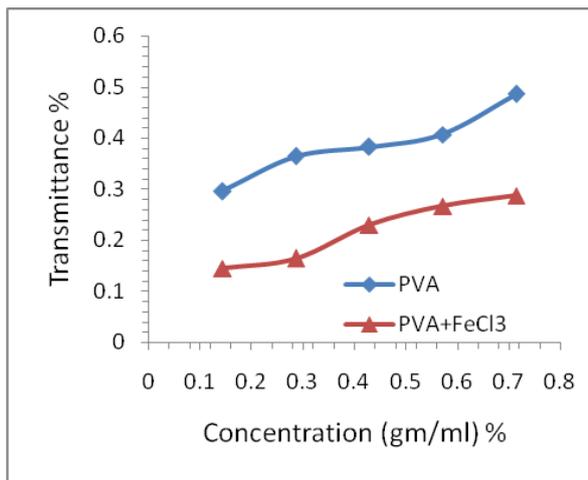
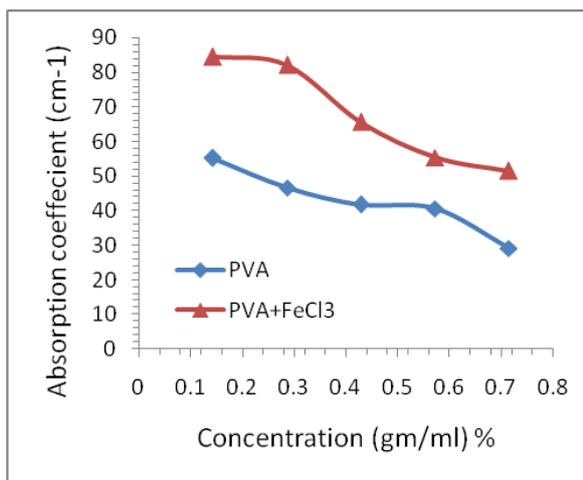
(Fig.5) Reduce viscosity vs. concentration



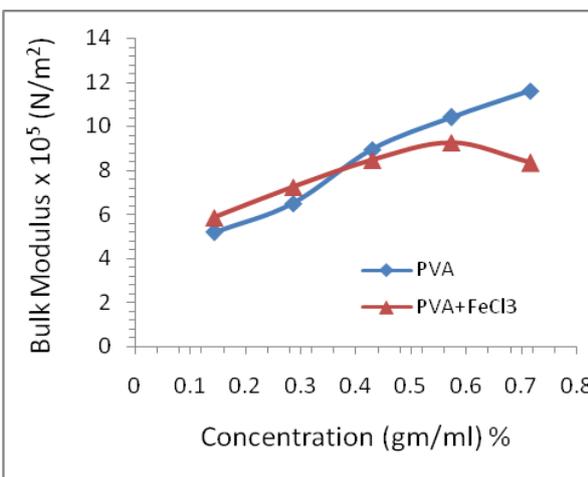
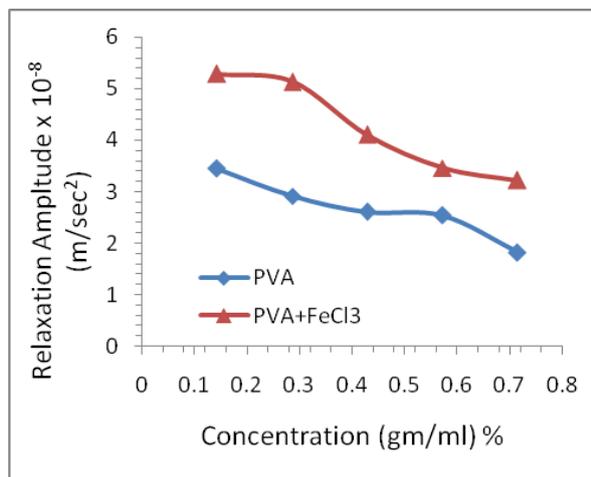
(Fig.6) Ultrasonic velocity vs. Concentration

3.2 Mechanical properties:

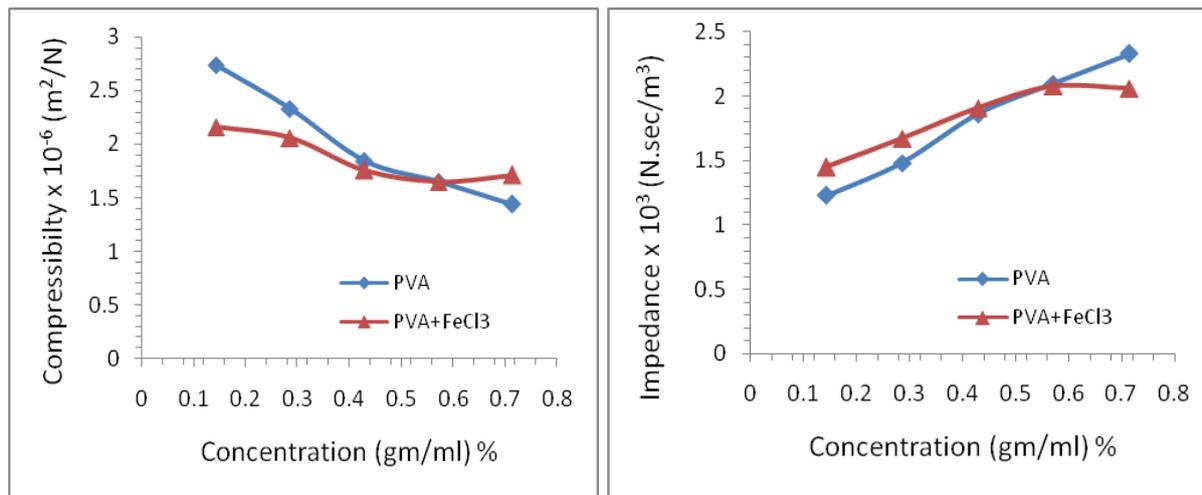
A useful method of studying mechanical properties of liquids is based on ultrasound. (Fig.6) shows the measured velocity of the ultrasonic wave; since the variation in density increasing, the velocity of ultrasonic waves is determined mainly by the chemical composition of the solution, so the addition of FeCl_3 leads to lower values of the speed of sound in PVA/ FeCl_3 solutions in comparison with the PVA solutions.



(Fig.7) Absorption coefficient vs. concentration (Fig.8) Transmittance vs. concentration



(Fig.9) Relaxation amplitude vs. concentration (Fig.10) Bulk modulus vs. concentration



(Fig.11) Compressibility vs. concentration (Fig.12) Acoustic impedance vs. concentration

The velocity decreases with adding FeCl_3 , this because structural or volume relaxation it occurs in associated liquids such as polymers, a liquid when at rest has a lattice structure similar to that possessed by solid when waves are propagated through it, the resultant periodic changes of wave pressure causes molecules to flow into vacancies in the lattice during compression phase and to return to their original positions in the lattice during rarefaction so when concentration increases the velocity will be decrease, because there are more attenuation of polymer molecules to ultrasound waves [17]. Adding FeCl_3 reduces the velocity because of increasing network formation between polymer chains against the ultrasonic velocity waves, the speed-of-sound values allow the determination of the adiabatic compressibility as shown in (Fig.11), the bulk modulus as shows in (Fig.10) and the acoustic impedance as shown in (Fig.12).

(Fig. 8) shows that the transmittance is decreasing with adding FeCl_3 , this attributed that the polymer molecules absorbed the sound waves according to Lambert-Beer Law which is biased on concentration [18] rather than as shown in (Fig.7) absorption coefficient is increasing, this is because the attenuation of the ultrasonic wave in liquids is determined mainly by the size, shape, and distribution of particles dispersed in the carrier liquids, this is attributed to the fact that when polymer concentration increase there will be more molecules in solution this lead to more attenuation against wave propagation and the changes in the particle size distribution function rather than the increase in the shear viscosity, the attenuation can be attributed to the friction and heat exchange between the particles and the surrounding medium as well as to the decay of the acoustic wave in the forward direction due

to scattering by the Particles [11], , increasing of solution concentration always results in increase of solution viscosity, and vice versa [19]. Ultrasonic relaxation amplitude was calculated by using equation no. (8) Shown in (Fig.9) is increasing with adding FeCl₃, this attributed to the fact that ultrasonic energy depends on viscosity thermal conductivity, scattering and intermolecular processes , thermal conductivity and scattering effects are known to be negligible [12, 13] so viscosity is responsible for the increase of relaxation amplitude for this reason absorption coefficient commonly known as visco –absorption.

4 Conclusions

As the frequency is fixed to 40 kHz, then the variation of the velocity will depend only on the density and viscosity of the material, adding FeCl₃ made enhancement to the shear Viscosity with concentration because the increasing in the size of the molecules, so it reduce tensile strength and increase its chains viscosity which is responsible for the increase of relaxation amplitude; this study shows that intermolecular processes are responsible for the relaxation and indicating increase in the size of molecules in bath of ultrasonic waves then reducing the velocity. With adding FeCl₃ the velocity decreases there will be complexes molecules were formed in the solution by the effect of peroxide and roots that rebounded to formations between polymer chains this lead the polymer molecules to absorb the sound waves according to Lambert-Beer Law which is biased on concentration so reducing velocity and transmittance.

5 References

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